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THE INFLUENCE OF THE COMPRESSION RATIO ERROR AND THE PRESSURE ERROR AT THE BEGINNING OF COMPRESSION ON THE HEAT RELEASE CHARACTERISTIC CALCULATED BASED ON INDICATOR DIAGRAM MARINE DIESEL ENGINE

Kazimierz Witkowski

Gdynia Maritime University
Mechanical Faculty
Morska Street 83, 81-225 Gdynia
tel.: +4881 69 01 332, fax: +48 58 5586399
e-mail: wika@am.gdynia.pl

Abstract

In the operational diagnostic of marine engines, the analysis of indicator diagrams is important. In addition to analysing changes in the values of indicated parameters, 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.

In the diagnostics of piston engines, including marine engines, special interest arouses to use single-zone model based on indicator diagrams as a source of information. There are calculated heat release characteristics: net heat release (Q) and intensity of heat release (q).

The article discusses the impact problem the characteristics of heat release calculated based on experimental indicator diagram various errors – the compression ratio error and the pressure error at the beginning of compression.

Based on the results of own research we analysed the impact on the characteristics of heat release the compression ratio error and the pressure error at the beginning of compression.

The effect of the errors on the course of characteristics q and Q, to the typical marine medium speed engine Sulzer A25/30 and low speed engine Sulzer RTA 76 shown.

Keywords: *marine diesel engine, indicated parameters, indicator diagram, heat release characteristics, compression ratio, compression pressure*

1. Introduction

The improvement of diagnostics methods of marine diesel engine is a very important task to monitor engine operation, fault detection at an early stage of their formation, which helps to 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. Diagnostic activities of engine room engineers significantly support electronic indicators and their analysis of indicator diagrams.

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 (α) (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 ensure the possibility of their diagnostic use. Those 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 measurements are 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. The accuracy of calculated heat release characteristics can also be influenced by errors in parameter values used to calculate heat release characteristics. For example, the compression error and pressure error at the beginning of compression may have an impact.

2. 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 an electronic indicator. It is marked on the all-important characteristic values. In addition, those indicated in the figure administered are the values of the mean indicated pressure and indicated power.

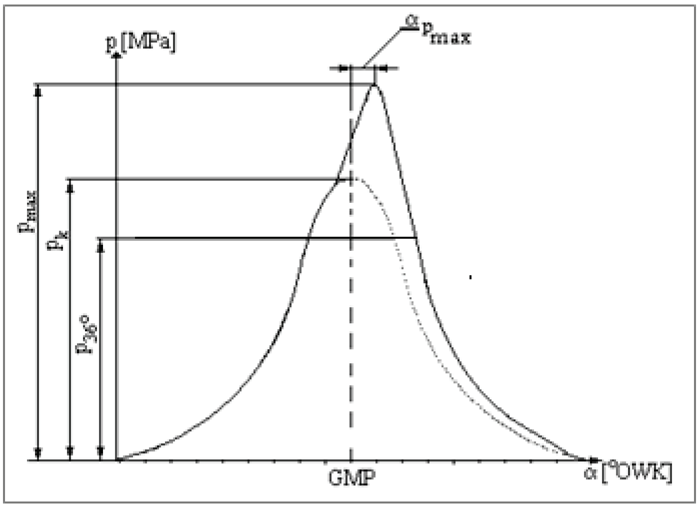

Fig. 2. Indicator diagram obtained from the electronic indicator and its characteristic values: p_{max} – the maximum combustion pressure, p_k – compression pressure, $p_{36}{}^o$ (or p_{exp}) – expansion pressure read 36 degrees of crankshaft rotation after TDC, α_{pmax} – angle after TDC obtain maximum 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. 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 (α) two graphs – curve 1 and curve 2. The pressure value on the expansion curve ($p_{36}{}^o$) graph of measured current (curve 2) is higher than the corresponding value for the standard graph (curve 1). This may be 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 too dynamic gain in pressure. Data from the graph allow calculating the value of Δp2/Δα2. Based on a comparison of the measured Δp2/Δα2 with exemplary Δp1/Δα1; you can quantify the degree of damage. The cause of excessive dynamic rise pressure – (Δp2/Δα2) >> (Δp1/Δα1) – 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 Δp/Δα causes mechanical engine overload, especially bearings piston-connecting-rod system.

