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THE PROBLEMATICS OF DETERMINING THE CHARACTERISTICS OF HEAT RELEASE, BASED ON EXPERIMENTAL INDICATOR DIAGRAM FOR DIAGNOSTIC PURPOSES

Kazimierz Witkowski

Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 83, 81-225 Gdynia
tel.: +081 69 01 332
e-mail: wika@am.gdynia.pl

Abstract

The article discusses the problem of determining the characteristics of heat release based on experimental indicator diagram for diagnostic purposes. The importance of the operational diagnosis of marine engines is the analysis of indicator diagrams was identified. In addition to analysing changes in the values of indicated, should be aimed to oriented broader analysis, including the determination on the basis of experimental indicator diagram of heat release characteristics during the combustion process. Then it is essential to choose the right model of heat release for reciprocating piston engines with direct fuel injection. In the diagnostics of piston engines, including marine engines, special interest arouses use single-zone model based on indicator diagrams as a source of information.

Based on the results their own research we analysed the impact on the characteristics of heat release of simplifying assumptions in the model of heat release, including constant value adiabatic exponent. In the temperature, range 300÷2800 K waveforms κ are considered to be linearly dependent on the temperature. Based on the above, for the gas temperature from 800 K to 1850 K value of the exponent κ decreases about 3%.

The effect of the value κ on the course of characteristics q and Q, to the typical marine engines was shown.

Keywords: *marine diesel engine, indicated parameters, indicator diagram, heat release characteristics, adiabatic exponent*

1. Introduction

The improvement of diagnostics methods of marine diesel engine is a very important task to monitoring engine operation, fault detection at an early stage of their formation, which helps improve the economy and increase the operational safety of the ship.

Marine piston internal combustion engines represent the vast majority of the main propulsion of commercial vessels (over 80%), as well as drive generators in ship's power plants. When one talks about the need to equip the ships engine room in modern systems and diagnostic equipment, it refers primarily to the diagnostics of marine engines.

Great importance in the diagnosis of operating these engines has indicator diagrams analysis. In addition to the analysis of changes indicated parameters values, it should be aimed to oriented broader analysis, including the determination on the basis of experimental indicator diagram of heat release characteristics during the combustion process.

2. Indicator diagrams

The indicator diagrams determine the dependence of pressure in the cylinder on the instantaneous position to the piston relative to the top dead centre (TDC). The instantaneous position of the piston can be determined by the angle of rotation of the crankshaft and then the indicator diagram is called an opened (developed) or as a function of instantaneous volume of the cylinder – a closed indicator diagram.

For making real indicator diagrams we use measuring devices called indicators. During exploitation of marine piston diesel engine, mechanical-type indicators were used. Currently indicators of the electronic type one more commonly used and also known as analysers pressure or mean indicated pressure calculators – MIP calculators [3, 18].

The electronic indicator, whose the schematic diagram shown in Fig. 1, consists of: sensor measuring the combustion pressure installed on the indicating cock (valve) sensor, the angular position of the crankshaft and a microprocessor (personal computer) for processing and visualization of obtained measurement results . Such indicator is simple to use, is characterized by high precision, quickly followed by treatment of results.

This device may give indicated results as the average of several or a dozen cycles. By the encoder on the shaft, it is possible on the abscissa plotting the angle scale, and also the determination of the piston top dead centre (TDC) for each cylinder. All relevant values are displayed on the screen, and in addition presented; an indicator diagram is opened (developed). The values of mean indicated pressure and indicated power are determined automatically.

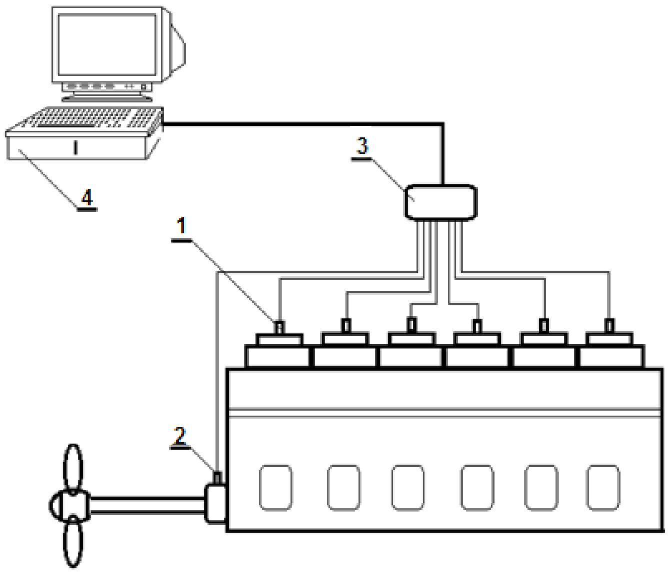

Fig. 1. Block diagram of the electronic health indicator: 1 – measurement sensor combustion pressure, 2 – sensor angular position of the crankshaft, 3 – amplifiers signals and analogue-digital converters, 4 – computer

