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INFLUENCE OF GAS CHANNELS OF MEDIUM SPEED MARINE ENGINES ON THE ACCURACY OF DETERMINATION OF DIAGNOSTIC PARAMETERS BASED ON THE INDICATOR DIAGRAMS

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Abstract

Analysis of the indicator diagram is the basis of technical state evaluation of marine diesel engines. The indicator diagram contains a large amount of diagnostic information. A major problem for the diagnostic use of the indicator diagrams in case of medium speed engines are distortion caused by the gas channels between the cylinder and the pressure sensor. Indicator channel and valve may introduce significant distortions which increases with increasing engine speed. The paper presents results of results of the analysis of the indicator diagram of engines in onboard service, and research conducted on the medium speed laboratory engine Al 25/30. These engines are characterized by gas channels of high complexity. During laboratory research pressure measurement (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. Distortion of heat release characteristics for the sensor placed on the indicator valve is important, but it is estimated that diagnostic information is not erased. For medium speed engines is to be expected the use of a portable pressure sensors placed on the indicator valve. For this reason, further research is needed to assess the impact of channels and valves on different cylinders. During the research the course of heat release rate q and the heat released Q were determined. The curve of heat release rate q is a full equivalent to fuel injection pressure curve in the fuel pipes. It allows identification of the failure of the injection system. The curve of Q allows such determination and assessment of internal efficiency of the cylinder.

Keywords: *marine combustion engines, indicator valve, indicator diagram analysis*

1. Introduction

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) is amounts to 1000 rpm. For the other engines of those company the range of speeds is 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).

Medium speed marine engines are mostly equipped with indicator valves which are used both for decompression and for cylinder pressure measurement (indication).

Gas channels in the indicator valves and channels which connects the valve to the cylinder causing the delay and distortion of the indicator diagrams, which increase with engine speed. For engines A25/30 and A20/24 ignition angles can range from 3 ° CA to 11 ° CA before TDC and receive variable values depending on the engine load.

Table 1 shows the TDC determination errors calculated on the basis of zero point of first order derivative estimated by extrapolation.

Tab. 1. Examples of values of TDC determination errors $\Delta\alpha_{G1}$ for the selected engine 6A25/30: n = 750 obr/min; engine idling

	Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Cyl. 5	Cyl. 6
$\Delta\alpha_{G1}$ [deg]	-0,85	-1,10	0,00	0,00	-0,80	-0,50

As shown in table 1 TDC determination error exceeded a value of -1 ^{o}CA, which is very high value. Analysis of indicator diagrams of many medium speed engines show similar values of TDC errors.

Several investigations have already been 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 know 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.

2. The object and subject of research

The objective of research was to determine the influence of the indicator channel and indicator valve on the form of cylinder pressure diagram. Research was carried out on the medium speed ship's engine Sulzer Al 25/30 in the laboratory. The tests were made at engine speed 750 rpm. In Sulzer Al engine, gas channel, which connect indicator valve with the combustion chamber, has considerable complexity and length (Fig. 1).

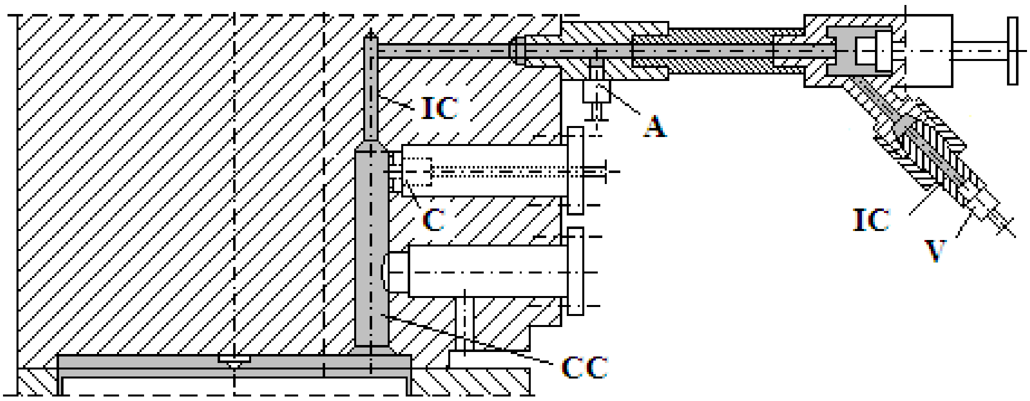

Fig. 1. The design of the gas channel, pressure sensors location of the test engine Al 25/30: CC – cylinder channel, IC - indicator channel, C - pressure sensor location in the cylinder, A - pressure sensor location in the adapter Kistler 7523A10 , V - pressure sensor location on the indicator valve

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

3. Distortion and delay of pressure graphs

Comparing the indicator diagrams (Fig. 2) 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, compared with the maximum values of pressure in the cylinder p_C.

