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INCREASING THE ACCURACY OF THE MEAN INDICATED PRESSURE DETERMINATION BY APPOINTMENT OF THE TDC CYLINDER POSITION

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Abstract

The paper describes the problems of mean indicated pressure determination and the piston TDC (Top Dead Centre) position impact on this parameter in marine diesel engines.

Mean indicated pressure Pi is one of the most important diagnostic parameters of marine engines. On the basis of its parameter, the assessment of the technical condition of each cylinder as well as the regulation of injection equipment can be made. Most of the available electronic indicators enable automatic calculation of mean indicated pressure on the basis of progress indicator diagram. As the research shows the greatest impact on the accuracy of the designation mean indicated pressure has errors of piston TDC position. These errors can be significant and therefore this may lead to engine misdiagnosis.

The actual piston TDC correction methods were discussed, and they justified the need of their use in marine engines, despite the wide use of methods of determining the angular position of the crankshaft.

The original method of TDC correction based on the model of curve of the compression with the exponent of a polynomial was introduced. The proposed method of TDC correction has been verified for a different types of marine engines.

Keywords: *Top Dead Centre determination, Mean Indicated Pressure accuracy, indicator diagram analysis*

1. Introduction

Mean Indicated Pressure is a very important diagnostic parameter, based on which an assessment of both the engine load as well as its distribution in each cylinder can be made. Knowledge of the mean indicated pressure is thus a basis for evaluating the mechanical and thermal loads each cylinder and overall engine condition.

Most contemporary electronic indicators enable an automatic determination of mean indicated pressure for each cylinder based on recorded pressure curves. It is possible, of course, only when the pressure curves are formed as a function of crank angle and the TDC (Top Dead Centre) position is known.

One of the basic measurement problems faced by producers and users of the pressure analyzers is to provide a sampling in the crank angle domain. The portable analyzers are often used sampling in time domain and then transform to the crank angle domain which, unfortunately, brings a significant errors. In this case, an important informational value has only a maximum value of pressure, which can be measured using an ordinary indicator.

Creating the angular axis is realized by special angular markers placed usually at the flywheel of the engine or the free end of the crankshaft of the engine. Depending on the solution, they allow to determine the angular position of the crankshaft with a resolution exceeding 1 CA. It appears, however, that even such a solution does not allow avoiding significant errors of determining TDC on the indicator diagrams especially with regard to low-speed engines. The importance of this issue, evidenced by numerous attempts to apply the methods of TDC correction, available in the software recognized manufacturers of electronic indicators such as PREMET or ABB.

The article attempts to estimate the TDC determination errors on the indicator graphs obtained by means of PREMET electronic indicator. The study focused on both diagrams of the low-speed marine engine, which was the main propulsion of the ship, as well as for medium speed auxiliary engine.

2. TDC position determination methods

A significant impact of TDC determination errors on the mean indicated pressure (MIP) value points to the need to correct TDC position on the indicator diagrams. This problem was addressed by both the research centres as well as the producers of electronic indicators.

In operating diagnosis of marine engines, TDC is usually attributed to the zero coordinate of the first order derivative of pressure. To set the above parameters, as well as thermodynamic TDC, it is necessary to dispose of the graphs of pure compression, which requires a shutdown of the fuel supply to the cylinders, for the measurement time. In the case of marine engines, this kind of measurement threatens to breach the tightness of the fuel systems, cause unstable engine operation, as well as being associated with changes to the thermodynamic condition of a cylinder after a shutdown of the fuel supply. A shutdown of the fuel supply to the cylinders on higher engine loads in the operation conditions is simply not feasible, and these loads are most diagnostically reliable.

Figure 1 illustrates a method of determining TDC patented by LEMAG (Lehmann & Michels) [11], known in shipbuilding-PREMET manufacturer of electronic indicators. The operator raises the cursor to the vertical marker (straight) on the visually estimated mid-point between the peak and valley of the derivative (Fig. 1). Then rotate the marker to the position of approximation. Following the approximation is designated zero point derivation, which is associated with a dynamic TDC. Indicator graph is pushed to the designated angle.

