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THE VALVE GEAR SYSTEMS TIMING PARAMETERS IDENTIFICATION FOR MARINE DIESEL ENGINES DIAGNOSTICS

IDENTYFIKACJA PARAMETRÓW UKŁADÓW ROZRZĄDU SILNIKÓW OKRĘTOWYCH DLA POTRZEB DIAGNOSTYKI

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Abstract: *In the paper results of studies that aim was to develop a diagnostic method for high-speed marine diesel engines are presented. Polish Navy is operating significant number of engines of this type also on board of submarines. Engines of this type do not have indicator valves, which complicates the assessment of combustion process and their technical condition. Polish Naval Academy in Gdynia for years has been developing methods of diagnosing marine internal combustion engines. In recent years, a diagnostic method for high-speed marine diesel engines based on the analysis of envelope of vibration accelerations generated by the valve gear mechanism and fuel system has been developed. Some tests results made on Mercedes-Maybach MB820 engines used on Kobben class submarines are presented in the paper.*

Keywords: *transport, maritime transport, marine high-speed diesel engines, diagnostics*

Streszczenie: *W referacie przedstawiono wyniki badań, których celem było opracowanie metody diagnozowania okrętowych szybkoobrotowych silników tłokowych. Polska Marynarka Wojenna eksploatuje znaczną liczbę silników tego typu również na okrętach podwodnych. Silniki tego typu nie posiadają zaworów indykatorowych, co komplikuje możliwość oceny procesu spalania i ich stanu technicznego. Akademia Marynarki Wojennej w Gdyni od lat prowadzi badania związane z rozwojem metod diagnozowania okrętowych tłokowych silników spalinowych. W ostatnich latach prowadzone są prace nad metodami diagnozowania szybkoobrotowych silników okrętowych bazującymi na analizie obwiedni przyspieszeń drgań generowanych przez układy rozrządu zaworowego i układ paliwowy. W referacie zaprezentowano wybrane wyniki badań prowadzonych na silnikach Mercedes-Maybach typu MB820 stosowanych na okrętach podwodnych klasy Kobben.*

Słowa kluczowe: *transport, transport morski, okrętowe szybkoobrotowe silniki wysokoprężne, diagnostyka*

1. Introduction

The high-speed marine diesel engines type MB820 which drive DC generators are used on board of Polish Navy submarines Kobben class. Diesel engine generators are all the time the least reliable element of onboard machinery of conventional ships and Navy vessels [3]. Diesel engine generators are a mission critical feature of a submarine on patrol [2]. During exploitation process of MB820 engines in Polish Navy for about 12 years period, some their malfunctions occur. The most significant malfunction of these types of engines in PN was exhaust valve broken during one of patrols which is shown in Figure 1.

Figure 1. Cylinder head of submarine diesel engine type MB820 with broken exhaust valve

One of tools which could be useful in everyday engines monitoring and exploitation are diagnostic methods based on vibration signals analysis [5-10]. This paper presents one of possible methods developed for diagnosis of high-speed marine diesel engines type MB820. The method, based on the angular selection of vibration signal emitted by the engine running components, may be useful for diagnosing of these engines fuel and valve gear systems, a specially that these engines are not fitted with cylinder pressure valves. Presented method was worked out in Technical Institute of Ship Construction and Maintenance of Polish Naval Academy.

2. Objects of the research

The MB820 type submarine engine (Figure 2) is a high speed four stroke diesel engine of light compact design that works on the pre-chamber combustion process. The pre-chamber is connected with the cylinder space through the holes in the burner.


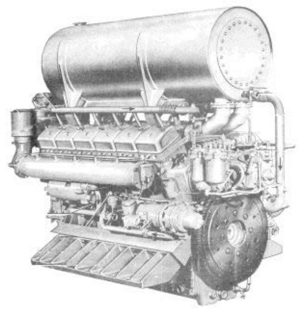

Fig. 2 Polish Navy submarine Kobben class and its diesel engine type MB820 [pictures: Wojciech Stróżyk (left) and MTU (right)]

The engine has 12 cylinders which 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 stroke of which is controlled by a camshaft common to both cylinder banks, by means of tappets, push-rods and rocker arms. The crankcase consists of a sturdy block which carries on up to the cylinder head in V form. Each cylinder head has separate cover fastened by the screws. Engine general technical data and static tuning parameters are given in Table 1.