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

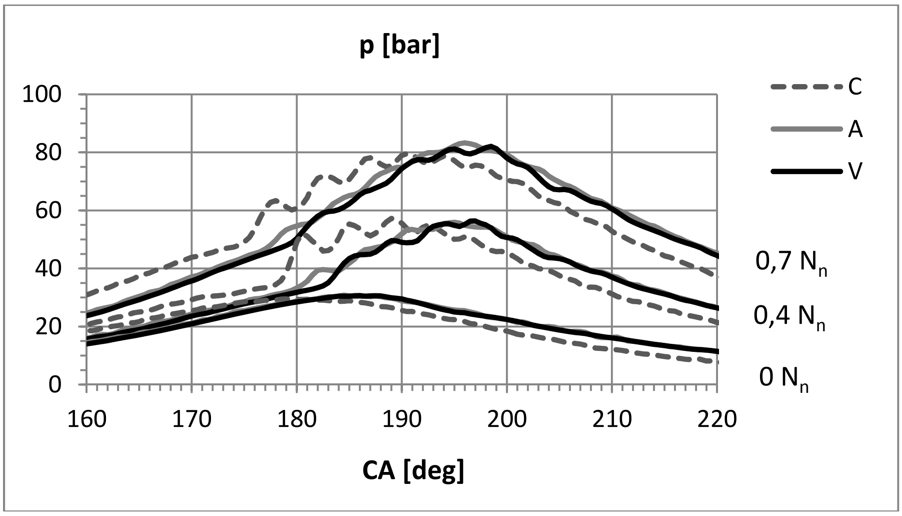

Fig. 2. Comparison of the indicator diagram in the range of the end of the compression and combustion: C - pressure in the cylinder, A – pressure in the adapter, V – pressure after the indicator valve. Coordinate 180^{o}CA (Crank Angle) corresponds to thermodynamic TDC on C pressure curve (in the cylinder)

Especially large distortions visible on the curves are caused by fading standing wave, excited at the moment of ignition in the channel CC (Fig. 1) and spreading to the indicator channel.

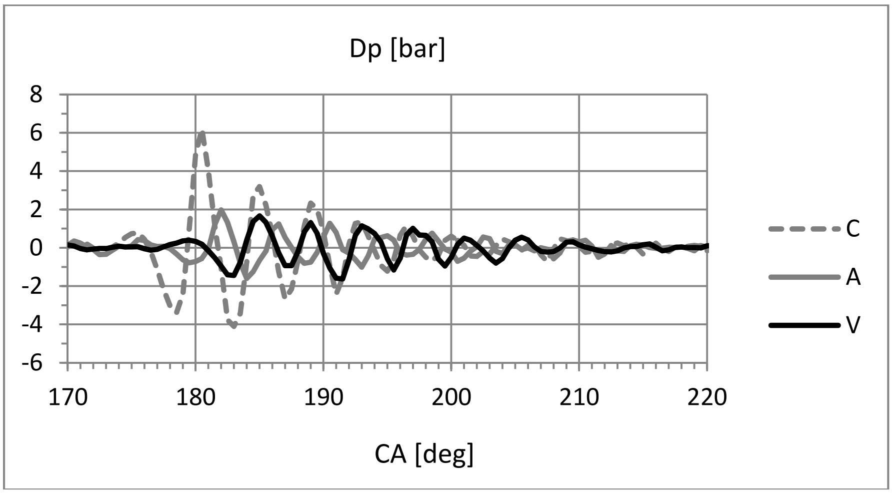

Fig. 3. Dp pressure curves oscillation at the open indicator valve (Fig. 1): C - in the cylinder channel, A - in the adapter, V - on the indicator valve

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. 4).

