DIAGNOSTIC SYMPTOMS OF PISTON COMBUSTION ENGINES OF SHIP MAIN PROPULSION RECEIVED FROM ITS DEVELOPED INDICATOR DIAGRAMS

Jan Rosłanowski, Adam Charchalis

Gdynia Maritime University
Department of Marine Maintenance
Morska Street 83-87, 81-225 Gdynia
tel.: +48 58 6901323, +48 58 6901347, fax: +48 58 6901399
e-mail:rosa@am.gdynia.pl, achar@am.gdynia.pl

Abstract

The following article describes parameters of developed indicator diagrams concerning piston combustion engine of ship main propulsion, which can be used to assess its technical condition. To make a diagnosis of the engine combustion only such parameters should be selected which are characterized by high information value, being closely connected with its one defined structure. This is the cause why such connections are of unmistakable character, which allows to make the right diagnosis of technical condition of piston engine. Special attention was also paid to the consequences of diagnostic symptoms qualification from developed indicator diagrams of ship propulsion engine working in different conditions. Deflection of average indicated pressure caused by inappropriate engine performance could be caused by: 1) faulty adjustment of injection pump; 2) leaky combustion chamber, 3) bad technical condition of injection apparatus and the loading air system. Wrong technical condition of the engine caused by a leaky combustion chamber brings about a decrease of its performance. Untight combustion chamber causes the change of such parameters as, suction pressure, pressure of final compression and burning, as well as, the change of exhaust gases composition, which influences the power of the engine and fuel consumption. It has been mentioned what gas pressures of working process in engine cylinders are connected with an untight combustion chamber. Random character of burning pressure course in engine cylinder has also been paid attention to. Reliability of diagnostic parameters of piston engine technical condition received based on developed indicator diagrams have been determined. Diagnostic symptoms have been defined, basing on measurements and statistical analysis of pressure values in the cylinders of properly adjusted engines being in excellent technical condition and not based on measurements received in the engine test bed of a new engine.

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

1. Introduction

Operational use of the piston combustion engine leads to deterioration of its functioning due to wear of its elements or systems. As a result, all irregularities of engine operation will be visible as changes in diagnostic symptoms, received on the basis of developed indicator diagrams. By means of comparison of these symptoms with the model ones, one can precisely enough, establish the reasons of engine failures [1, 4, 5].

The basic meaning for piston combustion engine diagnosis has the proper selection of diagnostic symptoms closely connected with the structure parameters and faintly connected with input parameters. Basing on changes of diagnostic symptoms values, it is possible to carry out a diagnosis including, elementary information about correctness of piston combustion engine functioning. Such diagnostic symptoms include, among others, characteristic points of developed indicator diagram received by means of electronic indicator.

Indicating and identification of statistic properties in the whole range of practical operation of the ship main engine, allow defining empirically, mutual dependences between diagnostic symptoms of engine operation [4, 6].

Faults and damages to the engine are very difficult and sometimes quite impossible for simulation, during normal exploitation of the ship.

Such simulation testing, considering technical difficulties and a high cost, is the most difficult stage of experimental verification of damages in engine operation. Standard diagnostic symptoms of piston combustion engine has been worked out by Autronica, on the basis, of theoretical considerations from the point of view of providing easy, logical and justified procedure of damage localization [1, 3, 7, 8].

Such symptoms can be worked out also by the engine producer, on the basis, of its indicating, during testing in engine test bench. Standard diagnostic symptoms proposed by Autronica are functions:

$$p_i \cdot p_d = f(p_i),\ \ p_{compr} = f(p_d),\ \ p_{\max} - p_{compr} = f(p_i),\ \ p_{exp} = f(p_i), \tag{1}$$

where:

p_i – medium indicated pressure,
p_d – supercharging pressure,
p_{compr} – pressure of compression,
$p_{\max}$ – maximal pressure of combustion,
p_{exp} – pressure of expansion.

Proposed standard diagnostic symptoms are received on the basis of developed indicated diagrams measured by means of electronic indicators of Autronica Company, type NK [3].