Figure 2 shows an example of a developed indicator diagram obtained using an electronic indicator. In the graph indicates the typical, automatically determined parameters.

An important feature of the electronic indicators is to archive diagrams and ability to use them after some time. This way you can compare the indicator diagrams executed at different times, which gives a fuller opportunity to analyse. This is especially important when comparing the indicator diagram registered after a while operation of the reference chart drawn up in good technical condition of the engine.

Figure 3 shows indicator diagram nine-cylinder marine engine SULZER 9RTA90.

To indicator diagrams could be used for wider targeted analysis, including the determination of characteristics of heat release during the combustion process, the indicators must meet a number of requirements. The most important of these include:
- high speed and accuracy of measurement.
- the ability to record the measured values.
- high-quality sensors, a suitable measuring accuracy,
- determined Credibly on the graph TDC
- visualization of graphs averaged of at least a dozen cycles,
- the ability to carry out smoothing the resulting graphs (filter out random disturbances diagram).

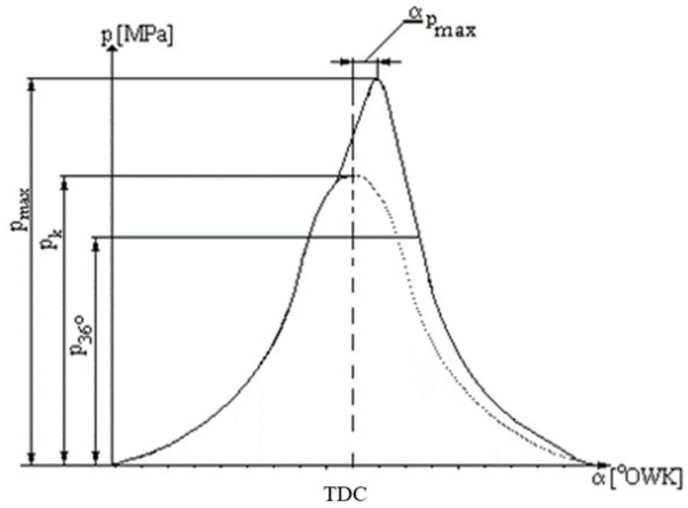

Fig. 2. Developed indicator diagram obtained from electronic indicator and its characteristic parameters: p_{max} – the maximum combustion pressure, α_{pmax} – the angle of occurrence p_{max} after TDC, p_k – compression pressure, $p_{36°}$ – expansion pressure 36 ° CA after the TDC

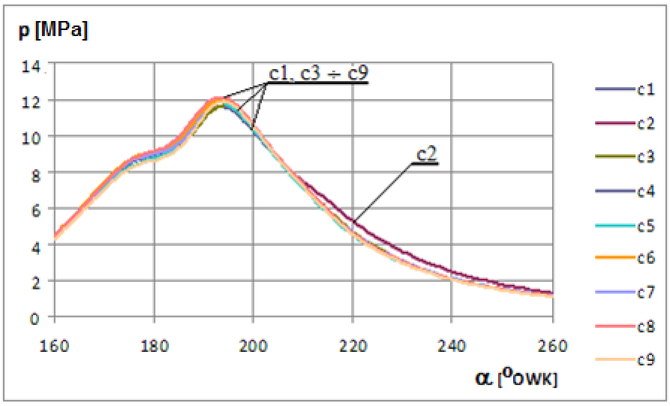

Fig. 3. Indicator diagram the marine diesel engine SULZER 9RTA90: c1-c9 – pressure in cylinders from 1 to 9

Having at one's disposal a properly made indicator diagram can be determined heat release characteristics using an appropriate model of heat release. In the case of marine diesel engine should be a model for engine with direct fuel injection.

3. Models of heat release for reciprocating piston engines with direct fuel injection

As a part of the simulation tests, both theoretical and the experimental, it was created a series of mathematical models of working cycle's piston engines.