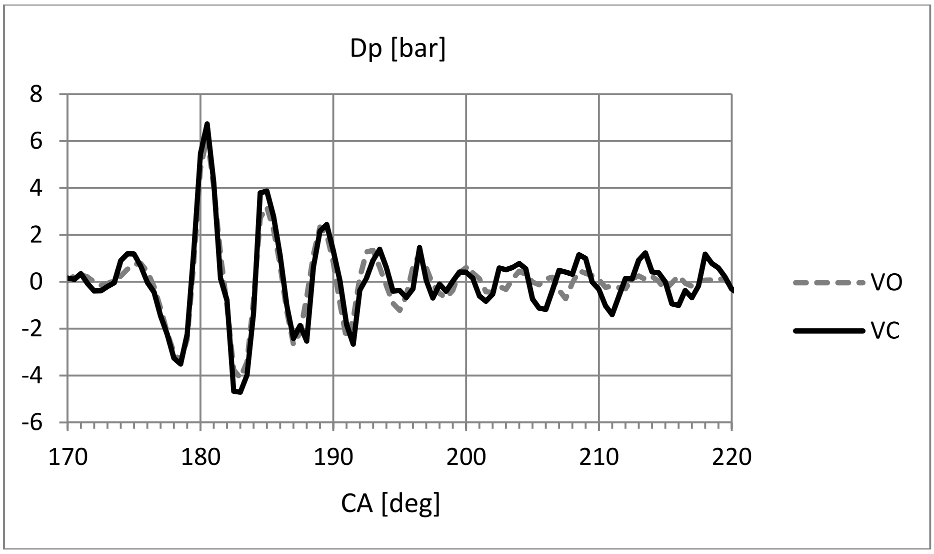

Fig. 4. Comparison of waves of pressure Dp in the cylinder channel: VO – indicator valve open, VC – indicator valve closed

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.

The analysis of indicator diagrams carried out for different type of medium speed engines shows that the wave phenomena for engine cylinders have the similar nature (Fig. 5).

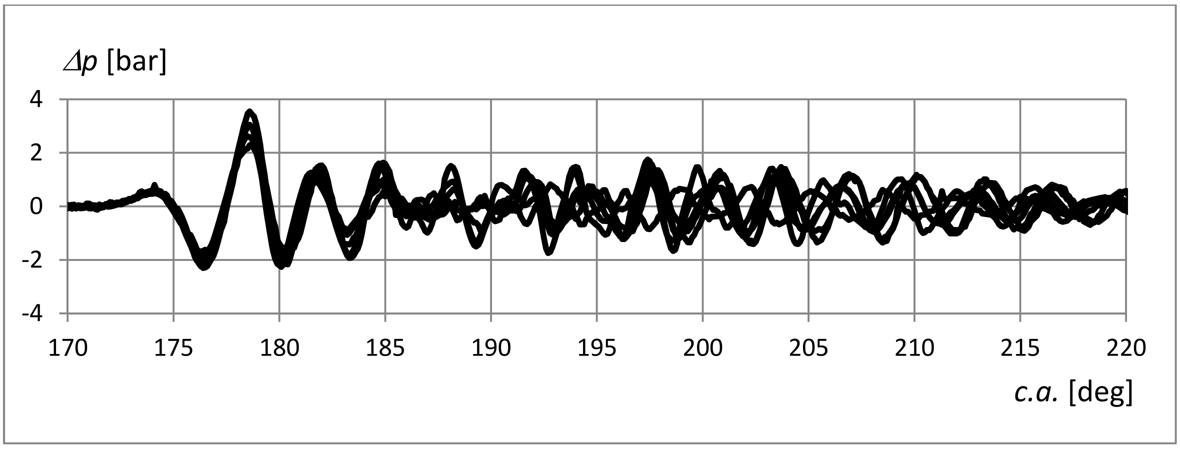

Fig. 5. Comparison of the oscillation of the indicator diagrams of 6A25/30 engine in service: n = 750 rpm, MIP = 13.94 bar

It is expected that indicators diagrams of the same type of engines will be burdened with systematic errors of the same value and the same course, which will enable the diagnostic use of mean indicated pressure and heat release characteristics.

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 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°CA. The difference between the TDC in the cylinder (C) and the position at TDC on the indicator valve was 5.9°CA.