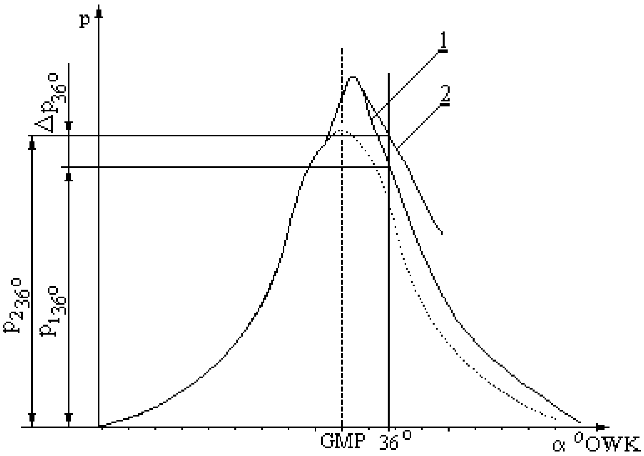

Fig. 3. Exemplary indicator diagram (1) and too high expansion pressure on the diagram (2)

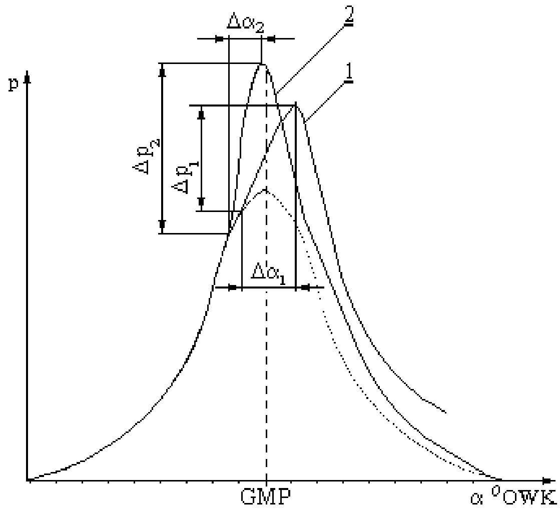

Fig. 4. Exemplary indicator diagram (1) and diagram with high value of Δp/Δα (2)

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.

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).

Having at ones disposal a properly made indicator diagram can be determined the 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.
Such a model is described in detail in [9], finally obtaining dependencies for:

- net heat release:

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

- intensity of the heat release:

$$q = \frac{đQ_n}{V_s d\alpha} = (\kappa - 1)^{-1}\left[v\frac{dp}{d\alpha} + \kappa p\left(\frac{dv}{d\alpha}\right)\right]. \tag{2}$$

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, but also the errors of the parameters values used to calculate the heat release characteristics. Among other things, this effect can be affected by the error of the degree of compression ratio and the pressure error at the beginning of compression.

In order to investigate the effect of these errors on heat release characteristics, indicator diagrams obtained were used:

- in laboratory tests on a medium-speed diesel engine Sulzer AL25 / 30,
- in ship operating conditions on a slow-speed diesel engine Sulzer RTA76.

3. Study of the influence of the error of the degree of compression ratio and the pressure error at the beginning of compression, on the accuracy calculated heat release characteristics

In order to demonstrate the error of the degree of compression ratio and the pressure error at the beginning of compression, simulation study was conducted in which was used indicated diagrams obtained on a medium-speed four-stroke marine engine type A25/30 (under laboratory conditions) and the low-speed two-stroke engine type RTA76, Sulzer company, in the operating of the ship.

Studies in laboratory conditions were carried out on a test bench of the marine engine SULZER type 3AL25/30. This diesel engine was loaded self-excited synchronous generator type GD8-500-50. This generator is loaded the water resistor, equipped with a tower cooler of water (brine). The test stand is located in the laboratories of the Department of Marine Power Plant Gdynia Maritime University and is shown in Fig. 5.

