EVALUATION ACCURACY OF COMBUSTION CHAMBER TIGHTNESS IN PISTON ENGINES, ON THE BASIS OF A DEVELOPED INDICATOR DIAGRAM

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Abstract

The following article describes the effect of combustion chamber leakage of piston engine on the quality of its performance. To make a diagnosis of combustion chamber tightness, only such parameters were selected which are characterized by high information value and are closely connected with its defined structure. For this reason such connections are unmistakable, which results in making the right diagnosis of combustion chamber tightness of piston engines. Special attention was paid to the fact, what consequences, combustion chamber leakage, can cause to the piston engine performance. The most dangerous for the engine efficiency is the leakage of combustion chamber. The leakage of combustion chamber brings about the change of such engine parameters as pressure of suction, pressure of final compression and burning and the change of exhaust gases composition, which effect on the engine power and on fuel consumption. Condition of piston rings and their influence on gas pressure in combustion chamber has also been characterized. Pressure of gases taking place in engine cylinder and their connection with leakage of combustion chamber have also been described. The article also exposes random character of combustion pressure in engine cylinder. Besides, the errors of indicator diagrams together with mapping error position GMP have been mentioned too. Reliability of diagnostic parameters of technical condition of combustion piston engines obtained on the basis of developed indicator diagrams has been defined. Such diagram must be made on the basis of measurements and statistic analysis of pressure parameters in correctly adjusted engines, being in perfect technical condition, and not on the basis of measurements obtained in the engine test bench of a new engine. Bad technical condition, especially leaks in its cylinders causes power differences in engine arrangements, which endangers its safe exploitation.

Keywords: *leakage of combustion chamber, the errors of developed indicator diagrams, characteristic points of developed indicator diagrams*

1. Introduction

During exploitation of the engine, wear of head and piston connecting rod system elements can be observed, which, in turn, leads to the loss of tightness in combustion chamber and worsening of technical engine parameters.

Wear of combustion chamber elements, such as piston rings, causes decrease of its tightness and the loss of part of the load in the process of compression and expansion.

Losses of the load during compression cause decrease of parameters of its end, i.e. pressure and temperature of air in combustion chamber.

Faulty tightness of the piston in cylinder causes a drop of

- 17% of excess air number at constant dose of fuel in a cycle,
- 7% indicator efficiency,
- 8% effective power of the engine [4].

Check of tightness in cylinder combustion chamber of slow-speed engine is carried out by means of compression end pressure measurement.

However, in medium and high-speed engine, pressure measurements are carried out in the crankcase.

Pressure of compression in engine cylinders is determined on the basis of developed diagrams obtained from electronic indicators [3, 9].

Developed diagrams of "clear" compression are carried out at nominal rotational speeds with switched of injection of fuel into examined cylinder.

Current control of characteristic points of developed indicator diagram of the engine, allows us to evaluate the tightness of its combustion chamber.

2. Determination of diagnostic parameters set, necessary to recognize combustion chamber leak in piston engines

In most electronic indicators not only compression pressure but also other parameters are defined they are as follows:

- expansion pressure i.e. pressure for the angle 36 after TDC,
- rotation angle of engine crankshaft accompanied by pressure values counted from TDC,
- rotational speed of the engine,
- indicated pressure,
- indicated power [2, 6].

Indicated values are arithmetic averages of ten to twenty or several dozen cycles of cylinder operation.

Elementary control parameters include:

- compression pressure pspr ,
- maximal burning pressure pmax ,
- average indicated pressure pi [2, 6, 7].

Pressure value p_{spr} at optional, fixed revolution angle of ship's main engine shaft α_{spr} and at fixed parameters of supercharging air and fuel is not constant, but changes from cycle to cycle of cylinder operation.

In connection with the above, comparison of pressure courses makes sense only if the values of compression pressure were measured at the same value of rotational speed and pressure of supercharging air.

These values are compared with adequate model values, obtained during tests at the engine test house. Differences of these values prove not only the tightness of engine combustion chamber but also the changes of its technical condition and correctness of regulation [5, 8].

Compression pressure p_{spr} , effects on the power obtained from cylinder. The value of compression pressure is influenced by:

- the volume of combustion chamber which is regulated by its depth,
- leakage of combustion chamber if the pressure of compression is lower than recommended in case of untight piston,
- excessive resistance of airflow into a given cylinder [1, 5, 9].