Valve gear mechanism and fuel injection systems were researched as sources of vibration signals which could be used in assessment of technical condition of the engines. Values of parameters measured on stopped and cold engine such as angles of valves closing and opening and fuel injector opening angle are used in typical technical condition assessment procedure. Values of these parameters in static conditions of tested engines are shown in Table 1.

Table 1. Basic data of Mercedes-Maybach diesel engine type MB820

Engine type	MB820 four-stroke, not turbocharged
Combustion chamber type	diesel pre-chamber
No. of cylinders / Configuration	i=12/ „V”
Nominal output	Pn=440 kW at 1400 rpm
Cylinder bore	D=175 mm
Piston stroke	S= 205 mm
Compression ratio	ε= 1:18,5
Total displacement volume	Vss= 59,2 dm^3
Firing order	1-8-5-10-3-7-6-11-2-9-4-12
Number of valves per cylinder	z= 4
Fuel injection pressure	pw= 17,0-17,5 MPa
Angle of intake valve open	14 deg before TDC
Angle of exhaust valve open	48 deg before BDC
Angle of intake valve close	56 deg after BDC
Angle of exhaust valve close	19 deg after TDC
Angle of fuel valve open	24-36 deg before TDC Adjustment range of automatic injection timer
Inlet and exhaust valves clearances	0,40 / 0,45 mm

Values of angle parameters given in Table 1 are specific for “static” measuring conditions. That means that they are measured on stopped engine and at engine temperature equal about 20^{o}C. For such measurements values of clearances are also changed to get exact values of valves timing angles. Engine monitoring or diagnostic system needs values of these parameters characteristic for operating and loaded “hot” engine. Aim of the research was to check if in vibration acceleration signals generated by the chosen engine systems and components are such parameters which are unequivocal, strongly connected with different object structure parameters, easy to asses and measure. Another aim of the research was exploration of the exact values of engines “dynamic” tuning parameters that are necessary in engine technical condition assessment when using on-line measuring systems on working engine.

3. Method and chosen results of investigations

The idea of vibration signal processing in carried out tests is similar to that which was developed for low- and medium-speed marine diesel engines [10]. It is the method where signal is processed in time/angle domain and characteristic events connected with fuel injector and cylinder valves operation accompanying by vibration impulses are read out and registered by engine analyser – Figure 3 and 6.

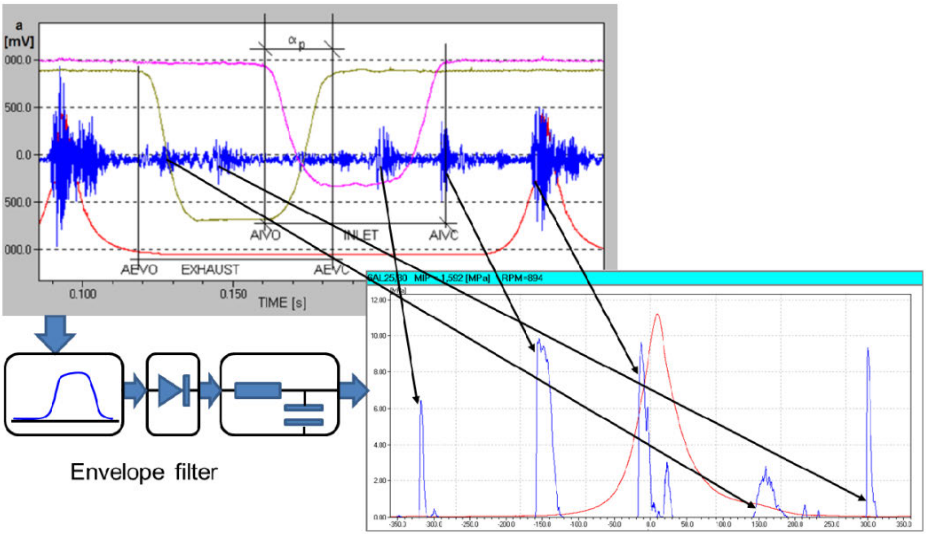

Fig. 3 Schematic illustrating how the transposition of the vibration signals in the time domain corresponding to the angular engine cycle [8]
αp - the dynamic angle of valves overlap,
AEVO - the dynamic angle of the exhaust valve opening,
AEVC - the dynamic angle of the exhaust valves closing,
AIVO - the dynamic angle of the intake valve opening,
AIVC - the dynamic angle of the intake valve closing