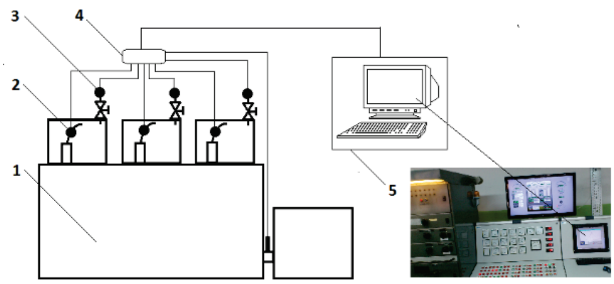

Fig. 5. Scheme of the research stand with the marine diesel engine Sulzer 3AL25/30: 1 - diesel engine Sulzer 3AL25/30, 2- injection press sensors, 3 – combustion press sensors, 4 – amplifiers and converters A/C, 5 – computer

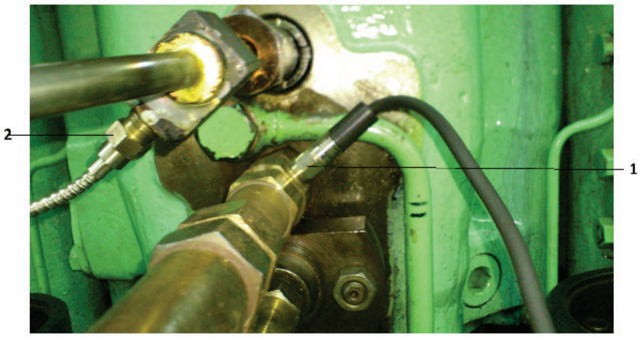

Fig. 6. The research stand with the marine diesel engine Sulzer 3AL25/30 – view on one of cylinder heads of the mounted sensors: 1 – injection press sensor Optrand AutoPSI-S, 2 – combustion press sensor Kistler 6353A24

3.1. The influence of errors in determining the compression ratio ε

The compression ratio values ε are sometimes given in the technical data of engines, they can be obtained from engine manufacturers or can be determined based on indicator diagrams. In the last case the accuracy of determining the pressure error at the beginning of compression have a significant influence on the errors of determination ε.

The deviations of q_{max} reach approximately ± 11.8% for the A25/30 engine and ± 4.7% for the RTA76 engine with error ε of ± 10%. The deviations of Q_{max} are small and amount to approximately ± 0.42% for the A25 engine and ± 0.57% for the RTA76 engine for 10% deviations ε. In practice, one should expect significantly smaller errors ε for individual cylinders. It is easy to notice (Fig. 7, Fig. 8) that errors ε have a small influence on the steepness of the build-up of the q characteristics.

3.2. The influence of the pressure error at the beginning of compression

Pressure sensors used in diagnostic measurements (Kistler, AVL, Optrand, Autronica) are generally dynamic sensors, which do not transmit a fixed component. The indicator diagrams are “truncation”. The pressure values of the compression beginning (“truncation” pressure) can be determined by thermodynamic methods based on compression diagrams of compression, or they can be adopted on the basis of separately measured charging air pressures.

For the purposes of simulation analysis, a significant range of the pressure error at the beginning of compression ± 20% was assumed.

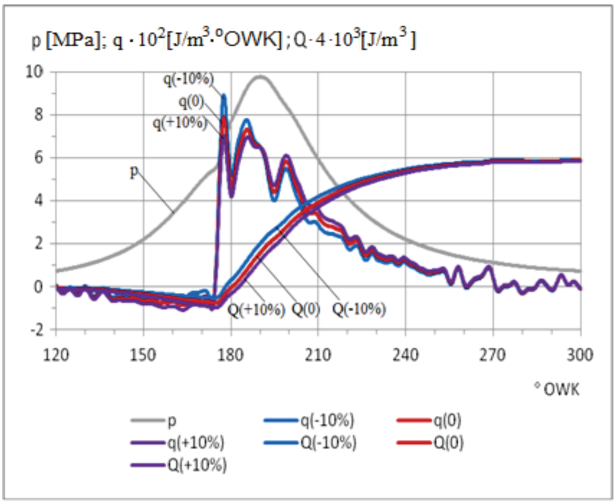

Fig. 7. The influence of errors on determination of the compression ratio ε on the heat release characteristics q and Q of the A25 / 30 medium-speed marine engine. The percentages of error ε are given in brackets next to the symbols Q and q