Overloading states are very dangerous for contemporary ship engines, as they cause damages and even dangerous and expensive averages of its con-rod-piston systems. Engine loading is, most by, determined by an intermediate method, on the basis of such parameters as: medium indicated pressure p_i, load indicator w_o, fuel consumption per hour G_e, fuel dose per cycle g_w and comparison of the above with values presented by the producer [2].

2. Diagnostic symptoms characteristics of piston combustion engines received on the basis of developed indicator diagrams

Basis diagnostic symptoms of piston combustion engines received on the basis of developed indicator diagrams include:

– pressure of compression p_{compr},
– maximal pressure of combustion $p_{\max}$,
– medium indicated pressure p_i [1, 3, 4, 6].

The control of combustion chamber tightness in the cylinder of slow-speed engine is carried out by means of pressure measurement of the compression end. Pressure of compression influences the power received from the cylinder. The piston- con-rod system works in the state of under loading when the pressure p_{compr} has lower value than recommended and the other way round. Pressure of compression is affected by:

– volume of combustion chamber which is regulated by its height,
– untight combustion chamber when the pressure of compression is lower than recommended,
– excessive resistance of air flow to a given cylinder [2, 4, 6].

Maximal combustion pressure $p_{\max}$ depends on compression pressure p_{compr}, fuel dose delivered to cylinder g_w and advance angle of fuel injection α_{ww}. An increase of injection advance angle causes an increase of maximal combustion pressure. However, for a given rotational speed of an engine, the greatest effect on maximal combustion pressure has the advance angle of fuel injection to a cylinder because it is greater than the dose delivered to the cylinder. Smaller value of this angle causes a decrease of maximal combustion pressure [1, 2, 3].

Medium indicated pressure p_i means a parameter defining real ability of piston-con-rod system to carry out a useful work. In other words, it is the pressure operating during the whole expansion

stroke, producing indicated work of piston-con-rod system. In connection with the above, comparison of pressure courses makes sense, only when, the values of compression pressure were measured at the same value of rotational speed and pressure of supercharging air.

Values of pressure measured in operation are compared with adequate standard values received during engine indication in the engine test bench or during sea trials. Differences of these values indicate not only the tightness of the engine combustion chamber but also the changes of its technical condition and correctness of adjustment.

3. Laboratory research connected with making use of diagnostic symptoms in piston combustion engines, obtained on the basis of developed indicator diagrams

Some researches were carried out in Maritime Academy laboratory of engine power plant, from the point of view of the use of combustions engines diagnostic symptoms received on the basis of developed indicator diagrams, for evaluation of combustion engine chamber tightness. The laboratory has at its disposal, among others, work-stand of the 3 AL 25/30 engine, propelling the generator. The research was carried out just on this engine. The engine is equipped with remote work control system which includes automatic measurement computer system ALFA- 5000 and registration of parameters together with their visualization. This system is connected with electronic indicator UNITEST 2008, cooperating with sensors of cylinder pressure measurements of the Kistler 6353 A 24 company and the sensors of pressure measurements in the injection system of the Optrand type Auto PSI-S company. Indicator pressure measurement was carried out every 1°HVAC. Laboratory research was realized in regard to engine load from 50 to 250 kW. The engine worked on diesel oil of $\rho_{pal} = 834.23$ kg/m^3 density and fuel furnace value $W_d = 42{,}657$ kJ/kg. Measured values, taken during research, are given in Tab. 1.

Tab. 1. Measured values during engine indication Sulzer 3AL25/30

No.	N_{el} [kW]	p_d [kPa]	n_{sil} [rpm]	p_i [MPa]			$p_{i\,med}$ [MPa]	$p_{\max}$ [MPa]			$P_{\max\,med}$ [MPa]
				Cyl. 1	Cyl. 2	Cyl. 3		Cyl. 1	Cyl. 2	Cyl. 3	
1	50	12	750	0.54	0.57	0.53	0.55	5.85	5.73	5.34	5.64
2	100	22	750	0.81	0.77	0.78	0.79	6.70	6.80	6.19	6.56
3	50	43	750	1.04	1.03	1.08	1.05	7.76	7.90	7.11	7.59
4	200	80	750	1.31	1.28	1.27	1.29	8.81	8.67	7.93	8.40
5	250	84	750	1.45	1.50	1.32	1.42	9.73	9.70	8.77	9.40

Values measured during engine indication, given in Tab. 1, indicate that together witch an increase of the power supplied by electric generator, its imposing load on the power supplied by electric generator, imposing load on the combustion engine, parameters of maximal pressure $p_{\max}$ and pressure compression p_{compr}, also increase their values.

