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THE DYNAMIC TDC ASSIGNING ON THE MARINE FOUR STROKE ENGINE'S INDICATION DIAGRAM

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Abstract

Determination of the internal combustion piston engine's indicated power is a complex task. A number of difficulties lead to lots of solutions utilized to increase the accuracy of the result. This paper reports on the experiments concerned with a four stroke engine's piston dynamic position determination. Although the paper is mostly concerned with the piston's TDC definition, the experimental methodology can be utilized in the entire piston movement determination. A specially developed measuring assembly and its working principle utilized in the experiment have been presented too. It allows the acquiring of a set of time-position coordinates. Based on the coordinates, the mathematical algorithm for dynamic piston positioning can be developed. As the piston movement was being observed from the crankcase side, the methodology proved to be relatively cheap and easier for installation, compared to proximity sensors installed in the cylinder head. The advantage of optical sensors and light pipes being used was reduction of the explosion risk in oil mist environment inside the crank case.

Keywords: *transport, marine diesel engines, combustion processes, power estimation, determination of piston's TDC*

1. Introduction

In order to accurate determination of the indicated power of the cylinder measurement of the in the cylinder pressure course, determining of cylinder volume changes course and finding the common point binding the two courses is essential.

Whereas the technology of measuring pressure course is currently on a high level [6], the task referring pressure value to a definite cylinder volume has not been solved in a satisfying manner yet. [1], [2], [5]. These difficulties mainly come from two sources; one is the non-stationary character of the engine's crankshaft rotational speed. Consequently the speed of cylinder volume change different from the theoretical course assuming constant rotational speed [3], [4]. The other is the determination of the moment when the piston is in its top dead centre (TDC) [5]. Statistic TDC determination is burdened with large error due mainly to the dynamic character of changes in the working engine and the elasticity of elements in the piston-crank system. The most exact methods consist in installing proximity sensors in the cylinder head permitting the piston's position observation in the vicinity of its TDC. [6]; they are expensive, however, and may be applied exclusively in specialized laboratories on experimental engines; besides, they do not permit determination of the piston's position when it is more than a few millimetres below its TDC. Methods are also worked out permitting to estimate TDC position analysing the compression curve of the indication diagram [1].

Because of the difficulties described above the conception arose to construct a station permitting the observation of the piston's position in a possibly wide range of its way; it should back up further work for seeking more easily available information capable of raising the accuracy of the piston's determined TDC and estimating the cylinder volume in intermediate piston positions.

2. Experimental station

The experiment was conducted on a research and training station, based on a four-stroke eight-cylinder CI engine, Buckau Wolf, type 8RDV136. This engine drives directly a fixed-pitch propeller immersed in the basin.

Tab. 1. The engine's basic technical data

Parameter	Symbol	Value
Piston stroke	S	360 mm
Connecting rod length	l	720 mm
Cylinder bore	D	240 mm
Rated power	P_n	220kW
Rated rotational speed	n	360 rpm

The third cylinder of the engine, counting from the flywheel, is equipped with a photo-electronic measuring system permitting the observation of the engine's position in the limited range of its stroke; a flowchart of the positioning installation has been presented in Fig.1.

The aim of the research was to verify the possibility of dynamic TDC position estimating of the engine's piston on the indicator diagram of a cylinder working in four-stroke cycle.

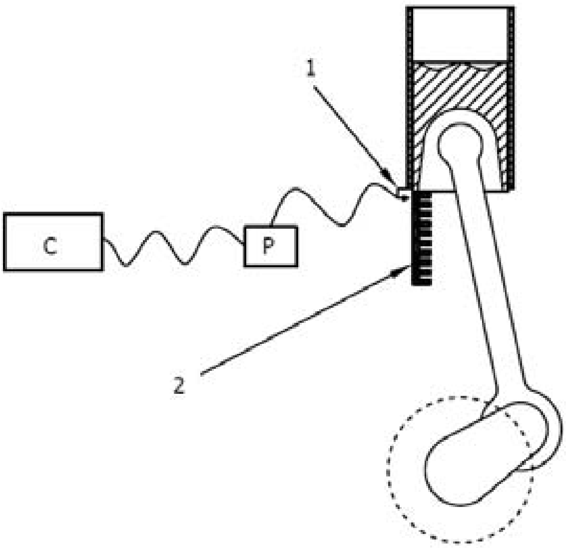

Fig. 1. Measurement system diagram for the piston's positioning; 1.- optical sensor, 2.-reflective template, P –optoelectronic transducer, C-computer with acquisition card

The system for piston positioning consists of an optoelectronic sensor and template with reflective elements rigidly affixed to the piston; this system permits the discrete observation of the piston's movement with 6mm resolution in the range from 84.5mm to 312.5mm above BDC. The determination of the above values was made statistically. For the experiment described there were chosen for analysis 39 upper template points out of 42 available.