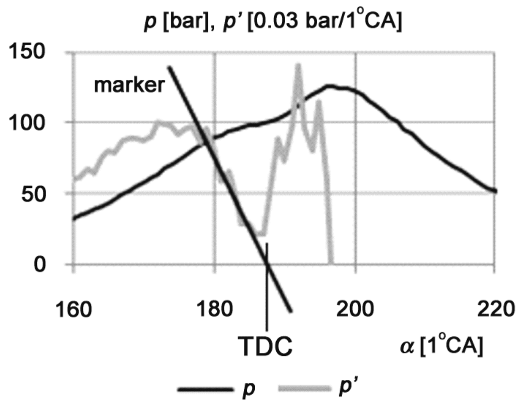

Fig. 1. Principle of forecasting of zero first order derivative on the indicator graphs proposed by Lehmann & Michel company

On-line TDC determination of the thermodynamic TDC was introduced in ABB Cylmate system (Fig. 8) [4].

As shown in Fig. 8 TDC position is changed after changing the load or during the inquiryto a new thermodynamics equilibrium, and because of the volatility of gas blowing.

A method based on a polynomial model of the compression process is an example of practical application of uses compression model for TDC determination [1],[2],[3]. Multi-parameter model of compression process is based on two main assumptions:

– at each point, the compression process is polytropic,
– in the compression interval, the exponent of the curve of compression can be described with a polynomial degree a.

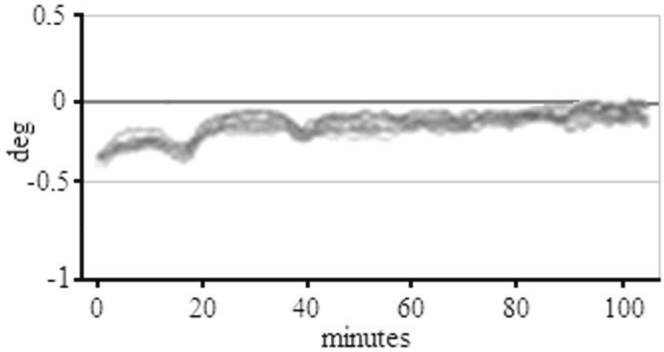

Fig.2. ABB Example curves of thermodynamic TDC appointed in on-line Cylmate ABB system [4]

The proposed method of TDC determination allows TDC location not only in the graphs of pure compression, but also in an indicator graph with combustion. The foundations of the method come from the assumption that the compression interval, the variable exponent of the curve of compression, can be presented with a power multinomial. Though this method does not give the possibility of direct location of TDC, it could be beneficial in the diagnostic practice of marine engines, in the case of sufficiently stable positions of those points in respect of the positions of TDC.

3. Research results

The aim of the research was to evaluate the possibility of increasing the accuracy of determining the mean indicated pressure by adjusting TDC position on indicator diagram.

Since there is no method that allowed to assess the accuracy of the TDC position and therefore the accuracy the MIP, the analysis was based on indirect methods. A comparison of the calculated mean indicated pressure based on the original presure curves and curvess with the revised location of TDC. In addition, the distance between a zero of the first order derivative and TDC possition on the indicator diagram was specified, which distance is a valuable indicator of the accuracy of the TDC position. Determination of the zero of the first order derivative, for engines tested was possible because the burning began a few degrees after TDC. The study also made a visual assessment indicator diagrams. Adjustment of the TDC position was carried out based on the compression model with the polynomial exponent.

The tests were conducted on two ships diesel engine during sea journey. First engine Wartsilla RTA 96C, two-stroke low speed marine engine with nominal power N_{en} = 24 000 kW at nominal rotational speed n = 82 rpm. Secound engine MAN L32/32, four-stroke medium speed marine engine with nominal power N_{en} = 2400 kW at nominal rotational speed n = 720 rpm.

The curves of indicator charts have been recorded with an onboard electronic indicator Premet with angular resolution of 1^{o} OWK for pressure measurement. The system used tensometric pressure sensors.

3.1. Research result for low speed diesel engine Wartsilla RTA 96C

Figure 3 shows the course of indicator diagrams for the nine-cylinder low-speed engine before (a) and after TDC correction (b) using a polynomial model of compression. In Fig. 3a, there are clear the phase error between the curves for the individual cylinders of the engine.

It should be emphasized that the manufacturer of the electronic indicator, installed on the shaft dedicated timing device that can measure the angular position of the shaft with the accuracy of 1 CA. The phase shift visible on the graph confirms the known difficulties associated with the TDC determination in respect to low speed marine engines.

