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# Diagnostics research of high-speed marine diesel engines using envelope vibration method

*Abstract: Tests results of the new diagnostic method dedicated to marine high-speed diesel engines type MB820 fuel injection system and valve gear mechanism tuning are presented in the paper. These engines are not equipped with indicator valves so vibrations traces registered on the cylinder heads are used to assess the engine technical condition. The cylinder pressure sensors were connected to the decompression valves to get the reference signal for vibration traces, which is not a standard procedure on the MB820 engines. The results of the investigation are the dynamic timing parameters of the engine which could be used by specialists to compare engine internal processes and assess its technical condition.*

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Key words: *Marine diesel engine, diagnostics, tuning, fuel injector, valve gear.*

## Badania diagnostyczne szybkoobrotowych silników okrętowych z wykorzystaniem metody obwiedni drgań

*Streszczenie: W referacie zostały przedstawione wyniki badań instalacji wtrysku paliwa i mechanizmu rozrządu szybkoobrotowych okrętowych tłokowych silników spalinowych typu MB820 z wykorzystaniem nowo opracowanej metody bazującej na kątowej analizie obwiedni przyspieszeń drgań. Silniki tego typu nie są wyposażone w zawory indykatorowe więc dla oceny stanu technicznego układów cylindrowych oraz procesu spalania próbuje się wykorzystać rejestrowane przebiegi drgań rejestrowane na głowicach cylindrów. Wynikiem badań są tzw. przebiegi czasowe a raczej przebiegi kątowe drgań, które są wykorzystywane przy ocenie stanu technicznego i regulacji poszczególnych cylindrów silników.*

Słowa kluczowe: *okrętowe tłokowe silniki spalinowe, diagnostyka, regulacja, wtryskiwacz paliwa, układ rozrządu.*

## 1. Introduction

The new diagnostic method was tested on compact high-speed marine diesel engines type MB820. Typical diagnostic methods which base on the analysis of vibration signals amplitude or their frequency are sensitive to engine load and speed changes [2,7]. The new diagnostic method is based on the envelope of vibration acceleration signal analysis in crank angle domain [5,6]. The conventional maintenance methods for valve gear mechanism of the engine depend on valve clearances checks between valve stem and rocker arm and valve timing diagram checks on crankshaft flywheel. There are several questions to be answered: how to check these critical clearances without stopping the engine and dismantling it, how to monitor valve timing diagram on running engine and what the difference exists actually between "static" and "dynamic" valve timing diagram. Answers to mentioned questions for submarine diesel engines type MB820 are given in this paper. Polish Navy operates four KOBBEN type submarine vessels. Diesel generators on these ships consist of the MB820 type diesel engines. Taking into account a diagnose-unfriendly construction of these types of engines and very restricted compartments of the submarine power plant, engines have to be very sound and diagnostic methods used for such objects should be reliable and easy to apply. The vibro-acoustic methods could be convenient for such systems in complex [3] environment. This paper presents some diagnostic problems related to information taken from tests of the MB820 type submarine high-speed diesel engines.

## 2. Object of investigation – the MB820 type marine diesel engine

The MB820 is a high speed vertical four stroke diesel engine of light compact design, which operation is based on the pre-chamber combustion process. The pre-chamber is connected with the cylinder volume through the holes in the burner. The end of the engine from which the power is taken off (flywheel end) is designated as the rear. The term "anticlockwise" or "clockwise" and the numbering of the cylinders as well as the direction of rotation of the crankshaft are as seen from rear. The first and the seventh cylinder are located at the rear therefore, and the direction of the crankshaft's rotation is anti-clockwise (Fig. 2). The engine has 12 cylinders those are arranged in two banks inclined at an angle of $60^{o}$ to one another. Each cylinder has 2 inlet and 2 exhaust valves, the operation of which is controlled by a camshaft common to both cylinder banks, by means of tappets, push-rods and rocker arms.

