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Influence of pressure sensor location on the quality of thermodynamic parameters calculated from the marine engine indicator diagram

Abstract: A major problem for the diagnostic use of the indicator diagram is the pressure sensor location. Indicator channel and valve may bring in significant distortions in the resulting pressure. The paper presents results of research conducted on the medium speed laboratory engine Al 25/30. Indication was made by the sensor placed directly in the cylinder (instead of starting air valve), before the indicator valve (with special Kistler adapter) and on the indicator valve. During the research the course of heat release rate q and the heat released Q were determined. Distortion of heat release characteristics for the sensor placed in the indicator valve is important, but it is estimated that diagnostic information is not lost. Influence of the pressure sensor location can be significantly reduced by proper adjustment of the TDC position.

Keywords: *indicator diagram, heat release characteristics, marine diesel engine diagnostics*

Wpływ lokalizacji czujnika ciśnienia na dokładność wyznaczania parametrów termodynamicznych w oparciu o wykres indykatorowy silnika okrętowego

Streszczenie: Jednym z głównych problemów diagnostycznego wykorzystania wykresów indykatorowych jest miejsce umieszczenia czujnika ciśnienia. Kanały oraz zawory indykatorowe są źródłem istotnych zakłóceń pomiarowych. W artykule przedstawiono wyniki badań dotyczących miejsca zamocowania czujnika ciśnienia spalania na silniku laboratoryjnym Sulzer Al25/30. Czujniki ciśnienia zostały umieszczony bezpośrednio w cylindrze (w miejsce zaworu startowego), przed zaworem indykatorowym oraz na zaworze indykatorowym. Oprócz podstawowych parametrów indykowanych na podstawie wykresów indykatorowych wyznaczono przebieg charakterystyk prędkości wydzielania ciepła oraz ciepła wydzielonego. Na podstawie uzyskanych wyników badań stwierdzono, że kanały gazowe silników średnioobrotowych wnoszą znaczące opóźnienia sygnałów ciśnienia i deformacje wykresów indykatorowych, jednak możliwe jest w dalszym ciągu ich diagnostyczne wykorzystanie. Wpływ lokalizacji czujnika ciśnienia może być istotnie zmniejszony poprzez prawidłową korektę położenia GMP.

Słowa kluczowe: *wykres indykatorowy, charakterystyki wydzielania ciepła, diagnozowanie silników okrętowych*

1. Introduction

Medium speed marine engines are mostly equipped with indicator valves for cylinder pressure measurement (indication). However, with increasing engine speed, signal delay and distortion of pressure signal are also increased. Significant impact on the level of interference, in addition to engine speed, is the design and length of gas channel between the cylinder and the pressure sensor. Despite the above-mentioned difficulties, the measurement of pressure in the cylinders of marine engines is a routine diagnostic activity.

Medium speed engines are used principally in shipbuilding as generators in a power plant of low speed engines and in power plant with gear drive systems, or as the main source of electrical power in a diesel-electric power plants.

Engine speed for the Wartsilla company smallest power engines (cylinder diameter from 200 mm to 260 mm) amounts to 1000 rpm. For the other engines of those company the range of speeds are from 750 to 330 rpm for Wartsila 64 engine.

In generating sets from MAN company, because of the lower cylinder bores, speeds range are from 1200 rpm for the smallest diameter cylinders (160 mm) to 500 rpm for the largest diameter of the cylinder (600 mm).

Several investigations have been already done on problem of indication valve influence on pressure curve. According to the authors of [1, 2] the main source of distortion is the geometry of the indicator valve. The problem is known but in this paper its impact on the diagnostic usefulness of the pressure signal will be assess.

Difficulties with the TDC position location on the indicator diagrams cause, that only one diagnostic parameter, which is the maximum combustion pressure is considered to be reliable [3, 4, 5]. In addition, this parameter should be related to the average from all cylinders due to the expected high value of the measurement error. In order to determine the level of errors and possible diagnostic use of mean indicated pressure and heat release characteristics, experimental research on the engines were carried out.

Improvement of diagnostic use of indicator diagrams is associated with the evaluation of the combustion process on the basis of the heat release characteristics. Significant impact on heat release characteristics errors are not only TDC determination errors, but also noise (oscillations of gases) in the indicator channels. The existing experience gained in operating conditions show the reproducibility of this type of influence (Fig. 1).