Visible phase errors were corrected by the applied method (Fig. 3 b).

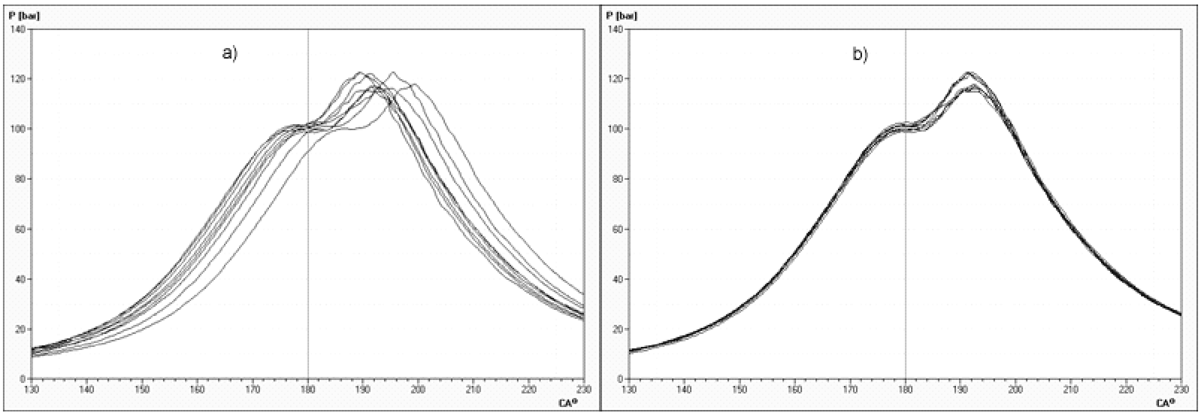

Fig. 3. Comparison of indicator graphs for all cylinder of low speed engine 9RTA96C: a before TDC correction (directly from measurement), b after TDC correction

Table 1 shows the TDC correction values for two independent measurement series for Wartsilla RTA 96C slow speed engine.

Tab. 1. TDC correction values for two independent measurement series (s1, s2) for Wartsilla RTA 96C

	Cyl 1	**Cyl 2**	**Cyl 3**	**Cyl 4**	**Cyl 5**	**Cyl 6**	**Cyl 7**	**Cyl 8**	**Cyl 9**
ME TDC cor s1 [CA]	0	-0.2	-4	2.6	1.2	-6.8	-1.9	1.8	0.2
ME TDC cor s2 [CA]	-0.5	-1.4	0.6	-3.1	0.1	-1.3	-6.3	2.2	-6.6

Taking into account obtained deviations values can say that they have a random and unique character. This indicates the need of TDC correction individually for each data set, it is also not possible to set permanent correc tion value for each cylinder. They draw attention to a very large TDC correction value for cylinder number 6 exceeding 5 CA. This situation practically excludes the possibility of any diagnostic with use of those data set.

Table 2 shows the results of calculations of mean indicated pressure for the original data and after TDC corrrection. The table also shows the MIP average values and of tilt (difference) of the average values for each cylinder.

Tab 1. MIP average values and tilt of the average values for 9 engine cylinders for data series s1 for the original data and after TDC corrrection $_{cor}$.

	Cyl 1	**Cyl 2**	**Cyl 3**	**Cyl 4**	**Cyl 5**	**Cyl 6**	**Cyl 7**	**Cyl 8**	**Cyl 9**	**Average**
MIP [bar]	11.2	10.9	15.3	8.3	9.2	18.2	13.1	8.7	10.7	11.7
div MIP s1 [%]	-5 %	-8 %	23 %	-41 %	-28 %	36 %	10 %	-35 %	-10 %	-6.4 %
MIP_{cor} [bar]	10.83	10.37	10.4	10.85	10.55	10.28	10.84	10.66	10.77	10.6
div MIP_{cor} [%]	2%	-2%	-2%	2%	-1%	-3%	2%	0%	1%	-0.1 %

The obtained results are different significantly. Deviations from the average for the results without TDC correction reach 36%, while the after correction does not exceed 6%. MIP deviations for each cylinder can not be, of course, confirm the effectiveness of the method, as may arise in with various technical condition of individual cylinders and incorrect engine regulation. However, given the clear phase shift graphs shown in Fig. 2 TDC correction does not appear to be subject to discussion and should be assumed that it is effective.

