ANALYSIS OF APPLICATION OF CHOSEN METHODS FOR TDC DETERMINATION IN MARINE DIESEL ENGINES

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Abstract

In the operating marine diesel engines the indication diagnostics tests are usually performed through a 0.5-1.0 meter long indication channel which delays and disfigures the pressure signal being measured. The delay depends on the engine's speed and load. The pressure sensor itself together with an amplifier is an additional source of delay and disfigurements, so the registered pressure curve is displaced even if the TDC piston's position had been estimated with the highest accuracy. When the overexploited engine is being tested the angle of delay can achieve several degrees and differ for each cylinder. In that case cylinders' load is unequal and torsional vibrations occur in the engine operation. In case when some simplifying assumptions have been adopted the part of diagnostic information is lost what could lead to a false diagnosis. In the paper the attention is focused on the mistakes which could be made in the marine diesel engine diagnostics when different TDC assessment methods are used.

TDC corrections with compression pressure analysis are possible only in case when crankshaft angle position is precise. In case of measurement with constant frequency such corrections are possible only when the engine is good balanced.

Keywords*: transport, diesel engine, marine diesel engine, indication, TDC*

1. Introduction

In marine diesel engines tests the most information about thermodynamic processes is derived from the cylinder internal pressure measurements. The first diesel engines were also equipped with such apparatus, they were so called mechanical indicators. At the beginning they presented pressure versus time and enabled mainly the maximum pressure measurement. Next when indicated power estimations and the heat emission researches were initiated it became important to present cylinder pressure versus piston stroke. At first mechanical systems were used to estimate piston stroke. This method is no longer used in contemporary electronic indicators as it is too complicated and un-precise. To estimate a crankshaft's angle position in laboratory tests it is common to use a decoder integrated with a pressure sensor of high resolution, e.g. 2048 or 3600 pulses per revolution and additionally one reference pulse per revolution. These solutions which prove correct in car engines laboratory tests are not necessarily always applicable in marine diesel engine diagnostics. In these engines usually there is no access to the crankshaft's ending what enables the installation of typical shaft position sensors.

2. Measure trigger methods

The most popular marine diesel engines cylinder indicating method which is used in engines everyday operation is the non-synchronous pressure measurement with a constant frequency. The time of revolution is established accordingly to the reference point. Than a temporary piston location can be calculated from geometrical relationships of the crankshaft system equitation. Such indicators are commonly used on board of the ships especially as mobile systems. If as the reference point the characteristic point on the pressure curve is used than the pressure indicator does not require any other sensors except a pressure sensor but still the problem of defining TDC is left. Usually the point where the cylinder pressure reaches a specified value, e.g. 2.5 MPa in Unitest 206 analyser, is chosen as the reference point. The distance of this point to the TDC depends mostly on the charging pressure and technical condition of the engine. How it is said in the literature the point of the bending on the compression curve is a characteristic point with a constant distance to the TDC with no influence of the technical condition and load of the engine [3]. However, to locate this point the determination of the first or second derivative from pressure curve is needed, what requires the approximation methods if there are some interferences. These methods lead to such curve deformation that defined point is not accurate and synonymous [2].

When an additional marker on the shaft with induction hallotron or optic sensor is used than the measuring system becomes more complicated but the achieved reference point is not sensitive for changes in combustion chamber tightness and charging pressure. In many simple measuring systems it is assumed that the angle distance from the reference point to TDC is constant. This presumption could be valid only in case of the multi-cylinder engines with high speed, considerable inertia of the flying wheel, equal distribution of load among all cylinders and under condition that there is no delay from a measuring system. The delay of the signal from the measuring system and the shaft bend cause that the measured pressure image is displaced according to a chosen point set on the end of shaft. Assumption that this delay is constant is usually abused. This is true only when the load is stable and the technical condition of the engine does not change. For the engines in a typical service these simplifications are not fulfilled. There are compression and maximum pressures variations which result in a considerably high engine speed non-satiability which leads to tensional vibrations of the crankshaft. For example, on the one of Sulzer TD48 engines it was found that because of load change and regulations the angle differences among TDC's for separate cylinders moved even to 3.9 degree.

Initial tests for engine speed inaccuracy were carried out on the one-cylinder test engine stand in the Polish Naval Academy. Simultaneous measurements of the combustion pressures and reference marker were made when the marker was placed close to TCD. Results of the measurements are shown in the Fig. 1.