Positions of designated TDC based on the zeros point of the first order derivatives were respectively: 108.4 °CA for the cylinder (C), 179.3 °CA for the adapter (A) and 179.8 °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. 5) shows their high similarity.

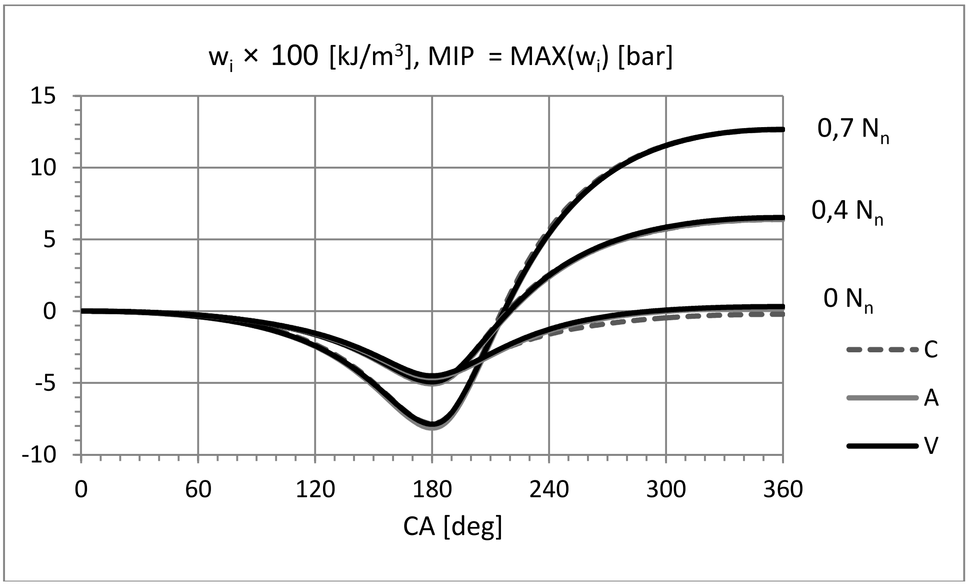

Fig. 5. Comparison of the indicated work curves w_i (referred to the volume of a cylinder), mean indicated pressure MIP for different values of the engine power N_n: C - in a cylinder channel, A - in the adapter channel, V - on the indicator valve

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 N_n	12,04	12,09	12,08	0,30	0,27
0,4 N_n	6,38	6,39	6,52	0,14	2,08
0 N_n	- 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 net heat release characteristics

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. 6).

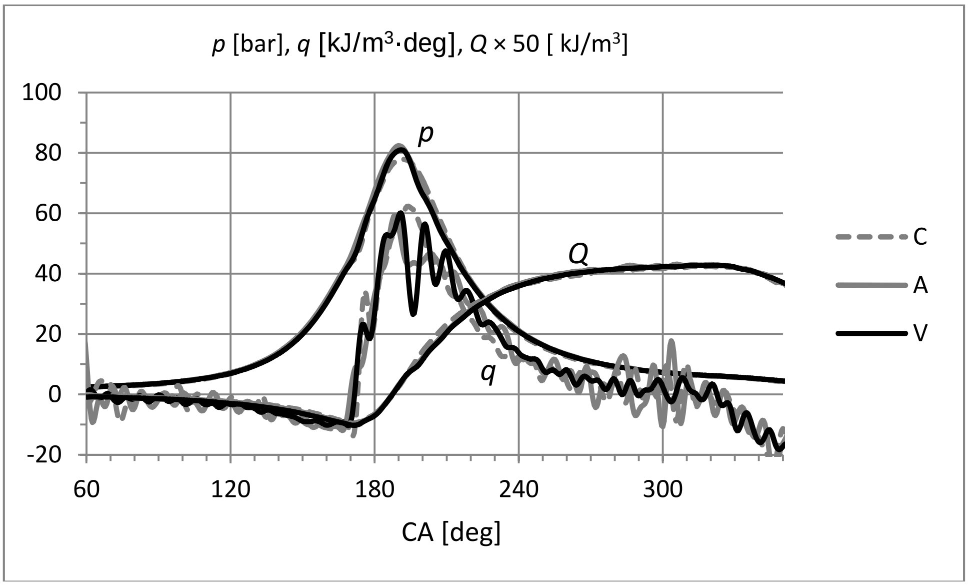

Fig. 6. Comparison of heat release characteristics designate for the set of indicator diagrams for the load 0.7 N_n: q – heat release rate, Q – heat released, C – for the measurement in the cylinder, A – for the measurement in the adapter, V – for measuring on the indicator valve

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.