The course of pressure changes inside the cylinder was measured by means of an Optrand dynamic pressure transducer. (Table 2).

Tab. 2. Transducers used in the experiment

Value measured	Producer	Model
Cylinder pressure	Optrand Inc.	F532A8-ACu
Cylinder position	Keyence	FU-85Z
Signal registration	Elan digital Systems LTD	AD126

The determination of the piston's real TDC position is based on the principle applied for measurements by proximity sensor installed in the cylinder head [6]. This concept has been presented schematically in Fig. 2.

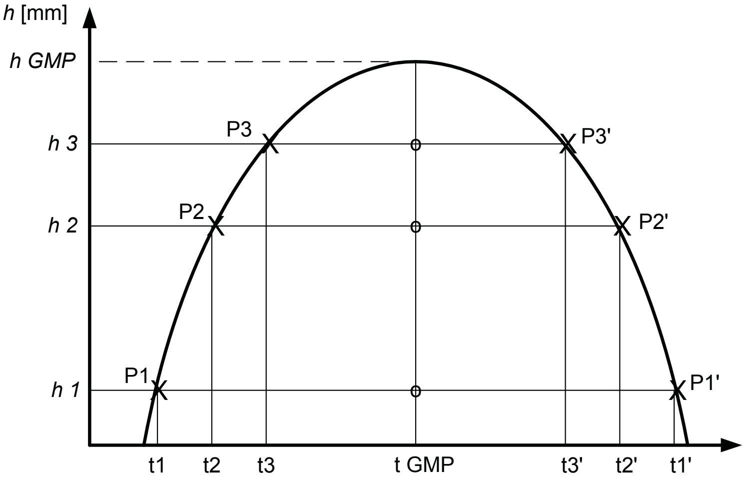

Fig. 2. The concept of determining dynamic TDC position in time by means of piston position observation

Applying the principle presented on the above graph, the time of dynamic TDC appearance can be designated from the formula:

$$t_{TDCi} = \frac{(t_i' - t_i)}{2} + t_i \qquad \text{for } i \in 1..39, \qquad (1)$$

where:

t_{TDCi} [s] – estimated moment of the piston passing through TDC designated for the ith element of reflective template,

t_i' [s] – measured moment of the ith reflective element of the template passing in front of the sensor during the piston's movement towards BDC,

t_i [s] – measured moment of the ith reflective element of the template passing in front of the sensor during the piston's movement towards TDC.

Assuming the rotational speed of the crankshaft to be ω=const and that the piston-crank system is not subject to elastic deformations, the moments t_{TDCi} determined in the above way should have equal values (for one considered revolution of the shaft and different reflective elements of the template); yet, as shown by experimental results that are considerably different from each other depending on the height of reflective element, by means of which they were determined (Fig. 3).

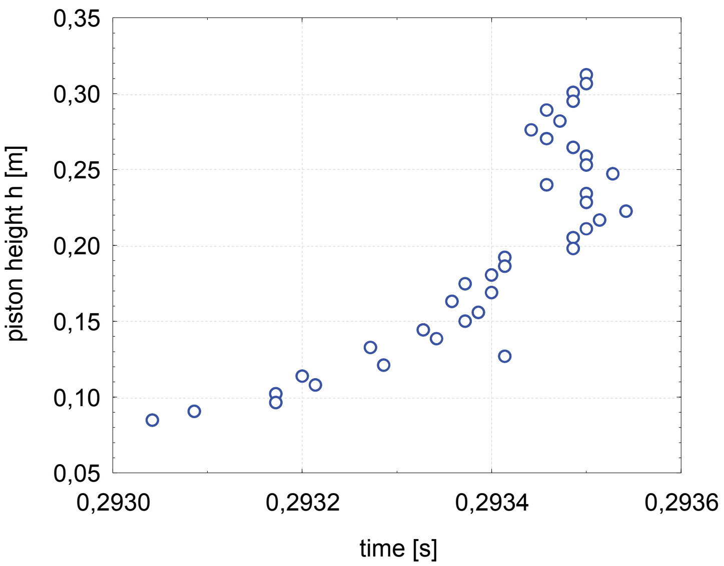

Fig. 3. Course of the piston's determined estimated t_{TDCi} *positions*

Analysing the determined values of t_{TDCi} presented in Fig. 3 it can be observed that determining the piston's real dynamic TDC position on the basis of mean value is likely to lead to erroneous results. It can be observed, on the other hand, that the designated points take positions that form a certain curve; this curve might serve the estimation of real dynamic TDC position of the piston.