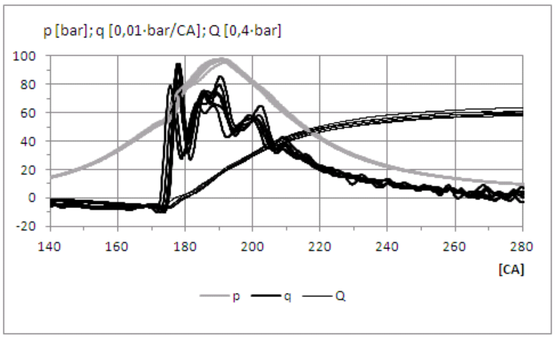

Figure 1. Dimensionless (related to the average maximum values for the motor) the heat release rate δq and heat released δQ for 6 cylinders of the medium speed marine engine 6A25/30 working on nominal load (750 rpm)

In this case, the measurements were done on the indicator valves. The paper presents the test results for the three pressure sensors locations.

In the case of low-speed engines low level of interference was found, and interference for each cylinder overlap was observed (Fig. 2).

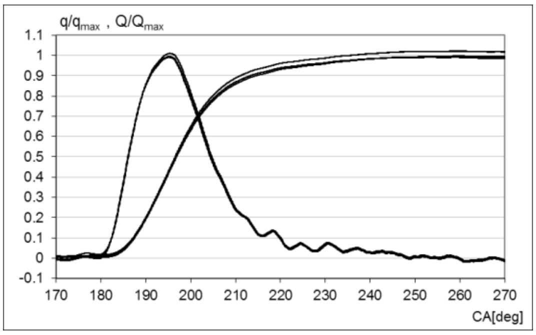

Figure 2. Heat release characteristics of q/q_{max} i Q/Q_{max} for the low-speed marine diesel engine 5RTA52: q_{max} , Q_{max} - average of maximum values of q and Q. Measurements were performed on newly built engine during sea trials

2. The object and subject of research

The objective of research was to determine the influence of the indicator channel and indicator valve on cylinder pressure traces. Research was carried out in the laboratory on the medium speed ship's engine Sulzer Al 25/30. The tests were made at engine speed 750 rpm. In Sulzer Al engine, gas channel, which connects indicator valve with the combustion chamber, has considerable complexity and length (Fig. 3).

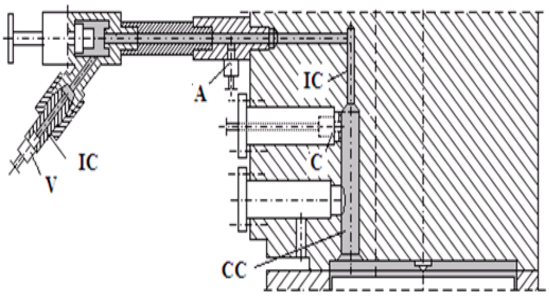

Figure 3. The design of the gas channel, pressure sensors location of the test engine Al 25/30: CC – cylinder channel, IC - indicator channel, C - pressure sensor location in the cylinder, A - pressure sensor location in the adapter Kistler 7523A10 , V - pressure sensor location on the indicator valve

The measurement sensors Kistler type 6353A24 were used during the test. The measurements were performed for three loads, all at the engine speed 750 rpm. Pure compression diagram were also registered by cutting-off fuel injection pump on the test cylinder.

3. Distortion and delay of pressure graphs

When comparing the indicator diagrams (Fig. 4) the following symptoms of gas channels impact can be observed: delay of pressure diagrams p_A and p_V compared with reference p_C, oscillations and distortions of the pressure curves and higher maximum pressures values p_V and p_A when compared with the maximum values of pressure in the cylinder p_C.

Pressure distortions are particularly well observable on the graphs of pure compression.

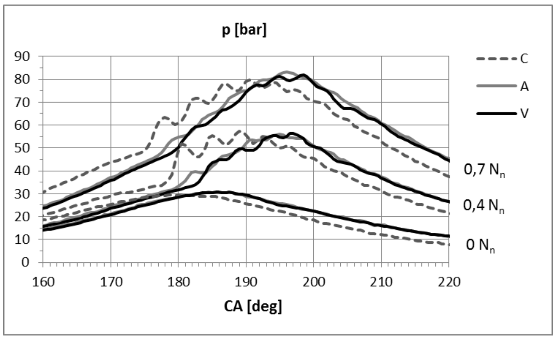

Figure 4. Comparison of the indicator diagram in the range of the end of the compression and combustion: C - pressure in the cylinder, A – pressure in the adapter, V – pressure after the indicator valve. Coordinate 180°CA (Crank Angle) corresponds to thermodynamic TDC on C pressure curve (in the cylinder)

Especially large distortions visible on the curves are caused by fading standing wave, excited at the moment of ignition in the channel CC (Fig. 5) and spreading to the indicator channel.

