# PROBLEMS OF DETERMINING MEAN INDICATOR PRESSURE OF PISTON COMBUSTION ENGINES FROM DEVELOPED INDICATOR DIAGRAMS

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***Abstract***

*The paper presents methods for processing and analysis of in-cylinder pressure course in the combustion chamber of marine engines. In literature are described determinate methods of mean indicator pressure from closed diagrams, with are but rarely recorded than developed diagrams. There have been showed on limitations occurrence at measurements fast-changed pressures of marine diesel engines in operating conditions and me asuring errors the attendants. Mean indicated pressure determined from the indicated timing or angul ar pressure courses in the cylinders is still a reliable diagnostic symptom.*

*The paper presents too the r esults of ex perimental measurement of in-c ylinder pressure signals, medium speed marine engines with application resistive sensor and using the photo-optical sensor of crankshaft position, and without the marker position of the cr ankshaft. Not always possible to attach t he marker for the position of the crankshaft, and even there is no way of stoppi ng the engine when you need to diagnos e it. The top dead ce ntre of the piston can be determined then analytically. The work developed a method of determining the mean indicated pressure of the developed indicator diagrams. Based on calculations of mean indicator pressure made many of diagnosis of the medium speed marine diesel engines in the operating conditions.*

**Key words:** *marine diesel engines, indicator diagrams, mean indicated pressure*

## 1. Introduction

The indicated is one of the main ways of testing the thermal piston machines, such as internal combustion engines or compressors. It involves recording the pressure change in the working medium in the cylinder of investigated object. Pressure as the dependent variable can be recorded depending on time, crank angle or position of the piston. In this way, the representation of the actual thermodynamic processes occurring inside the cylinder.

Using electronic pressure sensors to measure pressure course in the cylinder of heating piston engines, and digital signal processing and used computers, but this did not lead to significant changes in the automated determination of the mean indicated pressure. There was pressure, using them as maximeters, not even applied visualization investigated of pressure courses [3, 8-12]. In particular, these restrictions have been applied to medium and high- speed engines, due to the difficulty determining the piston top dead position (TDP). Measured of pressure courses in of the time or crank angle of the crankshaft were distorted by the valves indicated and intermediary channels [8].

The literature mainly the method of calculating the mean cylinder pressure chart closed, apart from a few [2-4]. More often, however, obtained are in the operation of developed indicator diagrams.

## 2. Assessment of worker process on the basis of the indicator diagrams

### 2.1. The mean indicated pressure

The mean indicated pressure is such a constant pressure of substitution (computing) in the cylinder at which the work done by a factor in one circuit would be tantamount to the indicated work. If so check the chart equivalent cylinder pressure will be replaced him on the field of the rectangle equal to the piston stroke in the chosen scale chart, the height of the rectangle will present to the indicated mean pressure.

## 2.2. Indicator diagrams

Depending on the operating principle of the following types of indicators distinguished [4, 12]: mechanical, optical, electrical and strobe. Electric pressure transducers are generational (active): piezoelectric, electrodynamics, and parametric: resistance, inductive, capacitive, etc.

Due to the specificity of the indicator measuring, recording and processing measuring signals are out of special equipment based on computer technology. An example of this type of solution is shown in Fig. 1.