On the basis of pressure values obtained from developed indicator diagram during engine operation, presented in Fig. 1, and on the basis of measured values of the torque, one can state that medium indicated pressure $p_{i\,med}$ is directly proportional to it. Indication of the engine was carried out at correct state of static and dynamic regulation, which, in turn, was a good reason to treat indicator diagrams as the standard ones. Tab. 1 shows directly proportional dependence of medium indicated pressure on the torque of the engine $p_{i\,med} = f(M_o)$ received in measurements of their values. Fig. 2 and Fig. 3 presents indicated operation parameters of piston–con–rod systems in the cylinders of Sulzer engine 3 AL 25/30 in dependence on its rotational speed with different load by its generator electric power.

Medium indicator pressure p_i is a very precise parameter of piston-con-rod systems operation, which allows evaluating their load and technical condition in respective cylinders.

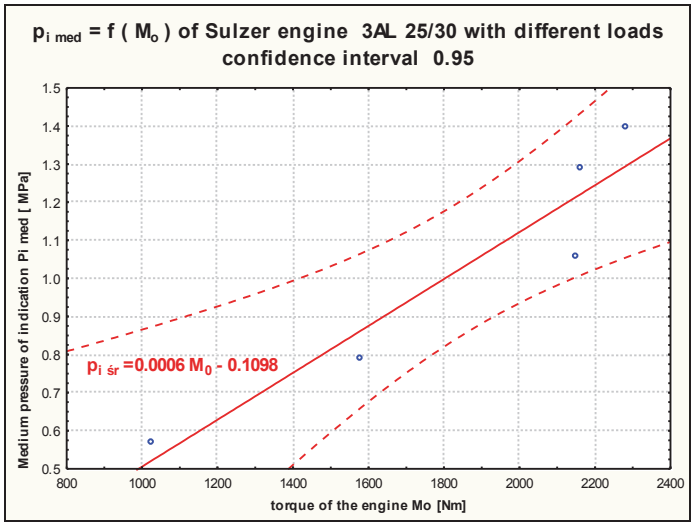

Fig. 1. Dependence of mean pressure of indicated engine Sulzer 3 AL 25/30 on its torque, received on the basis of measurements carried out during laboratory testing

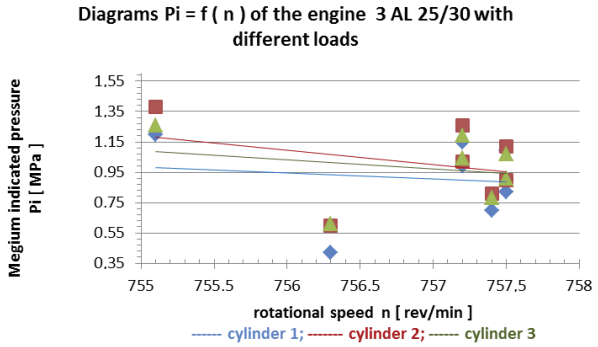

Fig. 2. Values of mean indicating pressure in cylinders of the Sulzer engine 3 AL 25/30 with its different loads by generator electric power, depending on rotational speed