Measurement was taken with the sampling rate equal 60 ms. It was determined that in the worst case (minimum engine speed and maximum load torque) mean time of duration of one full shaft revolution (work stroke and exhaust stroke) is 74.94 ms, and for the second full shaft revolution (inlet stroke and compression stroke) is 76.82 ms. After approximation of this measurements to the angle scale a mistake from the engine crankshaft speed fluctuation is ±4.47° . A scale of this mistake depends on the engine's mean speed and load. For a multi-cylinder engine with one cylinder shut off because of malfunction, the mistake of the piston stroke assessment could be similar. It should be taken into account that similar processes occur in case when the TDC is assessed by cutting off fuel to a tested cylinder. Torsional vibrations and variations of engine speed will generate a displacement of the assessed TDC according to the marker placed on the shaft's end which will be different than the displacement for the engine operating with all cylinders.

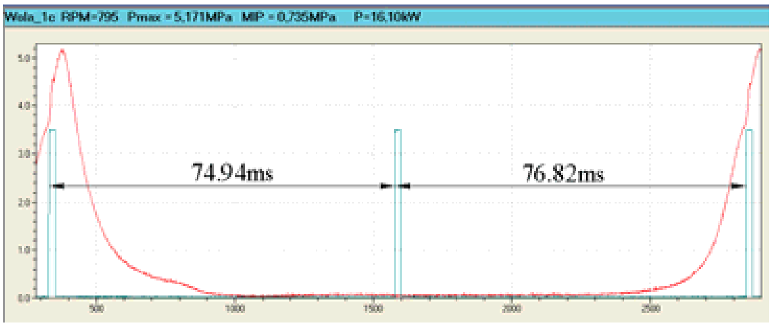

Fig. 1. Times of active (compression and work stroke) and passive (exhaust and intake) crankshaft revolutions, comparison on one-cylinder test engine

To shorten the influence of this mistake several markers on the shaft are used. In the case of the first such measuring systems Autronika NK100 there were thirty markers put in equal distances on the shaft flying well flange. Using PLL modules pulses from markers were multiplied giving the result of 360 pulses per shaft revolution 12 times. In the analyzers which were made in the Polish Naval Academy with author's participation the turning gear's teeth were used as markers. Using double PLL module and additional dividing system 3600 pulses per one shaft revolution were achieved regardless of the number of teeth It should be considered that PLL modules are follow up systems and when a change in speed occurs in one sector than the answer as a change of trigger measure pulses density accrues in the 3 and 4 sector. When a small number of markers is used it leads to a bigger curve deformation than it is typical for the time measuring method. Newest trigger measuring method which was invented and used by the author in the marine diesel engine generators diagnostics was multiplying of frequency from vessel electric power system. Multiplying frequency of voltage 3600/n times, where n means number of alternator poles we can achieve exactly 3600 pulses per engine shaft revolution can be achieved. In a similar way could be triggered measurements on the main engine with shaft generator or using tachometric generator on engine camshaft.

3. Possible reasons and consequences of TDC misalignment

Whichever of the measuring trigger methods is accepted there is still a problem of TDC determination on the registered curve. In the laboratory engine tests, especially those performed on the car engines, it is typical to place pressure sensors directly in the engine cylinder head through a special drilling made in such manner so the front of the sensor membrane is parallel to the cylinder's head surface. Even in this case only deformed cylinder pressure curve image is registered and not real inside cylinder pressure. A special measuring or separation membrane is in each pressure sensor, which should be treated as a vibrating element with finished mass and stiffness. The answer of such element to the impulse caused by pressure change is not immediate. The signal delay caused by membrane inertion depends on its resonance frequency. In the first thensometrics sensors, e.g. GT20 type, the resonance frequencies very rarely were higher than 1 kHz. These sensors could be used only for measurements on low-speed diesel engines. Nowadays, in piezoelectric and optic sensors with membrane diameters 1-3mm the membrane resonance frequencies are higher than 150 kHz and their influence could be omitted. The amplifier's influence is much higher as it is an integral part of the sensor. Such amplifier has to be equipped with a low frequencies filter to eliminate hum and membrane vibrations. For example in OPTRAND firm sensor C31294-Q type there is a filter with frequency limit of 5 kHz. Such filter generates a signal delay which has to be taken into account in case of high-speed engine.

During marine diesel engines cylinder pressure measurement long indicator channels with valves are used. Such channel even on relatively small SULZER AL25/30 type engine is about 0.33 m long. If we make presumption, that pressure wave in channel goes with sound speed it gives as result signal delay about 1 ms, which at rpm 750 means 4.5°. In practice this delay depends on engine load and speed. Images of pressure curves registered with sensors were one of them were inside of the cylinder had and second on the indicator valve are presented on Fig. 2.