Since, is not possible to determine the real TDC position on the indicator graph, it was only an attempt to estimate the errors of both methods of TDC determination. Because the start of combustion in the tested engines starts a few degrees after TDC, the TDC position reference point can be find in zero point of first-order derivative of the pressure curve. Differences between designated TDC position and zero point of the first order derivative is shown in Fig. 4.

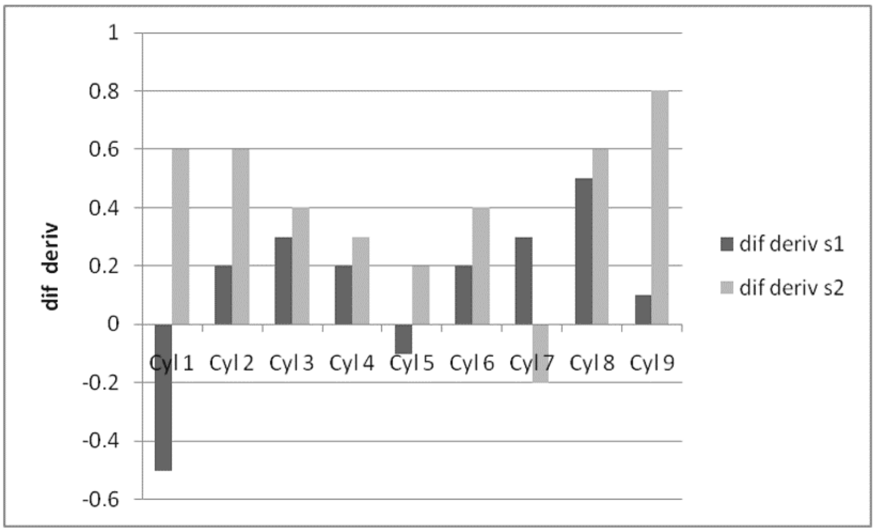

Fig. 4. Differences between designated TDC position and zero point of the first order derivative

The results shown in the Fig. 4 indicate the correctness of the proposed method TDC determination on the basis of polynomial compression model. Differences between TDC designated with the polynomial method and and zero point of the first order derivative are not greater than 0.8 CA. These errors are mainly due to the difficulty of determination of zero of the first order derivative of pressure. Derivative course is burdened with significant interference that may cause inaccuracies in the designation of the zero crossing. The solution to this problem could be pressure curve smoothing, however, it can introduce some phase errors on the derivative curve.

It should be emphasized that the reported difficulty in determination of zero point of the first order derivative of pressure, do not affect the proposed method of determining the GMP, as it is based on the compression model and not used in a direct zero point of the derivative. Course of pressure derivative around the cylider TDC is shown in Fig. 5