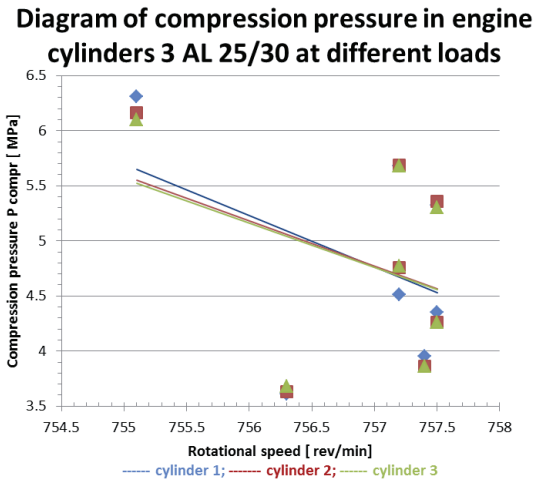

Fig. 3. Values of compression pressure in engine cylinders Sulzer 3 AL 25/30 at its different loads by electric power of the generator, depending on rotational speed

In case of incorrect operation of piston-con-rod system in one or some engine cylinders, indicated pressure will be lower than the mean value. The reasons can be as follows:

– incorrect adjustment of injection pump – too little dose of fuel,
– leakage of piston-con-rod system,
– bad technical condition of injection apparatus.

Too slow drop of compression pressure in long intervals of time shows an increasing wear of cylinder liner [6].

On the other hand, very abrupt drop of pressure can be caused by cracked or very much worn piston rings and worn seal of piston rod [4, 6]. At this place, it is worth to mention that an increased rotational speed of the engine improves the quality of piston tightness.

Figure 4 presents maximal values of combustion pressure in Sulzer 3 AL 25/30 engine depending on the load of its electric power generator.

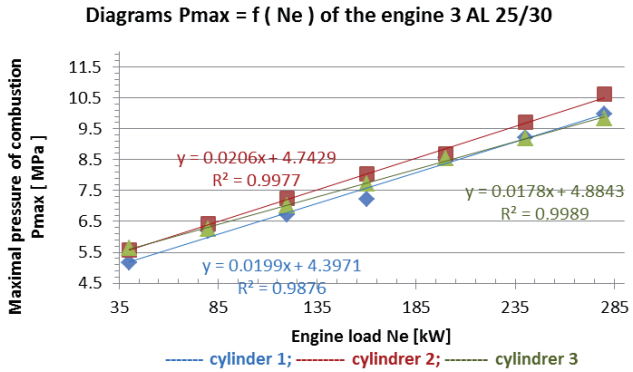

Fig. 4. Values of maximal combustion pressure in the cylinders of four-stroke engine Sulzer 3 AL 25/30 in dependence on the load by generator electric power

Operation irregularity of piston-con-rod engine systems above acceptable values causes many negative consequences connected mainly with dynamic load. In case of unequal operation of piston-con-rod systems in respective cylinders, it is necessary to find, immediately, the reason of this state and to remove this malfunction as soon as possible.

4. Diagnostic symptoms of piston combustion engines according to indicator diagrams during ship operation

Marine engines loaded according to propeller characteristic, possess strict dependence between rotational speed and supercharging pressure. This propriety of marine engines permits to make a scaling diagram, shown in Fig. 5, indicating dependence of compression pressure on supercharging pressure.

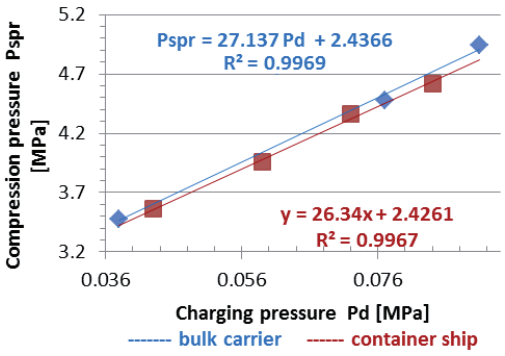

Fig. 5. Determination of compression pressure p_{comp} according to measurement of supercharging pressure of main engine 6 RND 90, installed on two different ships sailing in good conditions

Figure 6 presents standard diagnostic symptoms in the function of mean indicated pressure (1) carried out during main engine indication, 6 RND 90, on two ships in the course of operation, in good sailing conditions. They refer to a measured supercharging pressure and compression pressure in a function of mean indicated pressure.