A special development modelling of heat release piston engines took place in the late sixties and the seventies of the last century, which was largely linked to the development possibilities of computer aided design and simulation research and the emergence of new research opportunities, for example, use for the analysis of combustion processes laser methods.

In the diagnostics of piston engines, including marine engines, special interest arouses use single-zone model based on indicator diagrams as a source of information [4, 6, 14, 17]. These diagrams are commonly use also used in studies of the combustion process in the laboratory, including researches conducted in the Poland [1, 2, 8, 10, 11, 16, 17].

For the author of the first one-zone model the course of heat release based in the of indicator diagrams is considered Schweitzer [13]. Modelling of heat release issues have been under scrutiny, among other things in the works Heywood [4], Richter and Teodorczyk [12].

A model Krieger and Borman are commonly used for diesel engines with direct injection [7].

This is a model, in which is assumed that at any instant of time the working medium in the form of a homogeneous mixture of air and combustion products is in a state of thermodynamic equilibrium. Despite the simplifications made this model is still a composite for diagnostic use. This is influenced not so much for the computational complexity of the models, but the lack of a number of data for the calculation (boundary conditions).

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 for the open system can write as follows:

$$đQ_{sp} = dU + đW + đQ_{ch} + \sum đm_i h_i \,, \tag{1}$$

on the other hand, in the form equation of heat release dynamics in the time domain:

$$\frac{đQ_{sp}}{d\tau} = \frac{dU}{d\tau} + \frac{đW}{d\tau} + \frac{đQ_{ch}}{d\tau} + \frac{d}{d\tau}\sum đm_i h_i \,, \tag{2}$$

were:

$đQ_{sp}$ – heat delivered (freed) as a result of fuel combustion,
dU – change of internal energy in the combustion chamber,
$đW$ – the work done by the system,
$đm_i$ – the amount of a substance listed by the limits of the system: the blow and the fuel supply (generating exhaust gases),
h_i – specific enthalpy,
τ – time.

In order to introduce variability of the mass of air, fuel and exhaust gas in a time domain, and their reliance to changes in other parameters, the internal energy are expressed as follows:

$$U = m_c u(T) = m_c c_v T \,, \tag{3}$$

where:

m_c – mass in the cylinder,
u – specific internal energy,
T – temperature of medium,
c_v – specific heat at constant volume.

As a result, differentiation the formula (3) in the time domain was obtained:

$$\frac{dU}{d\tau} = u\frac{dm_c}{d\tau} + m_c\frac{du}{d\tau} \,. \tag{4}$$

3.1. Net heat release and intensity of heat release

Due to the high level of uncertainty calculation task cooling heat and load losses of the following blow by gas, for diagnostic purposes it is appropriate to use the characteristics of the net heat release, namely heat which is the sum of the internal energy and the work. It is assumed that the heat of the cooling will be the same for each cylinder, and will have little impact on the character of the course of heat release characteristics.

The formula for Q_n net heat release as a result transformation equation (1) obtains the following form:

$$đQ_n = đQ_{sp} - đQ_{ch} - \sum đm_i h_i = dU + đW \,. \tag{5}$$

This approach is justified in that the heat of cooling depends almost collinear on the temperature in the cylinder and the cooling surface. Waveforms heat exchange coefficients using different depending show a high correlation (similarity) with the indicator diagrams waveforms [12].

Assuming that the gas is an ideal and neglecting the load loss, equation (5) takes the form [12]:

$$đQ_n = \frac{\kappa}{\kappa - 1} pdV + \frac{1}{\kappa - 1} Vdp, \tag{6}$$

where κ = const – isentropic exponent.

Dividing equation (6) by the displacement volume of the cylinder and take into consideration dimensionless cylinder volume, the intensity of the heat release (q) in the form can be saved:

$$q = \frac{đQ_n}{V_s d\alpha} = (\kappa - 1)^{-1} \left[v \frac{dp}{d\alpha} + \kappa p \left(\frac{dv}{d\alpha} \right) \right] [10^5 \cdot J/^\circ\, CA\ m^3]. \tag{7}$$

Net heat release (Q) to point α_n crank angle is expressed integral:

$$Q = \int_0^{\alpha_n} q d\alpha \ [10^5 \cdot J/m^3], \tag{8}$$

where the start integration was adopted in TDC piston for α = 0° crank angle.

The example of heat release characteristics calculated on the basis of the models discussed and indicated diagrams shown in Fig. 3 are shown in Fig. 4 and 5.