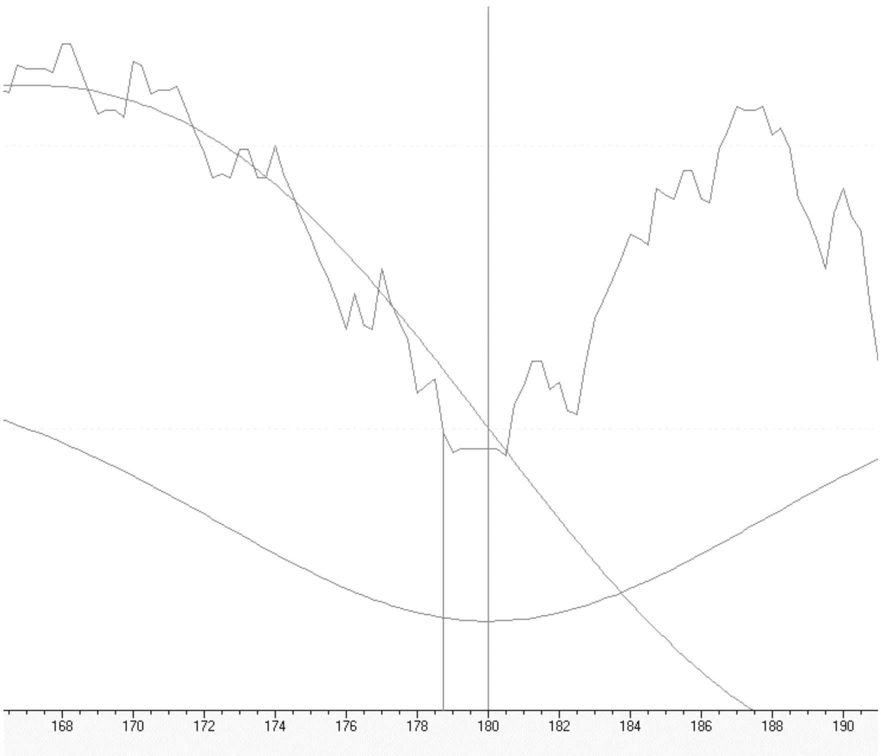

Fig. 5. Course of pressure derivative around the cylider TDC

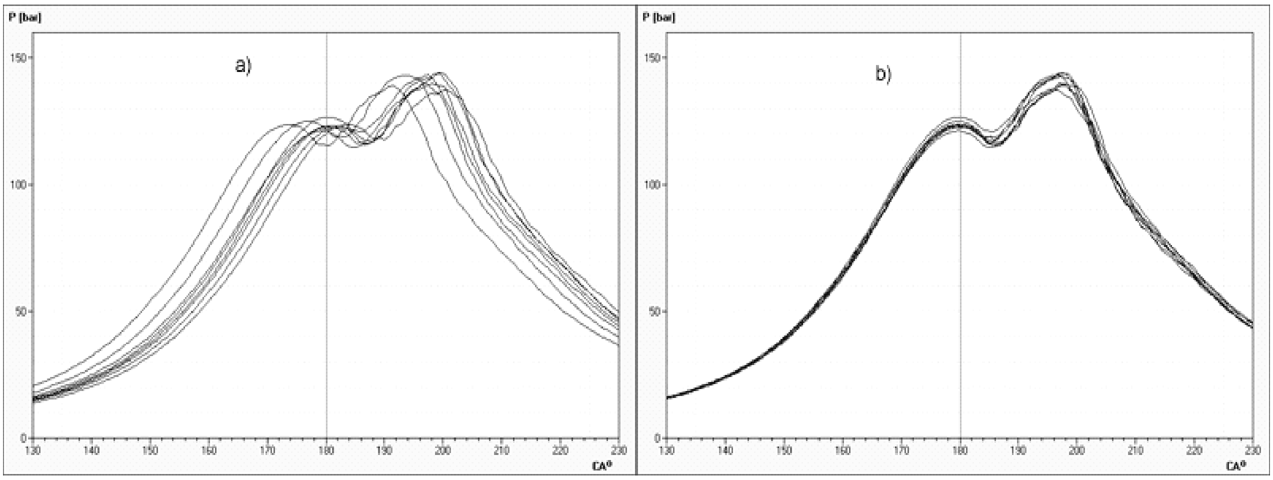

Fig. 6. Comparison of indicator graphs for all cylinder of medium speed engine MEN L32/32: a before TDC correction (directly from measurement), b after automatic TDC correction

3.2. Research result of medium speed engine MAN L32/32

Exemplary indicator diagrams for the medium speed engine MAN L32/32 are shown in Fig. 6.

In the case of medium speed engine significant phase errors (related to TDC possition) are also present. It should be emphasized that in this case measurements were performed using an apparatus for determining the angular position of the camshaft, which was equipped with only one marker at 360 CA.

Table 1 shows the TDC correction values for three independent measurement series for MAN L32/32 medium speed engine.

Tab. 1. TDC correction values for three independent measurement series (s1, s2, s3) for MAN L32/32

	Cyl 1	**Cyl 2**	**Cyl 3**	**Cyl 4**	**Cyl 5**	**Cyl 6**	**Cyl 7**	**Cyl 8**
AE TDC cor s1 [CA]	0.5	1.1	1.5	1.1	1.1	0.9	0.9	0.5
AE TDC cor s2 [CA]	0.5	0.1	0.9	0.3	1.2	1.1	1.1	0.3
AE TDC cor s3 [CA]	0.5	0.5	1.2	1.4	0.2	0.5	1.4	0.4

TDC correction values are much smaller and do not exceed 1.5 CA. As in the case of low speed engine obtained diferences values are purely random and unique. TDC correction of indigator diagrams are necessary as with the low speed engine.