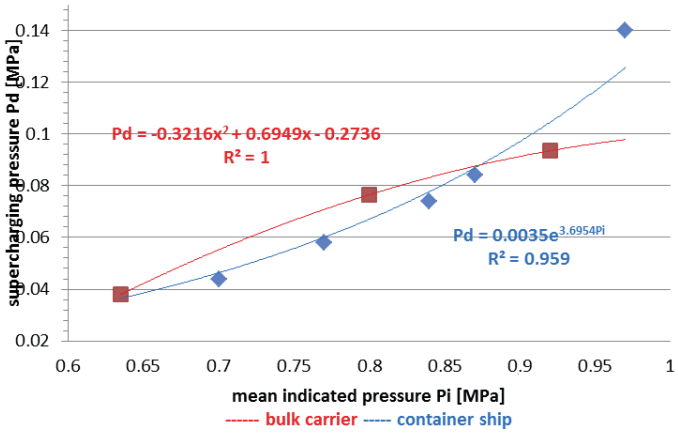

Fig. 6. Supercharging pressure in the function of indicated pressure of main propulsion engine 6 RND 90, installed on two different ships, operating in good conditions

Figure 7 presents exemplary diagnostic symptoms of piston combustion engines received according to developed indicator diagrams in a function of rotational speed of the engine, received during ship operation.

The figures reveal considerable differences between symptoms determined in engine test-bench and the ones received during ship propulsion engine operation, in different sailing conditions. On the other hand, differences between measurements results during ballast sailing and cargo sailing are not of great importance (Fig. 7). Measurements are rather doubtful as to usefulness of standard symptoms determination on the basis of the results of parameter measurements concerning engine operation during testing in the engine test-bench.

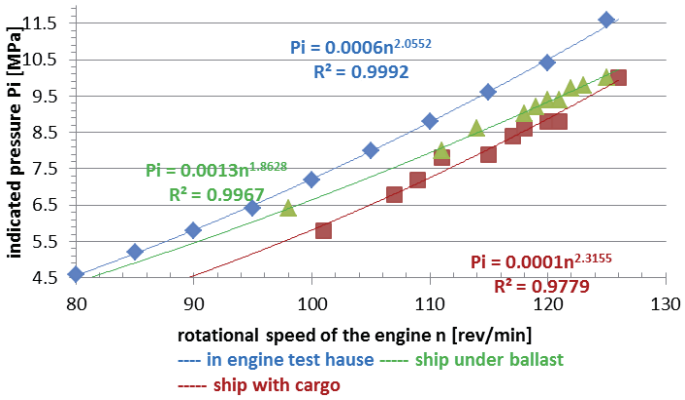

Fig. 7. Measurements of indicated pressure of main propulsion engine type 6 RND 90, installed on general cargo vessel in different work conditions

In order to check usability of pressure differences of maximal combustion and compression in a function of mean indicated pressure, to discover faulty operation of piston-con-rod system of 5 RD68 engine, its indication was carried out. Indication of 5 RD68 engine was carried out during its normal operation on general cargo vessel voyage. Faulty operation of piston-con-rod system was simulated by a tight combustion chamber of the cylinder, opening partly for a short time, indicator cock of the cylinder head. To carry out this experiment, they chose piston-con-rod system of the highest number of work hours. Value differences of maximal combustion pressures and compression in a function of mean indicated pressure is shown in Fig. 8. Symptom of pressure differences of maximal combustion and compression in engine cylinder 5 RD68 in a function of mean indicated pressure has a considerable dispersion of values during its work in time of general cargo vessel voyage. Besides it is not too much sensitive to simulated leaks of combustion chamber of indicated cylinder (Fig. 8 measurement points marked by number 1).