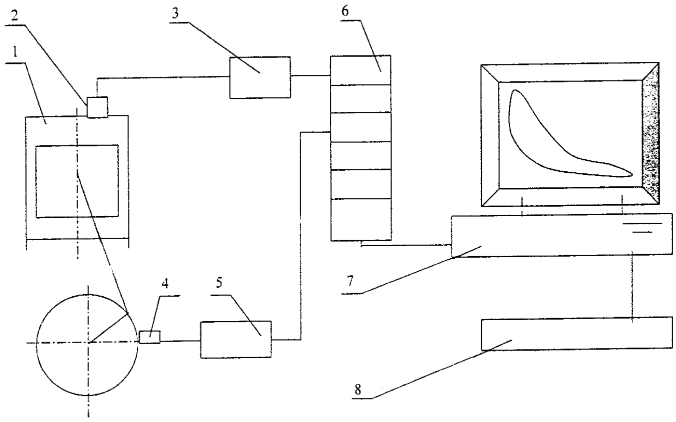


*Fig. 1. Scheme of the meas urement system for indication with digital pr ocessing and computer registration: 1 - thermal test machine piston, 2 - pressure sensor, 3 - pressure signal amplifier, 4 - crankshaft position sensor, 5 - amplifier, 6 - analog-to-digital converter, 7 - computer, 8 - printer*

Analysis processes in the engine cylinder requires monitoring pressure course within a single circuit. The image is called an opened or a developed indicator diagrams. With the registered signals from the tag angle, the timeline can be divided into sections corresponding to the rotation of the crankshaft of the $\Delta\alpha$, creating a secondary-axis angular scale.

The calculation of the mean indicated pressure on the basis of the developed indicator diagram can be done by rebuilding the diagrams in the coordinates of $p$ - $V$ and methods of calculation or graphic-calculation, using the ordinates of developed diagram [2, 3]. Developed indicator diagram of two-stroke or four-stroke engine is divided into 24 or more intervals and determine ordinates (Fig. 2).

The division can be done graphically, separately for left and right of the diagram. According Michalecki [3] ordinates entered in the order given below and is the appropriate altitudes:

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $y_0$ | $y_1$ | $y_2$ | $y_3$ | $y_4$ | $y_5$ | $y_6$ | $y_7$ | $y_8$ | $y_9$ | $y_{10}$ | $y_{11}$ $y_{12}$ |
| | | $y_{23}$ | $y_{22}$ | $y_{21}$ | $y_{20}$ | $y_{19}$ | $y_{18}$ | $y_{17}$ | $y_{16}$ | $y_{15}$ | $y_{14}$ | $y_{13}$ |
| Difference | | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | $h_6$ | $h_7$ | $h_8$ | $h_9$ | $h_{10}$ | $h_{11}$ |

Aggregating those of altitudes $h_i$ analytically or graphically, and with the formula (1) can calculate $p_i$:

$$p_i = \frac{\sum_{i=1}^{i=x} h_i \mu}{x} \text{ [MPa]}, \tag{1}$$

where:

$h_i$ - height "i" ordinates of indicator diagram,
$x$ - number of totalised ordinates of indicator diagram,
$\mu$ - pressure scale.

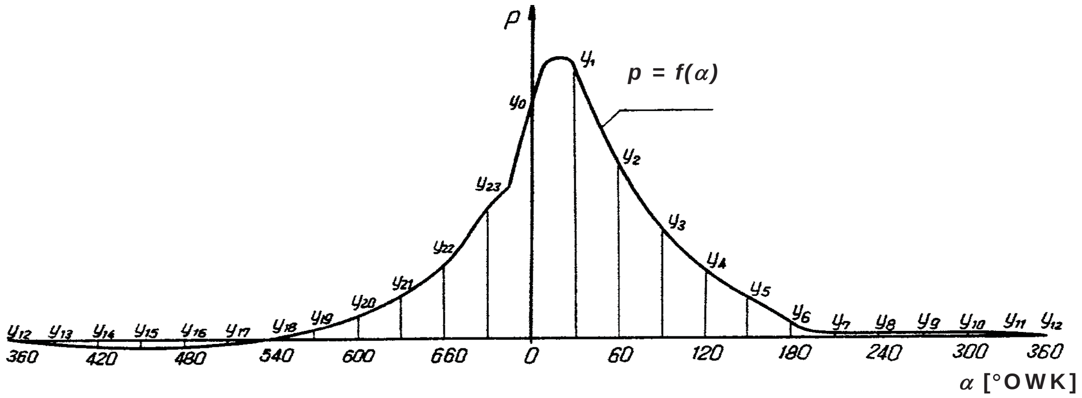


*Fig. 2. The section of developed indicator diagram on the ranges [3]*

### 2.3. Other calculating methods the mean indicated pressure with indicated diagram

The most important step when calculating the mean indicated pressure from the diagram is to determine the area of the diagram. The surface diagram, you can get, but measuring planimetry, as a result of the mathematical one of the approximate methods of integration surface. One of the following methods is the area under the curves in the interval *ab* (Fig. 4 - the section of the upper and lower diagram), and after deduction of the surface obtained in the individual strokes obtained interesting field value.