Figure 7 shows the values of MIP deviations from the mean value for the three measurement series.

There are clear differences mean indicated pressure between the cylinders reaching up to 15%. Such differences may, of course, provide poor condition of the engine or the defective regulation, in that case, however, the proportions of deviations between the cylinders in each measurement series should have similar values. This regularity is shown in relation to specific cylinders that are characterized by significant changes in deviations (cyl. 2, 5, 7 and 8). However, draws attention to the existence of significant differences for some of the cylinders in each measurement series.

In the case of the cylinder 1 the difference between s1 and s2 series is as much as 15%, similar to the cylinder 8 the difference between s1 and s3 exceed 15%. The reason for this error may be measuring the same sensors or errors of determining the angular axis.

The results are limited possibility to use for diagnostic inference single indicator diagrams, as they may be subject to significant measurement errors. In the case of mean indicated pressure rather use average values from several series of measurements, which will significantly reduce random errors.

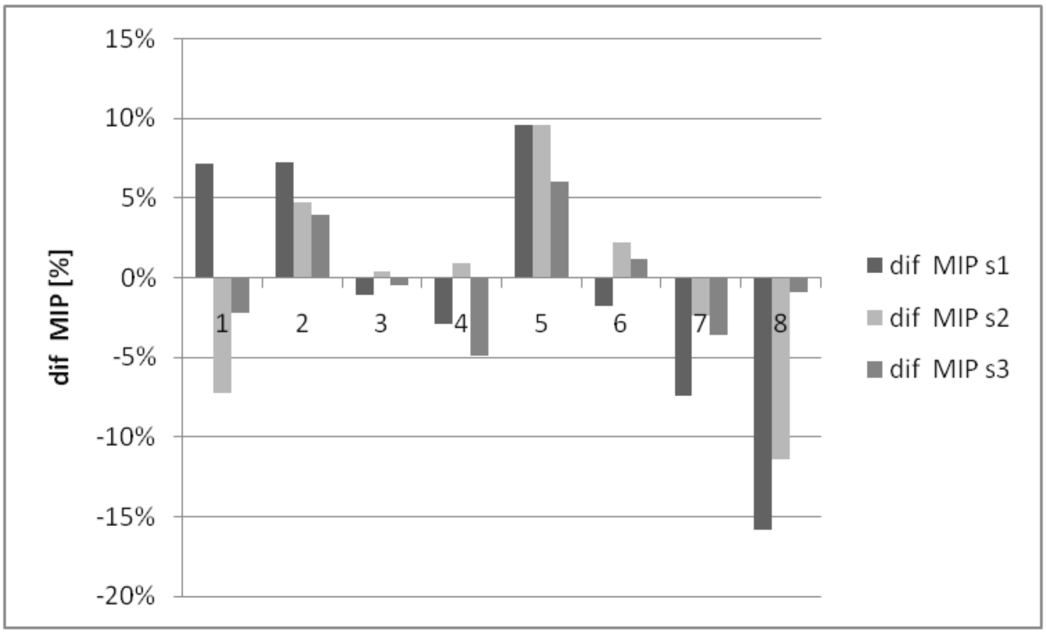

Fig.7. MIP deviations from the mean value for the three measurement series

4. Conclusion

The conducted research proved the possibilites of increase the MIP calculation accuracy by TDC dynamic correction.

The results indicate that the use of graphs and averages indykatorowych indykowanych pressure without correction of TDC, can lead to significant errors.

In the case of low speed engines RTA 96C, TDC position changes about the value of 1 ºCA causes an error in MIP calculation equal to 2 bar and therefore the relative error of 16%. Correction of TDC position is particularly important in relation to low speed engines, which are the main propulsion of the ship. Despite the use of special methods of the angular axis determination with an accuracy of 1 ºCA, research shows that the error of TDC determination could amount up to 7 ºCA. Such large errors virtually exclude the use of indicator graphs to any inference about the technical condition of the engine.

Similar results were obtained for the medium speed engine MAN L28/32A. So, significant differences of TDC location cause considerable errors in characteristics of heat generation amounting to 10%. Much smaller TDC errors were obtained for medium speed engines for which the errors do not exceed 2 TDC ºCA.

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