Table 1. The MB820 type diesel engine general technical data

| | | |
|---|---|---|
| 1 | Working cycle | Four stroke, not turbocharged |
| 2 | No. of cylinders/ Configuration | 12 in "V" |
| 3 | Cylinder bore/Piston stroke | 175 mm/205 mm |
| 4 | Total displacement volume | 59,2 liters |
| 5 | Injection system | PLI / pre-chamber |
| 6 | Compression ratio | 18,5 : 1 |
| 7 | Full load max. speed/ Idling speed | 1400 rpm / 600 rpm |
| 8 | Continuous output at 1400 rpm | 600 HP |
| 9 | Firing order | 1-8-5-10-3-7-6-11-2-9-4-12 |
| 10 | Inlet/Exhaust valve clearance when cold | 0,40 / 0,45 mm |
| 11 | Injection nozzle opening pressure | 170 – 175 kg/cm$^2$ |
| 12 | Dry weight | 3710 kg |

The inlet ports of individual cylinders are connected to a manifold on each side, at the front end of which a wet air filter is mounted. The exhaust ports on each side lead to a water cooled exhaust manifold. The two exhaust manifolds are connected to the silencer.

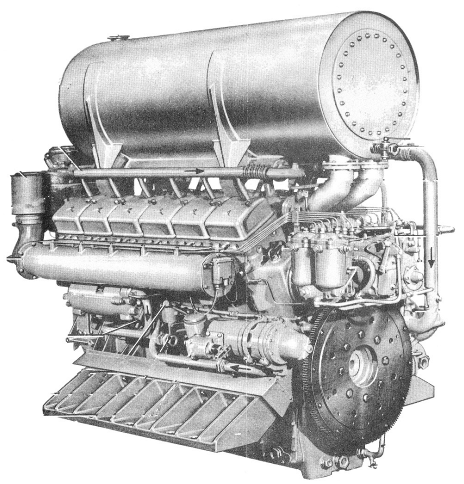

Fig. 1 Submarine diesel engine MB820 type

All the fuel, lubrication and cooling pumps necessary for operation of the engine are fitted on the engine and are driven from the crankshaft by means of a gear drive or V belt pulley. There are two injection pumps fitted on the gear case (one for each bank of cylinders) and the left pump carries the governor. On the right hand injection pump sits the fuel supply pump which is actuated by a cam arranged on the injection pump camshaft and is provided with a hand pump. The crankcase consists of a sturdy block which carries on up the cylinder head in V form. There are the gear case and the lugs for mounting the water-cooled exhaust silencer cast on to the crankcase. The cylinder liners are inserted in the top of the crankcase and sealed off at the top by the cylinder head. The cylinder liners are so-called wet liners made from centrifugal cast iron. Each of 12 cylinder heads is fastened to the crank-case with 8 strong studs and, at the same time, holds in the cylinder liners. At the bottom in the middle each cylinder head has a threaded hole for mounting of pre-chamber with the burner screwed into its body. Above the pre-chamber the cooling water circuit is sealed off from the oil space by means of an asbestos ring, spacer and ring nut. Each cylinder head has a separate cover fastened by the screws. General technical data of the engine and its static tuning parameters are given in Table 1 and Table 2.

Table 2. "Static" tuning parameters of the MB820 type diesel engine

| | | | |
|---|---|---|---|
| 1 | Inlet valve opens | $14^{o}$ | before TDC |
| 2 | Inlet valves closes | $56^{o}$ | after BDC |
| 3 | Exhaust valve opens | $48^{o}$ | before BDC |
| 4 | Exhaust valve closes | $19^{o}$ | after TDC |
| 5 | Valves overlap | $33^{o}$ | $14^{o} + 19^{o}$ |
| 6 | Start of fuel feed-in when idling | $24^{o}$ | before TDC |
| 7 | Adjustment range of automatic injection timer | $24^{o}$ - $36^{o}$ | before TDC |

The upper quoted timings apply to the cold engine only and are shown graphically on the Fig. 2.