4. Influence of TDC false determination on to MIP and initial pressure measurements

To find how is the TDC influence on indicated power calculation, registered pressure curve on SULZER 6AL25/30 type engine was moved according to set TDC up to ±2º. For each moving position indicated power were calculated. Results of experiments are shown in Tab. 1.

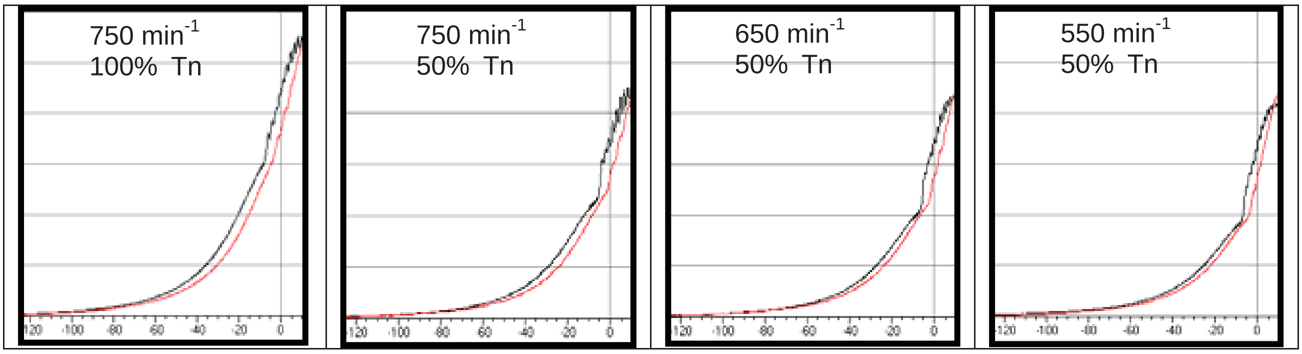

Fig. 2. Delays involved by indicator channel at different engine loads

Tab. 1. MIP and cylinder power determination mistakes caused by TDC angle movement

TDC movement	MIP [MPa]	δ MIP	Pi [kW]	δ Pi
-2˚	1.84	12.2%	171.2	12.2%
0˚	1.64	-	152.6	-
2˚	1.52	7.3%	140.9	7.3%

From data in Tab. 1 we could see that 1^{o} mistake in TDC determination gives as result about 5% mistake in indicated power measurement. Using intuition methods we should realised that 2% mistake in TBC determination results in about 10% mistake in indicated power assessment. When comparison measurement on neighbouring cylinders this mistake could be treat as systematic and not dominant in measurements of loads in separates cylinders. But when we analysed trends in mechanical power loses change in engine and friction losses in propeller shaft line, measured parameters values achieved values comparable with measurement accuracy which depends on TDC determination. To make trend analysis estimated parameters mistake in TDC determination if exist at all, should be repetitive no matter how load and technical condition of engine is.

Another problem during engine indication is constant part of the pressure signal. Because of temperature drifts and often because of sensor construction this constant has such big mistake so in practice in measurement taken in to account is changing pressure signal. Proper pressure curve is a basement for thermodynamic calculation constant part of pressure signal detection has important meaning. In basic calculations constant part of pressure signal is changeable by ambient pressure or charging pressure. Determination of this constant which based on thermodynamic analysis is shown in literature [AVL+21] but needs to earlier TDC determination. For example one of leading cylinder pressure sensor producers firm KISTLER had proposed constant correction method which based on monograms. Determination of the pressure 120° and 70° before TDC is whole which is needed. From TDC determination accuracy depends points of measurement and as a consequence pressure value and determined constant part of pressure. TDC accuracy influence on estimate this method initial pressure value has been checked initially on SULZER 6AL25/30 type engine. The measurement has been taken 120° and 70° before TDC according to author intuition with movement ±2°. Geometrical compression ratio ε = 13, polytrophic coefficient n = 1.35 and piston road to crankshaft radius coefficient L/R = 4.16 has been taken. For these values from monogram coefficient $\boldsymbol{C}$ = 1.735 has been read out. Pressure value in point 70˚ has been calculated according to formula:

$$p_{70}' = C \cdot \left(p_{70} - p_{120}\right), \tag{1}$$

Correction of constant pressure part has been made and value of initial pressure has been read out. Results of initial pressure estimation in TDC determination mistake simulation are shown in Tab. 2.

Tab. 2. TDC determination mistake influence on initial pressure value calculation

TDC movement	p(70) [MPa]	p(120) [MPa]	p0 [MPa]	δ [%]
-2˚	0.41	0.06	0.197	-7
0˚	0.43	0.06	0.212	-
2˚	0.47	0.07	0.224	+5.7

Mistakes in determination of constant part of pressure by using other methods which need earlier TDC determination are comparable. So determination of TDC is a critical problem in marine diesel engine diagnostics.