Tab. 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 ×50 [kJ/m^3]			δQ [%]	
	C	A	V	AC	VC
0,7 N_n	21,16	21,56	21,39	1,88	1,09
0,4 N_n	13,45	13,61	13,59	1,19	1,05
0 N_n	- 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.

Figure 7 shows the curves δq and δQ designated for marine engine 40DM with advanced wear (before main repair).

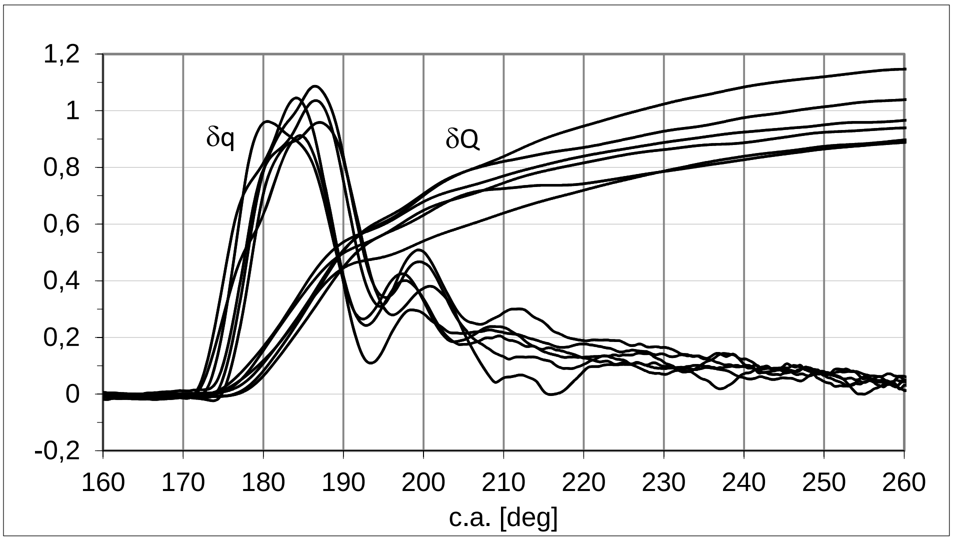

Fig. 7. Dimensionless (related to the average maximum values for the motor) the heat release rate δq and heat released δQ for the medium speed marine engine 40DM working on nominal load (750 rpm)

The presented examination of the heat release characteristics allows the diagnostic inference about condition and quality of control injection equipment, which is practically impossible on the basis of direct comparison of the pressure curves.

The design of gas channel in 40DM engine is different from Al type (straight channel directly from the cylinder), but can easily be seen waving arising to the right from coordinate 190^{o}CA.

In the case of low-speed engines such interference gas channels are not present, or are practically negligible.

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.

References

[1] Trunen, R., Kaario, O., Liljenfeldt, G., *Cylinder pressure measurement via indicating Cock*, CIMAC 2007.

[2] Oezatay, E., Onder, C., *Model based sensor reconstruction of in-cylinder pressure trace using indicator cock pressure information*, Cimac Congress 2010, Bergen paper no. 166.

[3] Pawletko, R., Polanowski, S., *Influence of TDC determination methods on mean indicated pressure errors in marine diesel engines*, Journal of KONES, Vol. 18, No. 2, Warsaw 2011.
[4] Pawletko, R., Polanowski. S. *Research of the influence of marine diesel engine Sulzer Al 25/30 load on the TDC position on the indication graph*, Journal of Kones Powertrain and Transport, Vol. 17, No. 3, p. 361-368 , Warsaw 2010.
[5] Polanowski, S, *Determination of location of Top Dead Centre and compression ratio value on the basis of ship engine indicator diagram*, Polish Maritime Research № 2(56), 2008, Vol. 15.
[6] Polanowski, S. Pawletko, R., *Application of multiple moving approximation with polynomials in curve smoothing*, Journal of Kones Powertrain and Transport, Vol. 17, No. 2, p. 395-402, Warsaw 2010.