Maximal burning pressure p_{max}, depends on compression pressure p_{spr} , dose of fuel fed into the cylinder g_w and advance angle of fuel injection α_{ww}. An increase of injection advance angle causes an increase of maximal burning pressure. However, for a given rotational speed of the engine, maximum effect on burning pressure has advance angle of fuel injection into the cylinder than a dose quantity fed into it. Lower value of this angle causes a decrease of maximal burning pressure. Maximal burning pressure p_{max} is defined on the basis of indicator diagrams or by means of maximeter measurement [2, 3, 5].

Special testing from the point of view of usefulness of developed indicator diagrams for evaluation of combustion chamber tightness in piston engines was carried out in the marine power plant laboratory of Mechanical Department in Maritime Academy in Gdynia. The above mentioned laboratory, has at its disposal, among others, the engine stand 3 AL 25/30 equipped with measurement system ALFA-5000 with electronic indicator UNITEST.

Engine indicating with proper condition of static and dynamic regulation was carried out, which had good reason for treating indicator diagram as the standard one. Such indicator diagrams can be used for evaluation of combustion chamber tightness. Owing to electronic indicator application, it was possible to obtain direct medium value reading of indicated pressure. Fig. 1-2 present indicated cylinder parameters of Sulzer engine 3 AL 25/30 depending on loading by electric current generator. Medium indicator pressure p_i, is a very precise parameter of pistons and connecting rods system, allowing estimating their load and technical condition in respective cylinders.

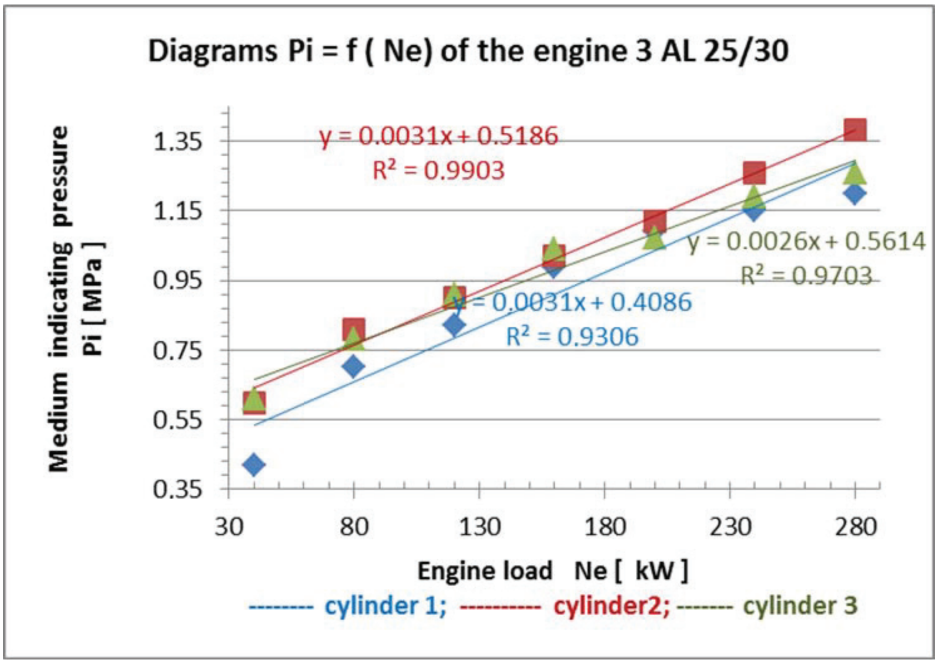


Fig. 1 Values of medium indicating pressure in the cylinders of four-stroke engine 3 AL 25/30