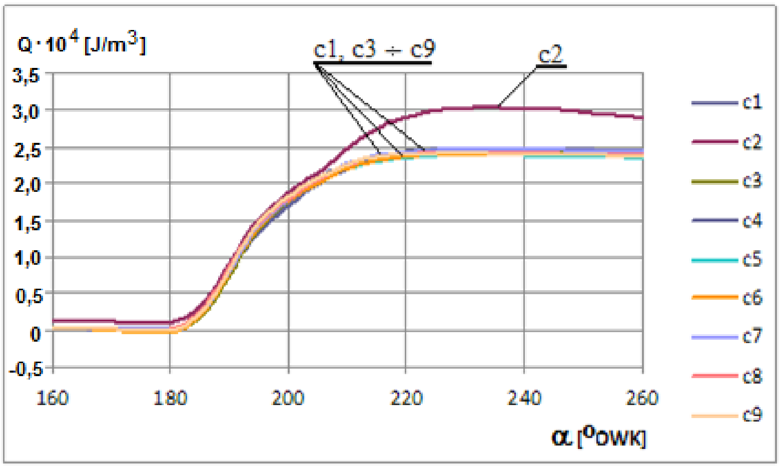

Fig. 4. The characteristics of heat release Q designated under on the indicator diagrams shown in Fig. 3: c1-c9 – Q for individual cylinders

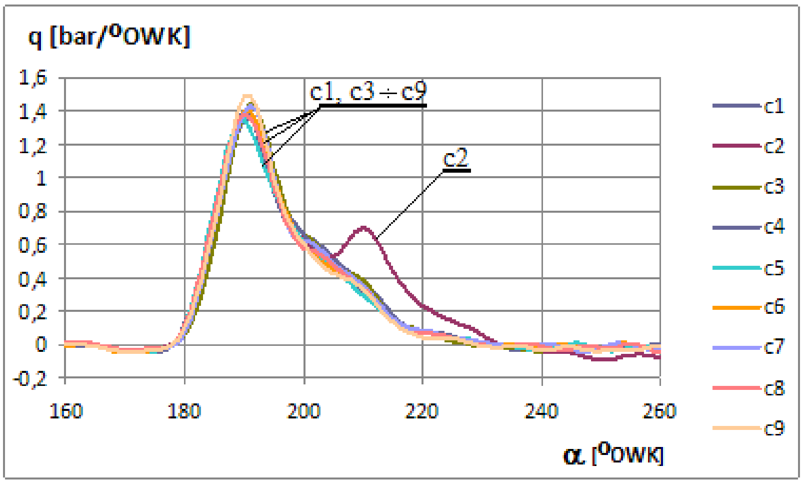

Fig. 5. The characteristics of heat release q designated under the indicator diagram as shown in Fig. 3: c1-c9 – q for individual cylinders

3.2 Analysis of the impact on the characteristics of heat release assumptions constant adiabatic exponent

To the model of heat release (dependence 6) it was assumed a constant value of the adiabatic exponent (κ=const). In fact, the value of κ is not constant and depends on the temperature and composition of the gas the compressed in cylinder (the composition of the "fresh charge").

In the temperature, range 300÷2800 K waveforms κ are considered to be linearly dependent on the temperature [17]. Based on the above, for the gas temperature from 800 K to 1850 K value of the exponent κ decreases about 3%.

The effect of the value κ on the course of characteristics q and Q, to the typical marine engines shown in Fig. 6 and 7.