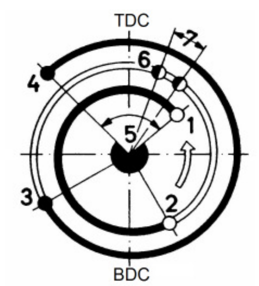


Fig. 2. Static fuel injection valve and valve gear timing diagrams of the MB820 type diesel engine

## 2. The MB820 diesel engine cylinder pressure tests

For assessment of the combustion processes on the low- and medium-speed marine diesel engines indicator valves (indicator cocks) are installed in the cylinder heads. Most of the high-speed marine diesel engines similarly to the land traction engines are not equipped with indicator valves including the MB820 type engine. In order to install the indicator valve for measuring the internal cylinder pressure on the MB820 engine (which is not equipped with indicator cocks) the decompression channel was used. KISTLER pressure sensor type 7613B was connected in place of the decompression valve as it is shown on Fig. 3.

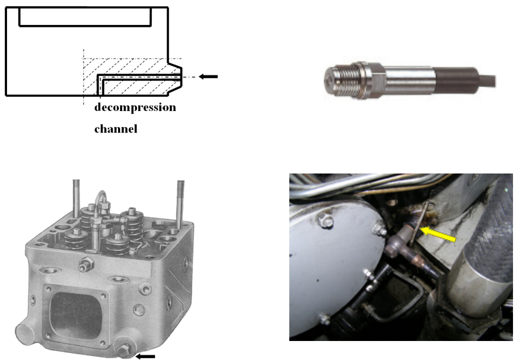


Fig. 3. Cylinder head with the cylinder pressure sensor passed through the decompression channel

Such solution can be done on two cylinders of the 12 cylinders on V-shaped engine only (on cylinder number 1 in the left bank and on cylinder number 7 in the right bank) because of a very complicated access. Furthermore, the decompression valve should not be used permanently for this purpose because it could endanger the engine, especially during the start.

Except of this modification the engine was prepared to the test as to the normal operation. The big advantage of the submarine engines is that there is possible to operate with the fully loaded engine in the harbor without a necessity to go for the sea trails. It is possible because the submarine engine is connected directly to the generator which is loaded by the storage battery. It is also important that special operating conditions of the submarine enable to load the engine in the same range of repeatability during the next tests making it possible to analyze and compare registered parameters with those obtained previously. Measurements were taken under generator loads (amperage) equal 1800A. Results obtained during investigation of the cylinder pressure are shown in figure 4. From the registered pressure traces obtained under engine load close to the rated value (Fig. 4) it is seen that in cylinder number 7 the ignition starts by 2 CA degree ($2^o$) earlier than in cylinder number 1 located at the opposite bank, which results in slightly higher value of maximum pressure.

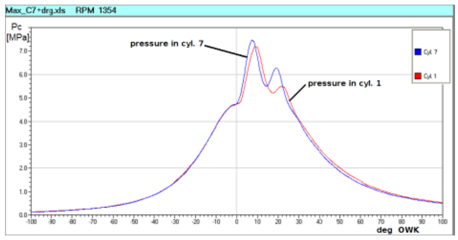


Fig. 4. Cylinder pressure curves in cylinders No. 1 and No. 7 measured under load (amperage 1800A) of diesel generator and speed of n = 1354 rpm

During idling of the engine the differences between considered angles of the fuel injection timing are within $0{,}6^o$ value level and cylinder pressures in both cases are practically identical. As it was noted above there is no possibility to measure the internal cylinder pressure from the other cylinders of that type of the engine so the new vibro-acoustic method is elaborated for checking and tuning of the engine in routine every-day maintenance practice. The in-cylinder pressure traces mentioned above were used as a reference signals for processing of the vibration signals.

## 3. Vibration method used to assess engine tuning and technical condition

To assess the engine tuning and technical condition on the base of envelope of vibration traces the values of so-called „dynamic" timing parameters are needed. Assessment of technical state of the diesel engine could be done in different loading conditions and acquired signals may be interfered with this phenomenon. Special filtration and envelope processing procedures has to been applied to separate recognizable traces from vibration signals.