3. Analysis of experimental data

For the purpose of comparing the determined piston's dynamic positions with the courses of pressure changes on the engine's indicator graph, some mathematical processes were performed. Based on analysis of the derivative of the course of pressure changes in time, time t_{ign} of combustion start in the cylinder was determined; the combustion start having been assumed as the moment of appearance of minimum pressure derivative in the neighbourhood of the piston passing through TDC. Next, the time of combustion start was compared with the times of successive t_{TDCi} within the range of each examined dynamic TDC cycle of the engine's work separately:

$$T_{REFi} = t_{TDCi} - t_{ign}, \qquad \text{for } i \in 1..39, \tag{2}$$

where:

t_{TDCi} [s] – estimated moment of the piston passing through TDC determined for the i-th reflective element of the template,

t_{ign} [s] – occurrence moment of combustion start,

T_{REFi} [s] – estimated ith moment of the piston's passing through TDC in a scale referred to the combustion start.

In a further course, the relative time scale was converted to angular scale, this process having been conducted with the simplified assumption that angular speed of the shaft was constant within one full turn. The advantage of applying the scale of crankshaft turning angle was a definitely better clarity of results obtained, even though with a certain loss of their accuracy:

$$\alpha_{REFi} = \frac{360 \cdot \omega \cdot T_{REFi}}{2\pi}, \tag{3}$$

where:

T_{REFi} [s] – estimated ith moment of the piston passing through TDC in a scale referred to the combustion start,

ω [1/s] – mean angular speed of one crankshaft turn, in which piston movement was observed,

α_{REFi} [deg] – i-th angle of the piston passing TDC referred to combustion start.

Eventually, piston position value was assumed as the independent variable, the values of determined α_{REFi} were accepted as dependent variable. Second degree curve was selected as approximating function. When selecting the mathematical model the criterion was mainly low calculation effort with preservation of possibly high matching quality. By the least square error method the coefficient of approximating function was determined:

$$\hat{\alpha}(h) = a \cdot h^2 + b \cdot h + c, \tag{4}$$

where:

a, b, c – coefficient of approximating function,

h [m] – piston position counted from BDC point,

$\hat{\alpha}(h)$ – function approximating changes in the piston's estimated TDC position.

Knowing individual approximating functions for particular examined TDC positions, their quality of matching the experimental data was also examined. The measure applied was the ratio of mean square errors of the approximating function and determined points α_{REFi}:

$$\delta_{\%} = \frac{\sum_{i=1}^{i=39} (\hat{\alpha}(h) - \overline{\alpha}_{REFi})^2}{\sum_{i=1}^{i=39} (\alpha_{REFi} - \overline{\alpha}_{REFi})^2} \cdot 100\%, \tag{5}$$

where:

$\hat{\alpha}(h)$ – function approximating changes in the piston's estimated TDC,

α_{REFi} [deg] – ith angle of piston's passing through TDC referred to combustion start,

$\overline{\alpha}_{REFi}$ [deg] – mean value of α_{REFi} for the analysed cycle of engine's work,

$\delta_{\%}$ [-] – percentage quality of approximating function matching $\hat{\alpha}(h)$.

4. Conclusions

The obtained results of matching quality of approximating functions have been contained in Table 3. As the approximating functions were matched with satisfying accuracy it was judged possible to estimate on their basis the piston's real dynamic TDC position. For this purpose, for each of these functions its value for piston position h=0.360 m corresponding to the piston stroke counted from its bottom position:

$$TDC_{dyn} = \hat{\alpha}(0.360), \tag{6}$$

where:

TDC_{dyn} [deg] – dynamic position of TDC in relation to combustion start on the indicator graph.

The course of approximating functions for four out of eight examined ones has been presented in the graph below (Fig. 5). It can be observed that the approximating functions $\widehat{\alpha}(h)$ are characterised by almost parallel course, small deviations possibly resulting from the engine's unequal running, as well as the imperfection of the engine's piston positioning system.

Tab. 3. Comparison of the experiment's numerical result

Cycle number	**$\delta_{\%}$**	**TDC_{dyn}**	**Coefficient of function $\widehat{\alpha}(h)$**		
			a	***t***	***c***
1	91.7	5.53	-21.3946	10.8248	4.4055
2	97.5	5.10	-23.8840	13.2221	3.4382
3	97.7	5.05	-22.5320	12.9222	3.3146
4	97.3	5.02	-23.9519	13.4344	3.2851
5	97.0	5.21	-19.1457	11.4656	3.5683
6	97.2	5.02	-22.3142	12.6130	3.3724
7	97.5	4.54	-22.2274	12.3308	2.9796
8	95.7	5.06	-23.2540	12.6231	3.5259
Mean	96.45	5.066	-22.338	12.4295	3.4862

Figure 6 presents the courses of pressure changes of five successive work cycles of the examined cylinder system. The graphs are positioned in relation to the determined TDC_{dyn}. It can be observed that the compression curves are characterised by very similar courses; but it should be noticed that that these curves do not cover each other, as it can be noticed in some solutions of commercial indicators [8], [9].