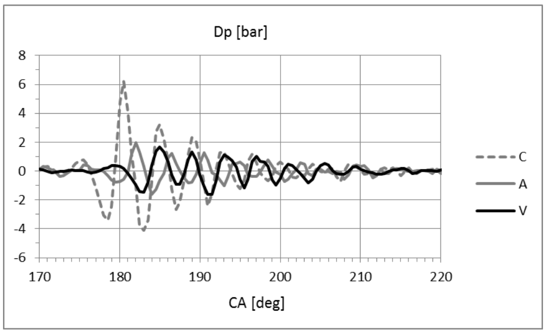

Figure 5. Dp pressure curves oscillation at the open indicator valve (Fig. 1): C - in the cylinder channel, A - in the adapter, V - on the indicator valve

The initial amplitude of observed waves in the channel CC exceeds 10 bar, which is about 18% of maximum pressure. The period of oscillation is about 4.5 ^{o}CA for engine speed 750 rpm. This wave does not change its form after closing the indicator valve when the space (channel) of indicator valves is cut off (Fig. 6).

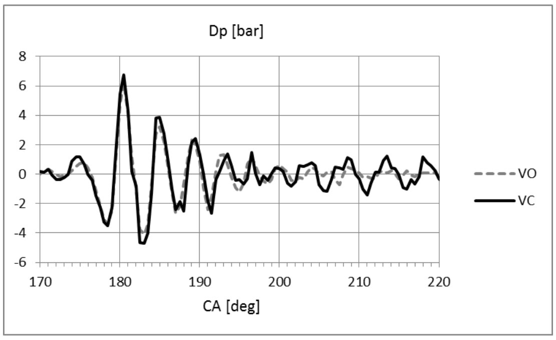

Figure 6. Comparison of waves of pressure Dp in the cylinder channel:VO – indicator valve open, VC – indicator valve closed

The results confirm the above observation is that the main source of pressure distortion is cylinder channel. If the engine load increases, waving phase changes with respect to TDC, but does not change its frequency. Phase shift is caused by a change of injection start, together with the engine load.

4. Gas channel influence on TDC designation errors, indicated work designation errors and the mean indicated pressure designation errors

The main source of errors of determination of the indicated work and the mean indicated pressure are errors of TDC positioning on the indicator diagram. Sometimes, in order to determine TDC positioning errors, a position of maximum of cylinder pressure of pure compression are used. The maximum of pure compression can be find with the zero point of the first order derivative of pressure curve.

The study assumed a TDC position as a thermodynamic TDC determined using the original method [4]. The difference between the position of TDC in the cylinder (C), and the position of TDC in the adapter (A) was 6^{o}CA. The difference between the TDC in the cylinder (C) and the position at TDC on the indicator valve was 5.9^{o}CA.

Positions of designated TDC based on the zeros point of the first order derivatives were respectively: 108.4^{o}CA for the cylinder (C), 179.3^{o}CA for the adapter (A) and 179.8^{o}CA for the indicator valve. These are significant values. To determine the mean indicated pressure, indicated work and heat release characteristics, thermodynamic TDC were designated individually for each pressure curve.

Comparison of the indicated work (related to the volume of a cylinder) (Fig. 7) shows their high similarity.

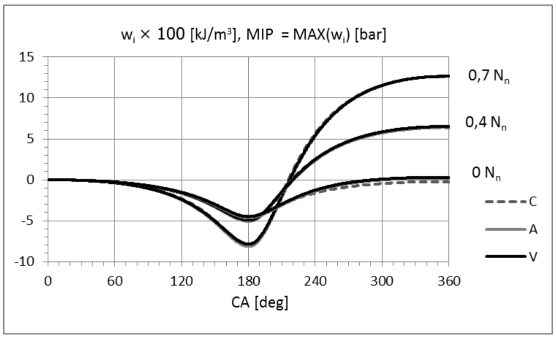

Figure 7. Comparison of the indicated work curves w_i (referred to the volume of a cylinder), mean indicated pressure MIP for different values of the engine power Nn: C - in a cylinder channel, A - in the adapter channel, V - on the indicator valve

Deviation of the MIP to the value measured in the cylinder (C) did not exceed 0.3% for nominal load (Table 1).