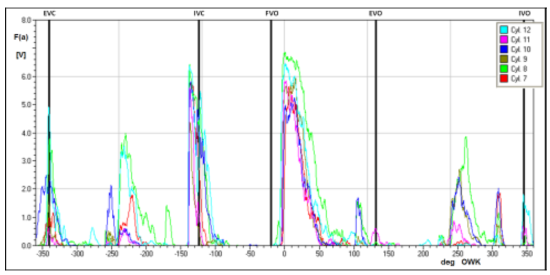


Fig.5. Vibrations traces from six cylinder heads in the same bank of high-speed marine diesel engine shifted to the TDC of the first cylinder of the bank–engine at rated load

Examples from vibration signals measurements taken on submarine diesel engines MB820 and methods of their visualization are shown in figures number 5 and number 6.

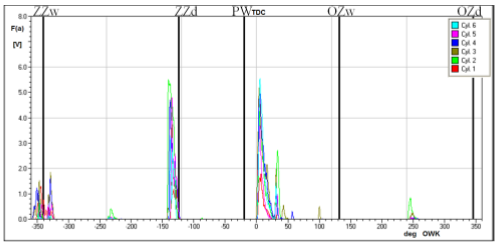


Fig.6. Cylinder vibrations traces from six cylinders in the same bank of high speed marine diesel engine shifted to the TDC of first cylinder of the bank– engine idling

The most important parts of the vibration traces are shown in "zoom mode" and analysed below.

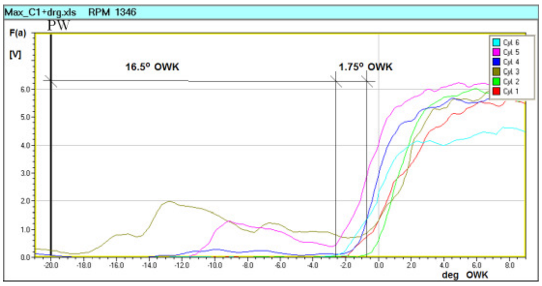


Fig. 7. Openings of the fuel injection valves

The points where curves sheer goes upwards are recognized as a start of the fuel injection or as moments of valve openings and closes. The differences between fuel injection valve openings presented on Fig. 7 for left engine bank of cylinders vary within the range of 1.75° of CA (crankshaft rotation degree). The difference between the "static" openings and "dynamic" opening angles of the fuel injection valves reaches up to 16.5° of CA.

Fig. 8 presents changes in signals generated by the inlet valve openings in the same engine left cylinder bank. It is clear from the analysis of graphs, that angles of valves openings differ in broad range by 5.5° of CA and signals patterns according to the amplitude differ actually much more.

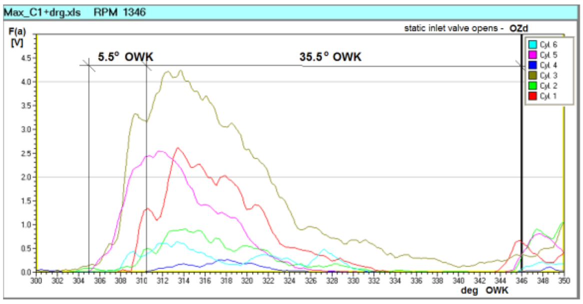


Fig. 8. Openings of the inlet valves

By applying a new developed diagnostic methodology, almost every change in the engine mechanical structure will be detected by analysis of the vibration signals pattern sequence. Specific read out values of „dynamic" angles for each banks of tested engine are gathered all together and shown in "bar chart" form for whole engine as it is shown in figures number 9 to number 11.