Measuring of internal cylinder pressure on this engine is very complicated or almost impossible. Engine is not equipped in indicating (cocks) valves. Cylinder pressure was measured only on utmost (side) cylinders by the decompression channel. KISTLER pressure sensor type 7613B was connected in place of the decompression valve as it is shown on Figure 4. Cylinder pressure signals taken from decompression valves were used as a reference signal to trigger the vibration signals measured on MB820 engine cylinder heads.
To find a proper signal and to assign to it the engine sequences order we have to use many different signal selection methods such as time selection, frequency and spatial selection. Sensor location and type of sensor fitting methods are important too. The closer to the signal sources the better for signal amplitude and quantity of information carried by the signal. If it is possible sensors should be mounted directly on the cylinder heads, injectors or valve housings. The engine body and cylinder covers are the places that should be avoided during the sensor montage as they are elastic or thin. In case of the MB820 engine intake manifolds of each cylinder head were chosen as places to put the vibration sensors – Figure nr 4.

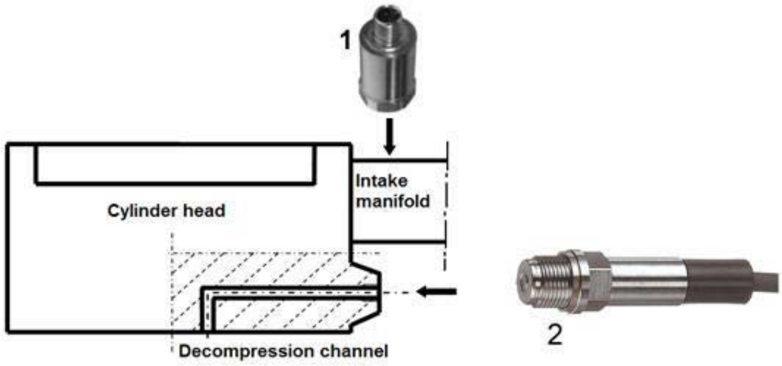

Fig. 4 Cylinder head with the vibration (1) and cylinder pressure (2) sensors passed through the decompression channel [5]

Fitting sensors by screw-in bolts or clamp bolts secure high frequency signal components transmission. Magnetic or stick sensor fitting methods result in big losses in signal spectrum. In case of real submarine's engine two-component adhesive glue was used to fixing sensors washers. Acquired signals where passed across the frequency window analyzer function to cut out some of the disturbed parts of the signals. When the signal is analyzed only as an event in time/angle domain and when the frequency sampling is high enough as well as the time/angle axis is stable, having appropriate reference signals we could easily check the signal sequence order. The proper signal sequence order means that engine or other technical assets are in a good technical condition. A problem appears when we have to observe signals on multi-cylinder engines and without any access to the angel axis of the engine crankshaft.

Vibration signals registered separately on cylinder heads of one of two banks of 12 cylinders diesel engine are shown in Figure 5.

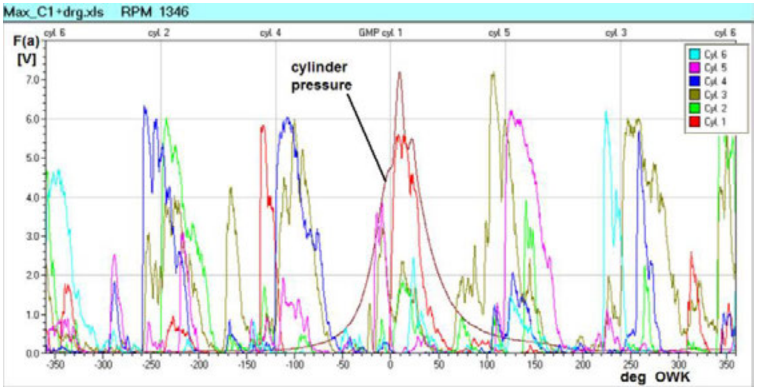

Fig. 5 Envelopes of vibration acceleration signals registered on one of the banks of diesel generator engine MB820 at~ 1400 rpm, engine load = 100% of nominal load together with cylinder pressure signal from cylinder number one as a reference signal [8]