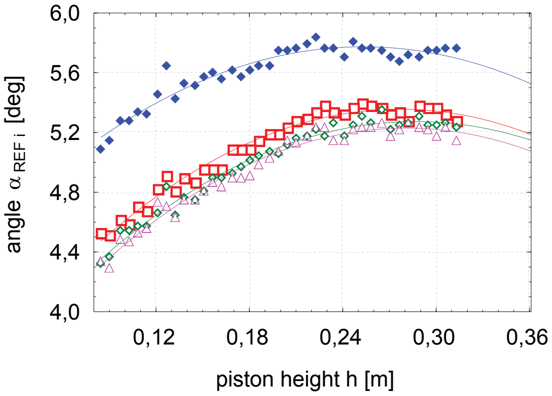

Fig. 5. Course of approximating functions against the background of α_{REFi} points; for piston position h=0,36 the determined real dynamic piston position in TDC has been marked

It has been shown that it is possible to designate a dynamic TDC of the piston by means of discrete observation of its shifts. The method permits determination of the piston's position even when the thermodynamic TDC cannot be read on the indicator graph. The suggested mathematical model of estimated TDC shifts is characterised by satisfying quality factor of mean value 96.45%.

Comparing successive courses of cylinder pressure on a common graph permitted the observation that compression curves did not have an identical course. This can bear out the contention that the shape of compression curve strongly depends on initial compression conditions. These conditions may be subject to changes resulting from gas pillar vibrations in the inlet channel.

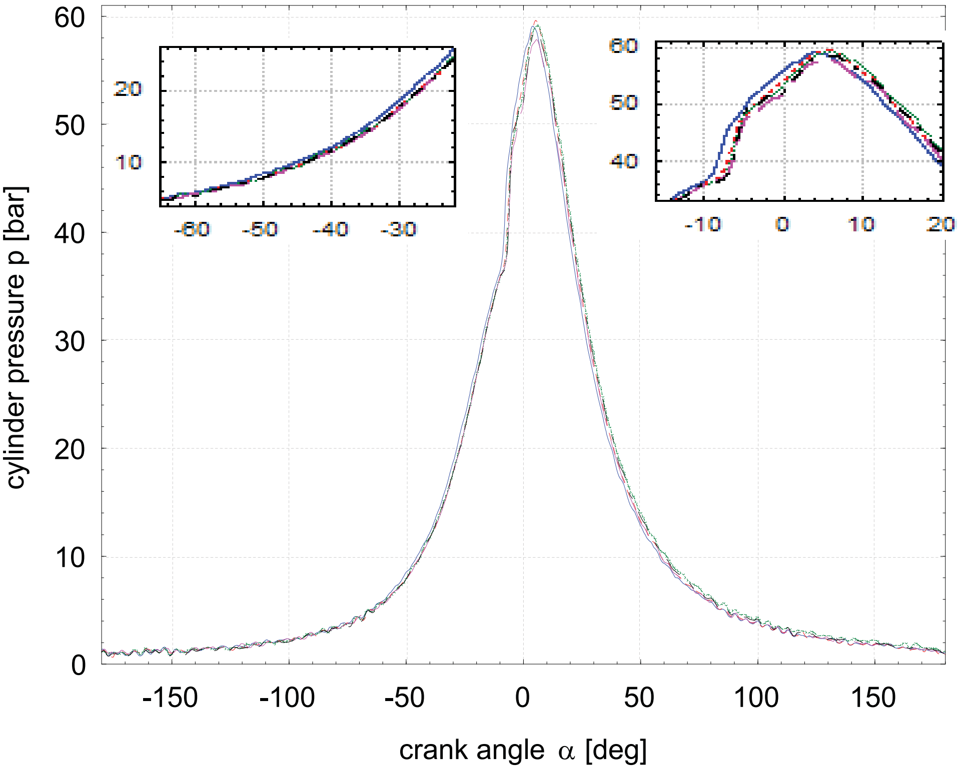

Fig. 6. Course of indicator graphs positioned in relation to determined TDC_{dyn}, for five successive cycles of the system's work

Further development of the method might help in working out a tool for determining dynamic piston position when observing piston rings applied e.g. by diagnostic systems like Sulzer SIPWA or CDS [7].

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