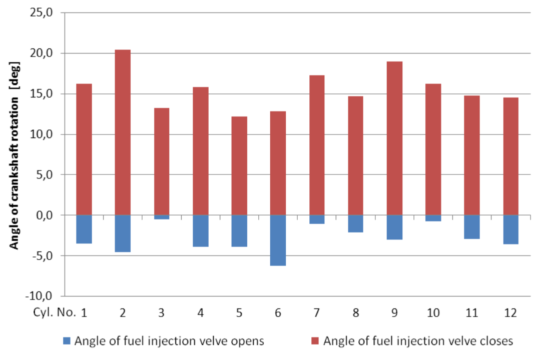


Fig. 9. Angles of fuel injection valves opens and closes – whole engine

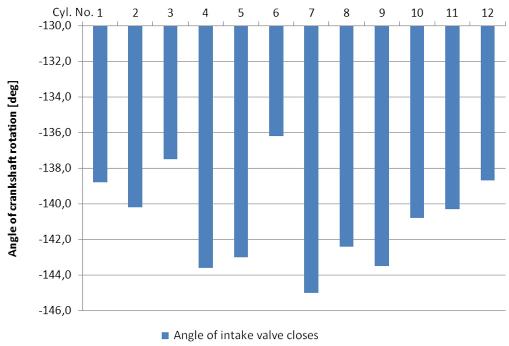


Fig. 10. Angles of intake valve closes – whole engine


Fig. 11. Angles of exhaust valve closes – whole engine

These graphics are kind of "foot prints" for tested engines and observed through several years normally does not change. If the change occurs in the pattern that means that engine needs tuning or other maintenance.

In the table 3 the specific "dynamic" and "static" timing parameters of the engine are presented. Differences between "static" and "dynamic" values in openings and closings of both inlet and exhaust valves vary from ~15$^o$ to ~40$^o$ degrees. There are also differences between data obtained from the left and right engine banks as well.

Table 3. "Static" and "dynamic" tuning parameters of the chosen MB820 diesel engine

| No. | Parameter | "static" | "dynamic" | | |
|---|---|---|---|---|---|
| | | | Left bank | Right bank | |
| 1 | Inlet valve opens | 14$^o$ | 51,8$^o$ | 55,9$^o$ | before TDC |
| 2 | Inlet valves closes | 56$^o$ | 41,5$^o$ | 40,3$^o$ | after BDC |
| 3 | Exhaust valve opens | 48$^o$ | - | - | before BDC |
| 4 | Exhaust valve closes | 19$^o$ | 16,5$^o$ | 15,1$^o$ | after TDC |
| 5 | Valves overlap | 33$^o$ | 68,3$^o$ | 71$^o$ | |
| 6 | Start of fuel feed-in when idling | 24$^o$ | 1,5$^o$ | 5,0$^o$ | before TDC |

For example the difference between "static" start of fuel feed-in, which compiles about 20$^o$, came probably from the fact that "static" parameters are adjusted for idling conditions of the engine and that there mechanic-hydraulic governing device is mounted, which controls fuel injection timing depending on engine speed. As it is matter of concern, differences in closings of the inlet and exhaust valves are equal approximately to 15$^o$ degrees (inlet valves) and 3-5$^o$ degrees (exhaust valves) that could be explained by the thermal lengthening of the valve gear mechanism (tappets, pushrods, rockets) during the engine operation. Changes in exhaust valves openings have not been studied during these tests but inlet valves openings differ by up to 40$^o$ degrees if comparing them with the static conditions.

## Conclusions

1. In-cylinder pressure signals taken by pressure sensors installed at the decompression valves locating positions are useful as a reference signal to trigger the vibration signals on the MB820 engine cylinder heads.
2. Due to a new developed diagnostic methodology it is possible to measure and register the vibration parameters generated by a high-speed the MB820 type marine diesel engine and use this information for diagnostic purposes of the fuel injection system and valve gear mechanisms.
3. So-called "dynamic" tuning parameters of the MB820 diesel engine were successfully assessed but with some exceptions. It was not possible to separate with acceptable accuracy the signals coming from exhaust valves openings because the sensor was located at the external part of the cylinder head whereas the exhaust valves are located close to the middle of the engine crankcase.
4. Signals that come from the valve closings are usually "sharper" and easier to be assessed than corresponding signals generated by their openings.
5. Although there are considerable differences in "static" and "dynamic" engine timing parameters this method could be useful for engine tuning and diagnostic without stopping the vessel. Such non-stop methods when used systematically in year-by-year marine engine inspections could be effective for adapting of cost lowering Condition Based Maintenance [1,4] strategy.

## Nomenclature

CA Crank Angle
BDC Bothom Dead Center
TDC Top Dead Center
$^o$OWK Crank Angle degree

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