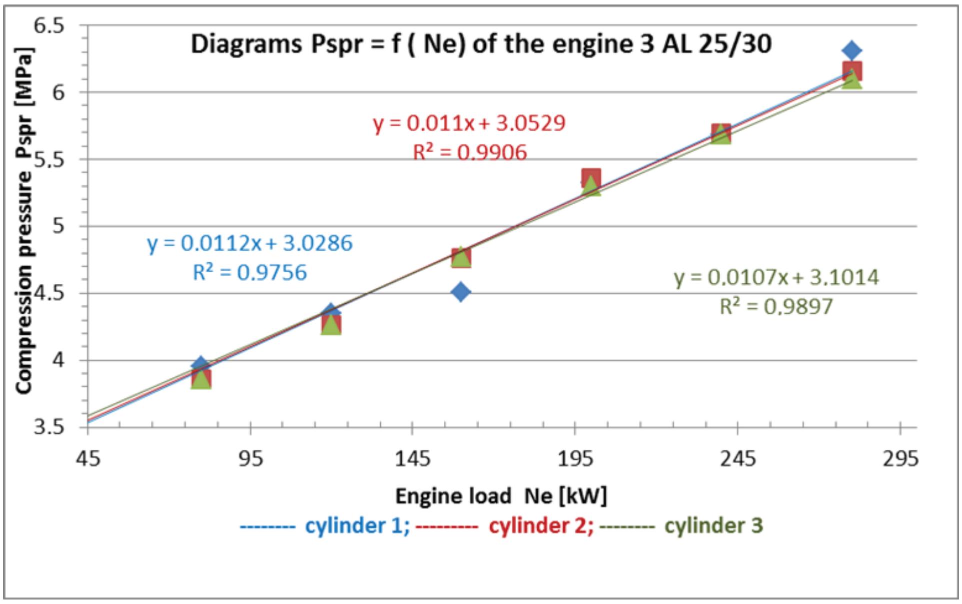


Fig. 2. Values of compression pressure in the cylinders of four-stroke engine 3 AL 25/30 in dependence on the electric power load produced by current generator

In case of incorrect performance of piston connecting rod system in one or in a few cylinders of the engine, indicator pressure will be lower than medium value. It can be caused by:

– faulty regulation of injection pump – too small dose of fuel,

– leakage to piston –sleeve system,
bad technical condition of injection apparatus.

Marine engines loaded according to screw characteristics have exact dependence between rotational speed and pressure charging. This property of marine engines allows making a scaling diagram shown in Fig. 3. Model line in scaling diagram (Fig. 3) is determined on the basis of measurement results obtained during testing in engine test house and at sea [2, 3, 9].

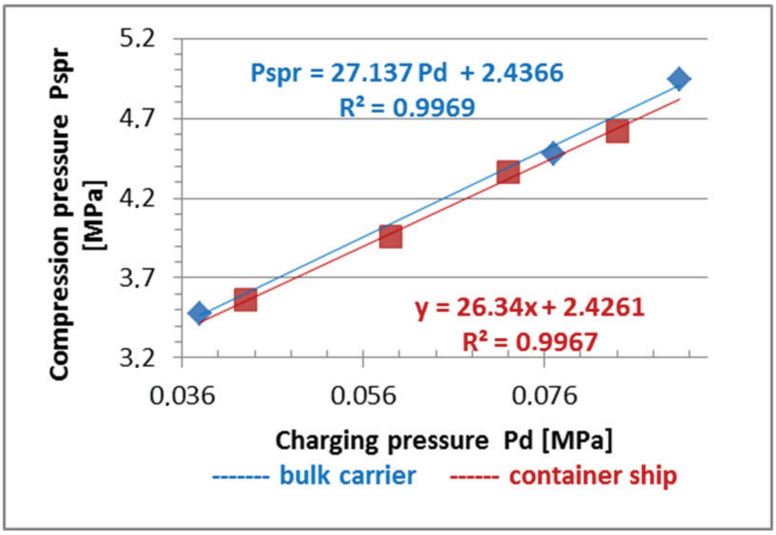


Fig. 3. Determination of compression pressure pspr on the basis of charging pressure measurement of main engine 6 RND 90 installed on two different ships sailing in good conditions

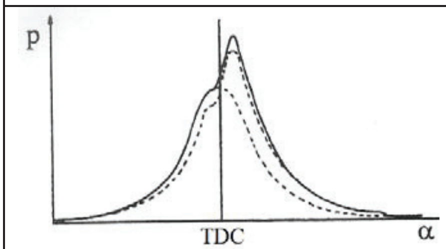
Too slow drop of compression pressure in long time intervals shows progressive wear of cylinder liner. On the other hand, too steep drop of pressure can be caused by broken or very much worn out piston rings and worn out seal of piston rod.

It is worth mentioning that an increased rotational speed of the engine improves the quality of piston sealing.

Moreover, by measurement of maximal compression pressure and comparison its value with a model one can assess tightness of combustion chamber.