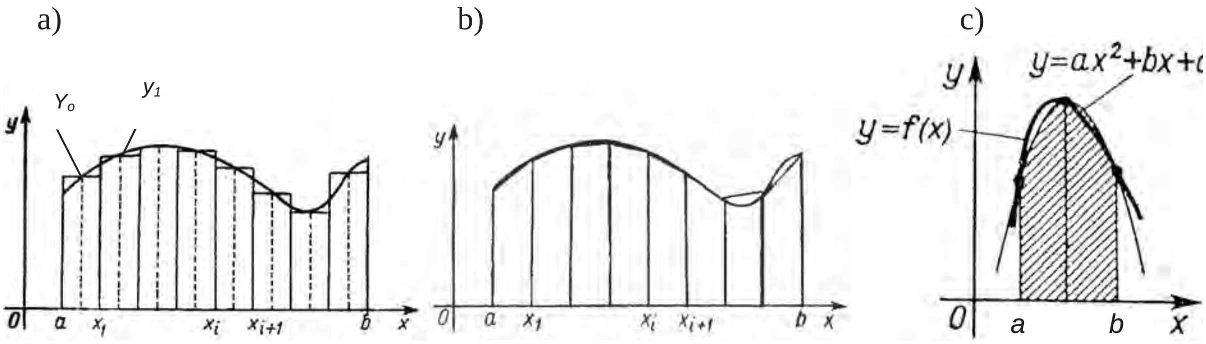


*Fig. 3. Approximate methods of integration surface [1, 4]: a) the method of rectangles, b) the method of trapezoids, c) the method of parabolic*

The most commonly used methods of approximate integration are based on replacing the integral a finite sum. To calculate $\int_a^b ydx$ divided into a range of $a = x_0$ to $b = x_n$ in n equal parts of points $x_0$ and $x_1, x_2, ..., x_{n-1}$ and for a range of points $x_0$ *i* $x_1, x_2, ..., x_{n-1}$ calculates the value of the total function $y$. Substitutes are:

$$h = \frac{b-a}{n}. \tag{2}$$

Applies and one of three formulas:

a) formula of rectangles (Fig. 3a):

$$S = \int_a^b y\,dx \approx h\,(y0 + y1 + ... + yn\text{-}1), \tag{3}$$

b) formula of trapezoids (Fig. 3b):

$$S = \int_a^b y\,dx \approx \frac{1}{2}\,h\,(y0 + 2y2 + ... + 2yn\text{-}1 + yn), \tag{4}$$

c) parabola formula (Simpson's) for n even (Fig. 3c):

$$S = \int_a^b y\,dx \approx \frac{1}{3} h\ (y0 + 4y1 + 2y2 + 4y3 + \ldots + 2yn\text{-}2 + 4\ yn\text{-}1 + yn). \tag{5}$$

All three models are more accurate, the larger *n*. With the same values of *n*, the second is more accurate than the first, third and even more accurate and therefore most often used.