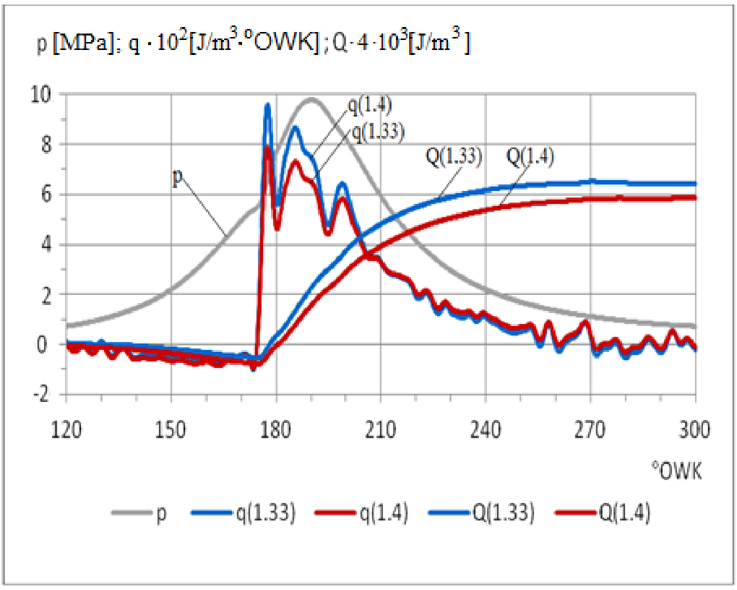

Fig. 6. Impact of errors κ on course of characteristics of the heat release q and Q medium speed marine diesel engine A25 / 30. Values κ are shown in parentheses next to the symbols q and Q

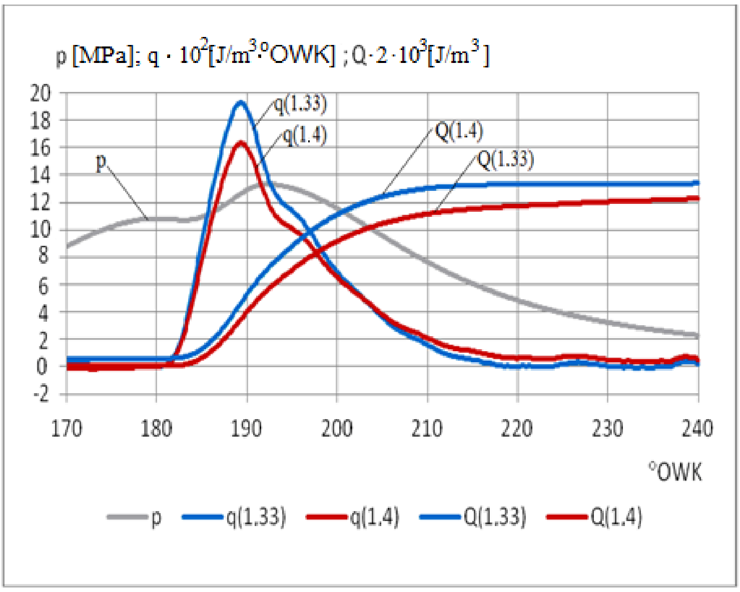

Fig. 7. Impact of errors κ on course of characteristics of the heat release q and Q low speed marine diesel engine RTA76. Values κ are shown in parentheses next to the symbols q and Q

From the analysis of diagrams in Fig. 6 and 7 results in reducing value κ for about 5%, an increase of the maximum value of q by 18% and increase the maximum value of Q by 9%, but these changes have no influence on the shape characteristics of q and Q.

It does not follow from the above the need to consider the variability κ during compression, combustion and expansion. You can watch that the waveforms κ(α) for individual cylinders of the engine will be comparable and determined the angles Ignition and end of the injection process.

The end of the injection process is well observable on the waveform q (Fig. 7) for the engine RTA76 as a point of inflection on the falling edge of the waveform. In the case of the engine A25 / 30, point is not visible due to the interference caused by interference waveform q paid by the gas ducts (Fig. 6).

4. Conclusions

In the operational diagnostics of marine diesel engines, of the great importance is the analysis of indicator diagrams. In addition to the analysis of changes indicated parameters values, should be aimed to oriented broader analysis, including the determination on the basis of experimental indicator diagram of heat release characteristics during the combustion process.

Then it is essential to choose the right model of heat release for reciprocating piston engines with direct fuel injection.

In the diagnostics of piston engines, including marine engines, special interest arouses use single-zone model based on indicator diagrams as a source of information.

Due to the high level of uncertainty calculation task cooling heat and load losses of the following blow by gas, for diagnostic purposes it is appropriate to use the characteristics of the net heat release, namely heat which is the sum of the internal energy and the work. It is assumed that the heat of the cooling will be the same for each cylinder, and will have little impact on the character of the course of heat release characteristics.

To the model of heat release was assumed a constant value of the adiabatic exponent (κ=const). In fact, the value of κ is not constant and depends on the temperature and composition of the gas the compressed in cylinder.

Based on the results their own research we analysed the impact on the characteristics of heat release of simplifying assumptions in the model of heat release, including constant value adiabatic exponent.

Based on the results, it was found that it is not necessary to take into account the variability κ during compression, combustion and expansion. You can watch that the waveforms κ(α) for individual cylinders of the engine will be comparable and determined the angles Ignition and end of the injection process.

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