Table 1. Values of mean indicated pressure MIP and their percentage deviations for each of the measurement points, referenced to the values measured in the cylinder (C)

Engine load	MIP [bar]			δMIP [%]	
	C	A	V	AC	VC
0.7 Nn	12.04	12.09	12.08	0.30	0.27
0.4 Nn	6.38	6.39	6.52	0.14	2.08
0 Nn	-0.22	0.22	0.31		

Very good convergence of results were obtained despite the high similarity level of interference. This follows from the integral nature of the values and the relatively small signal lost following the signal delays and waving.

5. Gas channel influence on TDC designation errors, indicated work designation errors and the mean indicated pressure designation errors

Net heat release characteristics were determined based on a simplified model for an ideal gas, based on thermodynamic TDC [4].

First order derivative of pressure curves was determined using a polynomial Savitzkiego-Golay filter for three passages and wide range of different approximations in each passage. The filter were built according to individual original study [5].

Despite considerable noise a good convergence of heat release rate q and heat released Q were obtained (Fig. 8).

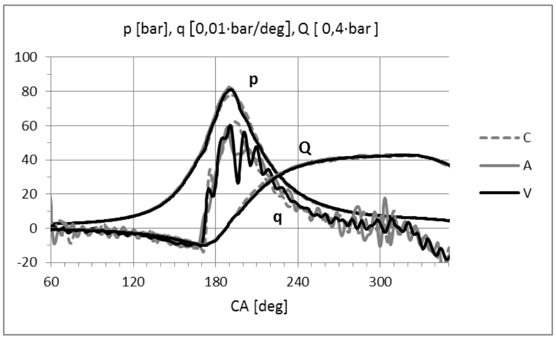

Figure 8. Comparison of heat release characteristics designate for the set of indicator diagrams for the load 0.7 N_n: q – heat release rate, Q – heat released, C – for the measurement in the cylinder, A – for the measurement in the adapter, V – for measuring on the indicator valve

A similar results were obtained for the other engine loads - the difference between the values of heat released for the various loads are small (Table 2) and have a systematic nature.

Table 2. Values of the maximum of heat released Q and their percentage deviations for each of the measurement, referenced to the those specified for the cylinder: C (C)

Engine load	Q [0,4*bar]			δQ [%]	
	C	A	V	AC	VC
0.7 Nn	21.16	21.56	21.39	1.88	1.09
0.4 Nn	13.45	13.61	13.59	1.19	1.05
0 Nn	-0.54	0.12	0.18		

Heat released curves Q are something distorted. Smoothing can be improved by developing a special filter. Further smoothing with applied filter (subsequent transition to wider intervals) lead to excessive phase deformation. It should be noted, however, that the systematic errors of comparable values do not affect the diagnostic usefulness of the signals.

6. Conclusions

Gas channels of medium speed engines bring significant delay and deformation of the indicator diagram. In the case of the test engine, the signal delay on the indicator valve reached 6 ^{o}CA at 750 rpm, compared with the measurement in the cylinder channel. In the cylinder channel (C) of test engine fading standing wave is formed with a large amplitude, which distorts the pressure curves on the adapter and on the indicator valve.

Deviation of the mean indicated pressure, maximum of heat release rate and a maximum of heat released does not exceed 2% on the surveyed engine loads.

It is expected that disturbances in the gas channels are systematic and derived characteristics will reproducible and diagnostic useful.

It is not excluded to improve the results of analyzes by increasing the accuracy of the determination of TDC, detecting changes in the characteristics of the measuring channels and the development of improved methods of the disturbed signals processing.

Taking into account small influence of interference on the parameters of heat release characteristics in the engine Al25/30 for low-speed engines, this effect can be considered negligible.

Nomenclature/*Skróty i oznaczenia*

- TDC Top Dead Center/*górne martwe położenie tłoka*
- ^{o}CA Crang Angle Position/*stopień obrotu wału korbowego*
- MIP Mean Indicated Pressure/*średnie ciśnienie indykowane*
- *q* Heat Release Rate/*prędkość wydzielania ciepła*
- *Q* Released Heat/*ciepło wydzielone*

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