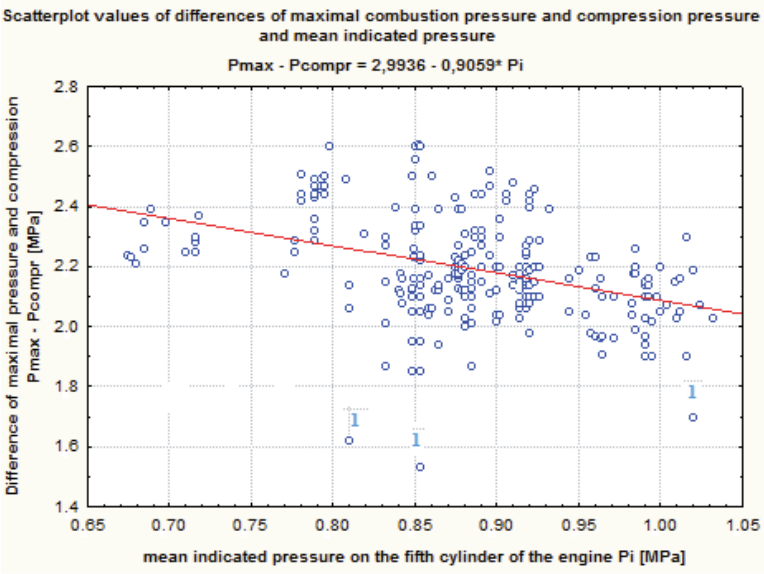

Fig. 8. Measured values of differences of maximal combustion pressure and compression pressure and mean indicated pressure on the 5th cylinder of main propulsion engine 5 RD68 of general cargo vessel during its voyage. Explanations: points marked with number 1 are adequate to partial opening of indicator cock during measurements

5. Summary

Running control of diagnostic symptoms of piston combustion engines, received according to developed indicator diagrams allowed us to evaluate its technical conditions.

Diagnostic standard symptoms should be made up on the basis of developed indicator diagrams, received during engine operation, properly adjusted and being in an ideal technical condition, that means a new engine should be installed on the ship. They should also take into account statistical analysis of pressure parameters values in cylinders of a good engine.

Attention should be also paid to the fact that values of pressure measurements cannot be used in an engine test-bench. Such measurements are carried out at other characteristic of static and dynamical load. In engine test bench there are differences between brake characteristic and the propeller characteristic in absence of forced random actions.

Analysis of diagnostic symptoms received by means of electronic indicators is carried out by their comparison with standard symptoms or earlier, on the basis of developed indicator diagrams.

Comparison of such diagnostic symptoms makes sense only when they are made up in the same conditions of engine operation.

References

[1] Pawletko, R., Polanowski, S., *Influence of Gas Channels of Medium Speed Marine Engines on the Accuracy of Determination of Diagnostic Parameters Based on the Indicator Diagrams*, Journal of Polish CIMAC, Vol. 7, pp. 139-146, 2012.

[2] Gałecki, W., Tomczak, L., *Indicating of Marine Combustion Engines.* Publishers – Gdynia Maritime Academy, Gdynia 2002.

[3] Kozaczewski, W., *Construction of Piston Cylinder Group of Combustion Engines,* WKiŁ Warsaw 2004.

[4] Piotrowski, I., Witkowski, K., *Exploitation of Marine Combustion Engines,* Publishers – Gdynia Maritime Academy, Gdynia 2002.

[5] Polanowski, S., Pawletko, R., *Acquisition of Diagnostic Information from the Indicator Diagrams of Marine Engines Using the Electronic Indicators,* Journal of KONES Powertrain and Transport, Vol. 18, No. 3, pp. 359-366, 2011.

[6] Polanowski, S., *Method Study of Indicator Diagram Analysis in Aspect of Marine Engines Diagnostics,* Scientific papers AMW, year XLVIII, No. 169 A, Gdynia 2007.
[7] Serdecki, W., *Investigation on Cooperation of Piston–Cylinder Element System of Combustion Engine*, Publishers – Poznań Institute of Technology, Poznan 2002.
[8] Włodarski, J. K., Podsiadło, A., Kluj, S., *Damages to Piston–Cylinder System (TC) of Marine Combustion Engines*, Publishers – Gdynia Maritime Academy, Gdynia 2011.
[9] Report on Research Project KBN No 9 TI 2D 033 17, *Energetic Evaluation of Contemporary Marine Power Plants and Ways of Activities Aiming at Improvement of Their Effectiveness*, Publishers – Marine Academy in Gdynia, Gdynia 2002.