In table 1 taken from diagnostic instruction of pressure analyser KN-5 of the Autronica firm, one can see deflection interpretation of a developed indicator diagram, when compared with a model diagram.

Tab. 1. Deflection examples of indicator diagram compared with a model one, taken from diagnostic table of pressure analyser NK-5 Autronica firm [6]

Symptoms in indicator diagram	Parameter deflection	Possible reasons of deflections
	P_i – low P_{max} – low P_{spr} – low P_{rozpr} – low α_{pmax} –no change	1. Worn out piston rings or damaged 2. Piston head burnt 3. Worn out cylinder liner

To evaluate tightness of combustion chamber in piston engine, one can use characteristic points of developed indicator diagrams. They are as follows:

– p_{spr} maximal compression pressure,

- p_{max} maximal burning pressure,
- p_{rozpr} expansion pressure,
- α_i ignition angle,
- α_{pmax} angle of maximum pressure [2, 6].

3. Diagnostic reliability of indicated pressure and of derived quantities

Mapping precision of pressure course in combustion chamber makes a diagram useful for analysis.

Compression course depends on measurement error:

- on pressure sensors,
- on gas channels and indicator valves,
- on determination of angle axis,
- on localization of TDC in indicator diagram.

To evaluate density of probability distribution of medium values of indicated pressure, it was assumed that they are of normal distribution. On the basis of measurements of medium values of engine indicated pressure 5RD68 of main propulsion of general cargo vessel during its voyage, it was possible to estimate the form of density distribution probability of their values determined by a formula:

$$f(p_k) = \frac{1}{0.07 \cdot \sqrt{2\pi}} \cdot e^{-\left(\frac{p_k - 0.88}{2 \cdot 0.07^2}\right)^2}, \quad (1)$$

where p_k – medium value of indicated pressure in engine cylinder.

In this way, it was possible to make a hypothesis about normality of medium value distribution of indicated pressure, which was verified for 228 pressure values measured by means of a test chi square χ^2.

In this way achieved level of statistical significance p= 0.019 allows us to admit that measured medium values of indicated pressure are representative for the remaining ones.

Assuming that measured medium quantities of indicating pressure are of normal distribution, we do not make a mistake of not more than 2%.

In Fig. 4 one can see fitting of measured medium values distribution of indicated pressure to normal distribution by means of chi square test.

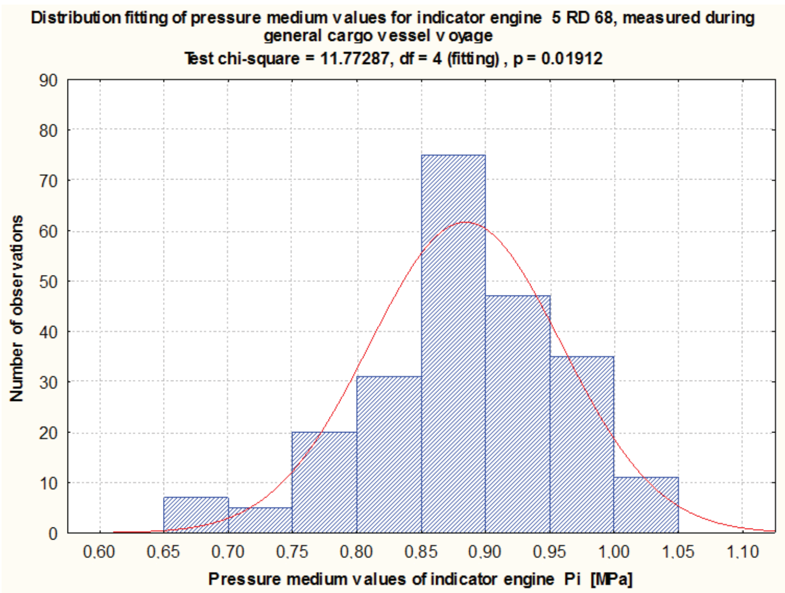


Fig. 4. Medium value fitting of engine indicator pressure 5 RD 68 of ship main propulsion measured during its voyage, compared with normal distribution

Pressure sensors and determination of upper dead point TDC localization in developed diagram have the greatest influence on the reliability of indication results.

Pressure sensor installed on indicator cock, has a direct contact with exhaust gases of the pressure reaching 20 MPa and of temperature above 400^0C. Fluctuations of pressure in the sensor produce changes of electrical characteristics of the circuit and after amplification are converted into a usable signal. Influence of high burning temperature produces momentary drift of the signal, caused by thermal shock of the sensor, which results in a measured pressure error of 3% [2].