In low-speed marine diesel engines of older generation ignition usually have taken place after TDC. So in this case maximum compression pressure was visible and it was usually assumption that it is in TDC. This assumption is true only on the engine which completely in good technical condition. During engine operation tightness of combustion chamber has worsen. Losses of working medium through not tighten piston rings or valves determined so called angle of losses that means movement between angle of maximum compression pressure and TDC. This angle in new engine usually is small and omitted. But on the one of tested engines with not tighten exhaust valve this angel achieved value of 3.8º. There could be assumption that there is important malfunction and next diagnostic tests are not rational. But accurate measuring of indicated power of damage engine is important to estimate of mechanical losses power in engine and in propeller shaft line. Important are also measurements in valve gear system, fuel injection angles, ignition delay angles and initial pressure for which TDC is reference point. These are crucial parameters which help to find out reason of the damage and needed repair works.

Author in his diagnostic tests to estimate TDC is using model research. Through compression process modelling TDC and initial pressure constant could be determined. In initial model data such as: initial pressure, TDC deviation, geometrical compression coefficient are change up to the area among calculated compression curve and model curve in angle zone from angle when intake valve is closed to the angle where fuel injection starts, does not achieve minimum value[1]. Accuracy in parameter determination depends on model size and minimum finding method. In simple polytrophic model with constant polytrophic coefficient high repetition of determined parameters could be achieved using local finding method. Together with model complication numbers of estimated parameters are higher but results staying much more random. If the measurements are taken with constant frequency or are triggered from follow-up sector marker multiplying, in case of non stabile revolution speed determination of engine crankshaft generated angle has a value with mistake. Example of measurement has been made with constant frequency and result of model approximation in case of balanced engine is shown in the Fig. 3. Result of model approximation with constant measure condition after implement no-stabile revolution speed through cutting off fuelling to neighbouring cylinder are shown in Fig. 4.

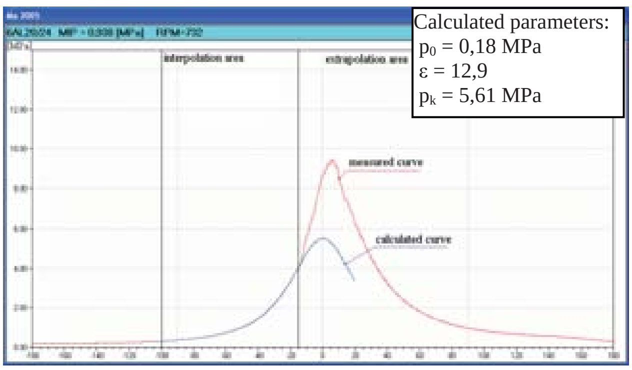

Fig. 3. Approximation result with model pressure curve measured on balanced engine

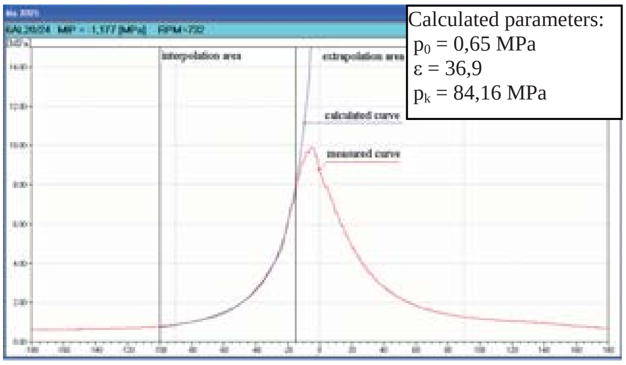

Fig. 4. Approximation result with model pressure curve measured on engine with one cylinder cut off

There has accrued non-remarkable curve deformation which completely change parameters estimated in the model.

5. Conclusions

The most accurate piston position could be achieved using decoder of angle position with integrated sensor with sensitivity for example from 2048 or 3600 pulses per revolution. Bur reference marker did not give accurate TDC position.

Registration with constant frequency lead to pressure curve deformation when rotational speed is not constant, but this deformation is much more less then in case sector markers using and sensor with follow up system type PLL.

Signal from sensor reference marker on the crankshaft or from piston position sensor could be used only to synchronise measuring system and to not accurate for start asses TDC.

If indicated power, value of start pressure, compression ratio or any angles are going to be estimate, TDC have to be corrected by compression pressure curve analysis. This correction is different for each cylinder and depends on engine speed, load and indicator valve condition

TDC corrections with compression pressure analysis are possible only in case when crankshaft angle position is precise. In case of measurement with constant frequency such corrections are possible only when the engine is good balanced.

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