## 3. The research results

Objects of research were mainly medium speed marine engines type 6AL20/24D, 6AL20/24H and 5ATL25/30H in operation and laboratory conditions (6AL20/24D) [5]. Measurements of pressure courses in combustion chambers were by means of resistive pressure sensor, where the signals were amplified through an amplifier and sent to the terminal and connecting a laptop computer (Fig. 4). On the crankshaft of aluminium foil glued to the bar cooperating with fhotooptical sensor mounted near crankshaft marker. The signals were analysed using DaqView acquisition computer program and transposed into Microsoft Excel (Fig. 5), where have been elaborated algorithms of final signal processing with the determining of the mean indicated pressure and indicated power.

a) b)

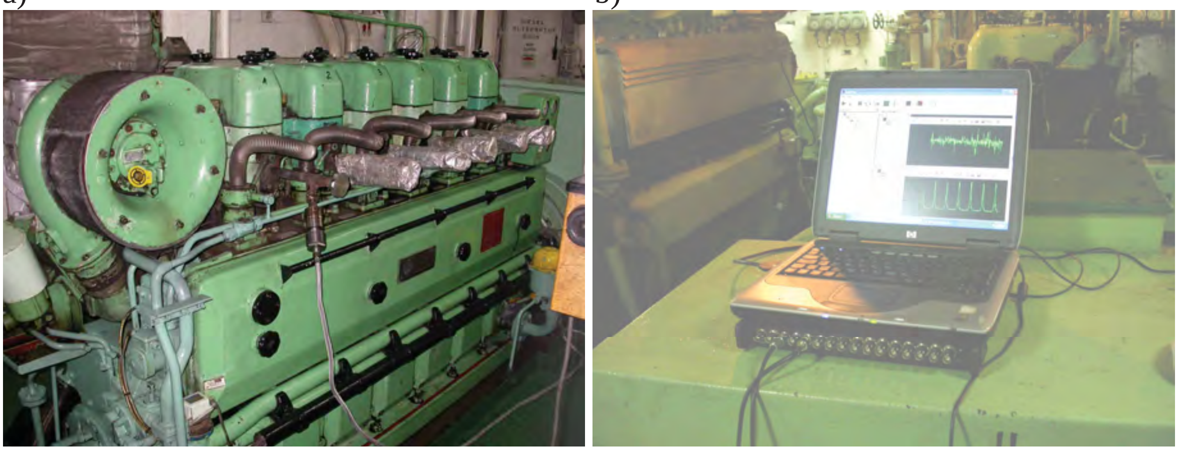

*Fig. 4. View the investigated engine with a pressure sensor attached to the indicator valve a) and visualization of test signals in the computer b)*

Not always possible to attach the crankshaft position marker, so that the TDC can be used to designate a derivation graph, where the TDC is in place at zero at *dp/dt* = 0 [6, 8], which switched in Fig. 6. The mean indicated pressure was calculated by subtracting the ordinates in each strokes and determinate of average value:

$$p_i = \frac{\left(\sum_{j=c+1}^{j=d-1} p_j - \sum_{j=c-1}^{j=b+1} p_j\right)\mu - \left(\sum_{j=d+1}^{j=e-1} p_j - \sum_{j=a+1}^{j=b-1} p_j\right)\mu}{n}, \tag{6}$$

where:

$p_j$ - the value of pressure ordinate,

*j, ..., n* - number of ordinates in two strokes.

Examples values of mean indicated pressure tested of marine diesel engine at constant load is shown in Fig. 7. The figure shows that there are essential differences in the values of average cylinder pressure, and thus of the indicated power, about inadmissible scatter [7]. These values corresponded to differences in the technical state elements of the injection apparatus and the cylinder-piston group.