Signal transfer band passing through pressure measuring system decides on registration recording efficiency of fuel burning dynamics in engine cylinder and causes a shift of burning pressure maximum. It should be underlined here that to measure pressure of burning, the band of 5 kHz is quite sufficient for marine engines running at a rotational speed not exceeding 1500 rot/min.

Definition error of TDC position, according to many opinions [2, 6], is crucial for definition of medium indicated pressure.

As a matter of fact, by reason of heat exchange during compression of gases in engine cylinder, maximum of pressure can be shifted in relation to volume minimum, by an angle from 1^0 HVAC to 3^0 HVAC. This means that TDC position can be determined with a determination error not larger than +/-0.3^0 HVAC, causing a shift of burning pressure maximum [2].

Delays of indicator courses, which generate systematic errors, are caused by long gas channels and large gas are as in indicator valves, as well as, turning of the shaft from the torque. As was mentioned in the paper [2], delays of indicator pressure courses of Sulzer medium speed marine engines amount to 3.5^0 HVAC of the rated speed. However, for the engines of rotational speed not exceeding 200 rot/min, delay of pressure courses is not higher than 0.6^0 HVAC. Delays of pressure courses cause large error values of their medium value determination.

Partial locking of indicator cock causes a shift and soundproofing of the measured burning pressure course. This is the reason why a developed diagram of an indicated pressure becomes similar to the diagram obtained in case of faulty engine regulation. In Fig. 6 following the papers [2, 9] we can observe the effect of indicator channel impurities on the course of indicated pressure.

In the paper [2] on the basis of research carried out on the engines 5RTA52 and 6L50MC, it was found that irregularity error of engine angular velocity is below 1^0 HVAC and can be ignored.

In spite of considerable increase of pressure measurement reliability, the calculation result of medium indicated pressure, burdened with method error, can be different from real value by 5 to 10%.

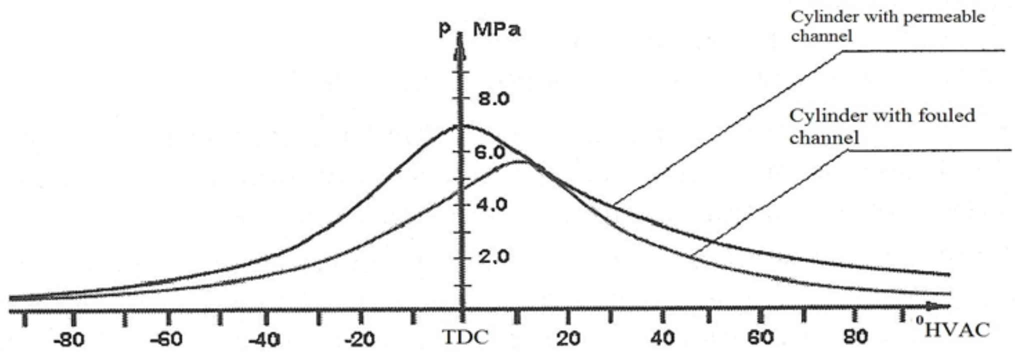


Fig. 6. Pressure courses with permeable and fouled indicator channels [2]

4. Summary

The greatest influence on reliability of indication results has the way of pressure sensor installation on the engine and position defining of the upper dead point (TDC) on a developed diagram. Pressure registration errors obtained by means of measurement system, are connected with an amplifier, convertor and registration itself and they are within the range of below 1%. The course registered by means of electronic indicator in the form of a developed diagram is the main source of information about the tightness of piston engine combustion chamber. In spite of considerable measurement errors within the range of 10% of measured value, one does not discredit an electronic indicator as a diagnostic device, considering its registration advantages of thermal process course. Electronic indicator software based on analysis procedures and comparisons of pressure course form in engine cylinder with a model course, allows us to evaluate the tightness of its combustion chambers. To evaluate tightness of piston engine combustion chamber, we do not take advantage of gas compression pressure only, but also of indicator diagram form.

Quality of measurement can be increased by:

- sensor calibration,
- determination of TDC position,
- taking into consideration the shape and length of indicator channel.

It allows decreasing the error margin of pressure course measurement up to 5%.

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