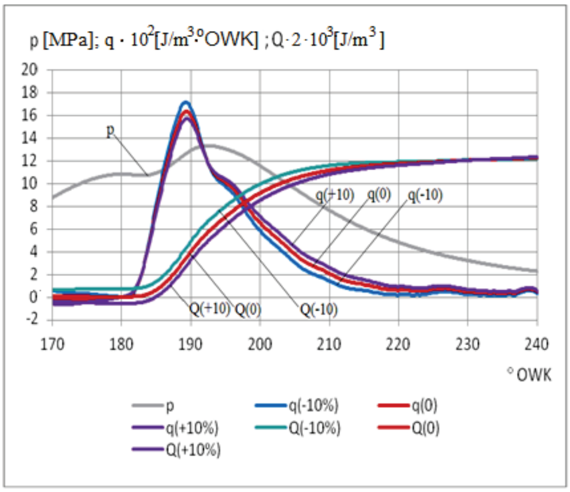

Fig. 8. The influence of errors on determination of the compression ratio ε on the heat release characteristics q and Q of theRTA76 low-speed marine engine. The percentages of error ε are given in brackets next to the symbols Q and q

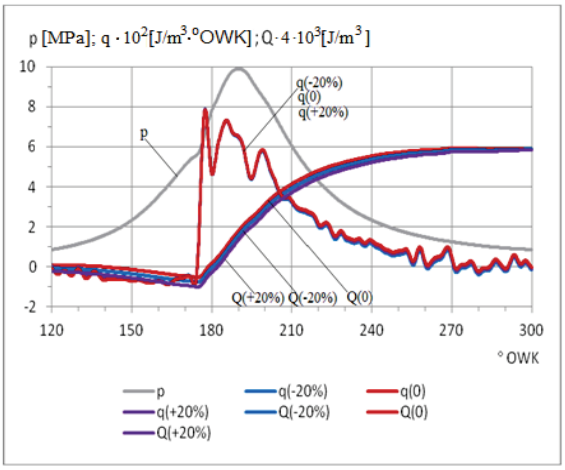

Fig. 9. The influence of the pressure error at the beginning of compression on the heat release characteristics q and Q of the A25 / 30 medium-speed marine engine. The percentages of error ε are given in brackets next to the symbols Q and q

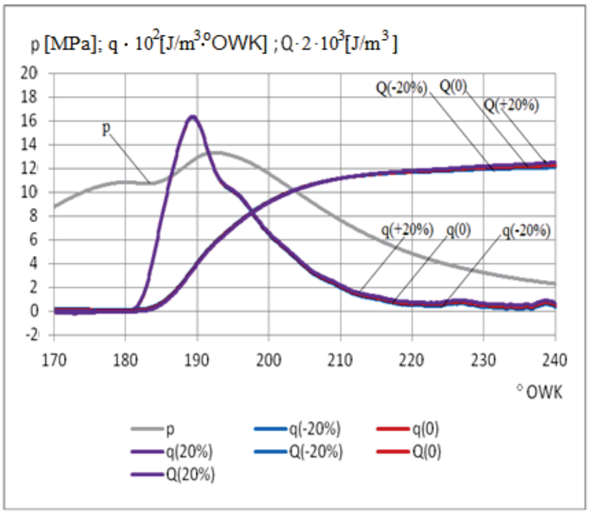

Fig. 10. The influence of the pressure error at the beginning of compression on the heat release characteristics q and Q of the RTA76 low-speed marine engine. The percentages of error ε are given in brackets next to the symbols Q and q

The analysis of the characteristics in Fig. 9 and 10 shows that the effect of pressure error at the beginning of compression on the waveforms of the q and Q characteristics can be considered negligibly small. In connection with the above, adopting the pressure of compression beginning based on the value of the charging pressure is justified.

4. Conclusions

In the operational diagnostics of marine diesel engines, 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.

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 of their own research we analysed the impact on the characteristics of heat release of error of the degree of compression ratio and the pressure error at the beginning of compression.

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 a small impact on the character of the course of heat release characteristics (equations 1 and 2).

The test results show that the error in the assumed pressure value at the beginning of compression is not significant for the calculated heat release characteristics. Therefore, the charging pressure can be taken as the compression pressure.

The errors of the assumed value of the compression ratio in the case of calculation of heat release characteristics for medium-speed marine engine are more important. However, this influence is low in relation to low-speed marine engines.

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