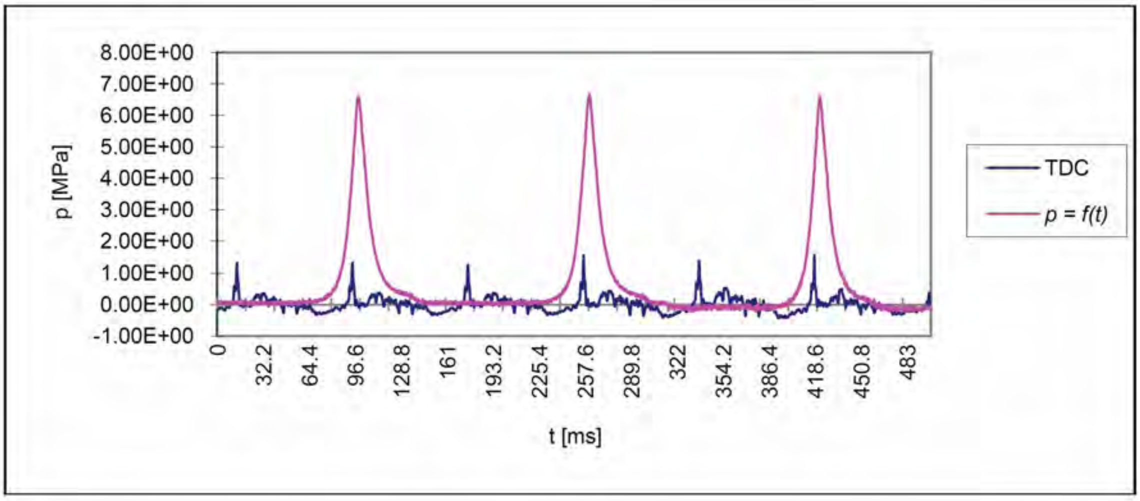


*Fig. 5. Example of the pressure course in the combustion chamber, depending on the time of marine engine and the pulses top dead centre (TDC)*

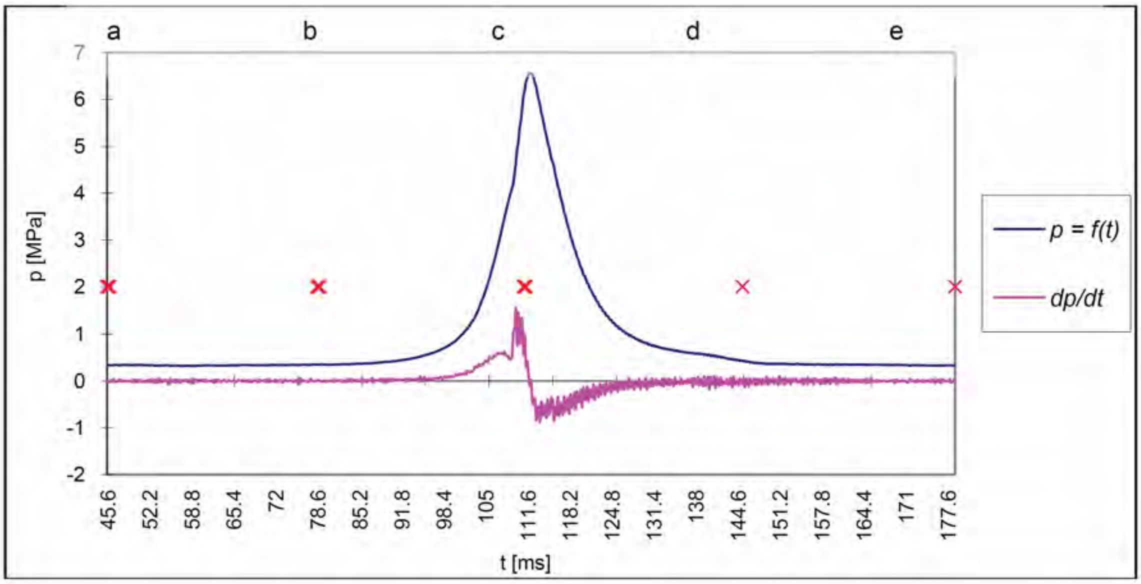


*Fig. 6. The pressure course in combustion chamber of engine type 6AL20/24D for one cycle with the first derivative dp/dt for the determination of the TDC and distribution of cycle at for 4 strokes*

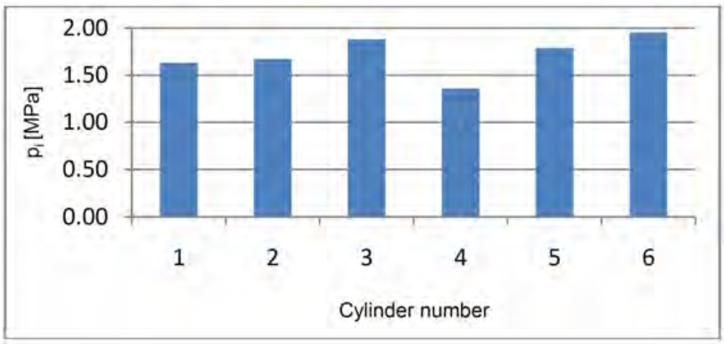


*Fig. 7. The values of mean indicated pressure of engine 6AL20/24D at the speed of 1000 rpm and relative load of 63%*

## 5. Conclusions

Indicator diagrams are still a reliable source of diagnostic information of marine diesel engines. In the absence of position marker of the crankshaft, it is possible to determine an analytical method using first derivative. It is significant to maintain a constant load and constant engine speed during the tests, which changes substantially affect the value of a set of parameters in a more meaningful way than the change of technical condition. In operating conditions are attached different receivers in a planned or unplanned, which affects the fluctuation of the load.

Investigations have been conducted mainly in operating conditions, where the pressure sensor can be connected to indicator valves, and because the test mainly to diagnose, so it seems acceptable. Diagnosis carried out in the operating conditions showed essential variation of technical conditions and regulations of individual engine cylinders.

## References

[1] Fichtenholz, G. M., *Rachunek różniczkowy i całkowy*, PWN, Vol. 2, p. 133, Warszawa 1995.
[2] Grudziński, J., Marcinkowski, J., *Ćwiczenia z okr ętowych silników spalinowych t łokowych*, Wyższa Szkoła Morska w Szczecinie, Szczecin 1984.
[3] Michalecki, M. [red.], *Ćwiczenia laboratoryjne z maszyn cieplnych t łokowych. Silniki spalinowe i sprężarki,* Politechnika Gdańska, Gdańsk 1974.
[4] Monieta, J., *Laboratorium termodynamiki*, Akademia Morska w Szczecinie, not published work, Vol. 1, Chap. 3, Szczecin 2008.
[5] Monieta, J., Dyba, K., *Diagnostyka eksploatacyjna wtryskiwaczy silników okr ętowych z wykorzystaniem analizy widmowej sygna łów ciśnienia*, Zeszyty Naukowe Wyższej Szkoły Morskiej, No. 71, pp. 327-334, Szczecin 2003.
[6] Obozov, A. A., *Algoritm poiscka korektivnogo položenija otmetki BMT v cistemach giagnostiki cudovych dizelej*, No. 1, pp. 27-30, Dvigatelectroenie 2006.
[7] Piotrowski, I., Witkowski, K., *Okrętowe silniki spalinowe*, *TRADEMAR*, Gdynia 2004.
[8] Polanowski, S., *Studium metod ana lizy wykresów indykato rowych w a spekcie diagnostyki silników okrętowych*, Zeszyty Naukowe Marynarki Wojennej, Nr 169 A, 2007.
[9] Siemens, A. G., Dick, J., Schütz, W., Freudenberg, H.: *Kontaktiervorrichtung für einen Injektor mit einer Kontaktiervorrichtung*, No. 103136231.
[10] Tsuda, M., Maeda, K., Miyoshi, Y., Koamtsu, K., *The test methods to measure power marine diesel engine during the operation*, J. Nat. Fish. Univ., No. 4, pp. 191-196, 2005.
[11] Tuan, T. N., Okada, H., Tsukamoto, T., Ohe, K., *Effects of rounding-off inlet hole in fuel nozzle on spray & combustion characteristic s under high-pressure & high-temperature*, CIMAC 2007, pp. 1-12, Vienna 2007.
[12] Wajand, J. A., *Pomiary szybkozmiennych ciśnień w maszynach t łokowych,* WNT, Warszawa 1974.