Complete diagnostic system build in PNA specially for high-speed diesel engines is presented in the Figure 6.

Fig. 6 Complete diagnostic system with 6 vibration signal channels and one pressure channel

In order to synchronize the vibration signals the cylinder pressure signal is used as a reference signal. The signal traces from six cylinders are shifted to the TDC (Figure 7) of the first (in this bank) cylinder to assure better signals positioning for analysis. The places where signals from different cylinders could interfere (for 4-stroke 6 cylinder diesel engine it is usually ±120^o , ±240^o to TDC) are also shown in Figure 7.

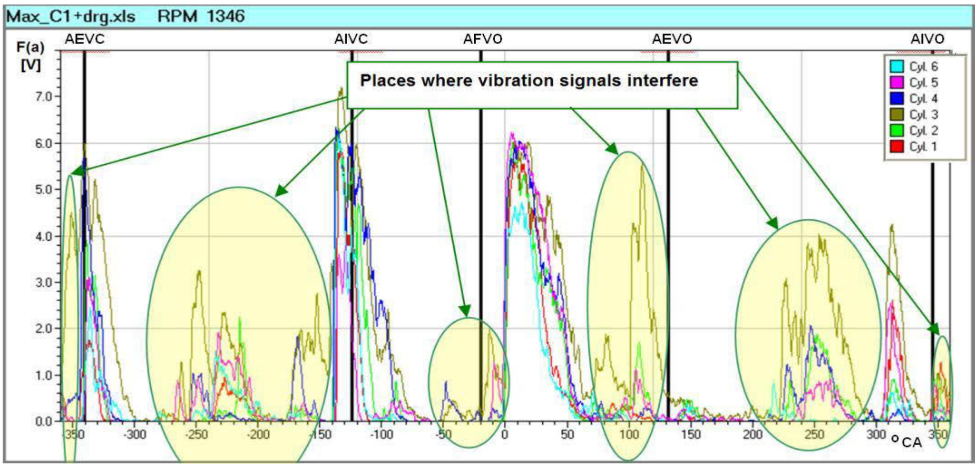

Fig. 7 Specific places where shifted vibration signals from different cylinders interfere with one another [8]

Additionally, on Figure 7 the static engine timing points are shown: AEVC – means static angle of exhaust valves closes, AIVC – means static angle of inlet valves closes, AFVO – means static angle of start of fuelling when idling, AEVO – means static angle of exhaust valves opens and AIVO – means static angle of inlet valves opens. Using this special analysing system with “zoom” function (as it is shown in Figures 8 and 10) each part of the diagram could be magnified to read-out the engine dynamic timing parameters. Using a cursor the analyser operator can asses’ angles of fuel valve openings and valve gear timing for each cylinder in the bank with reasonable accuracy. Reasonable means not worse that tolerance given in engine maintenance manual.

Fuel injectors

Fuel when goes through the high-pressure system is a source of noise and vibrations. Moving parts of the high-pressure pumps and fuel injectors are source of impacts which may be observed as displacements, velocity and accelerations of the vibrations. Fuel injector needle up and down movements’ (Figure 8 – left) coincide with sharp impacts on the fuel valve main body and needle seat. To get such signals from working injectors the vibration sensor should be installed directly on the injector or very close to it.

The points where curves abruptly go upwards are recognized as a start of fuel injection or as moments of valve opens and closes. The differences between fuel valve opens presented in the Fig. 8 for left engine bank of cylinders differ in 1.75^o of crankshaft revolution range. The difference between “static” and “dynamic” angle of fuel valves opens has about 16.5^{o}CA.

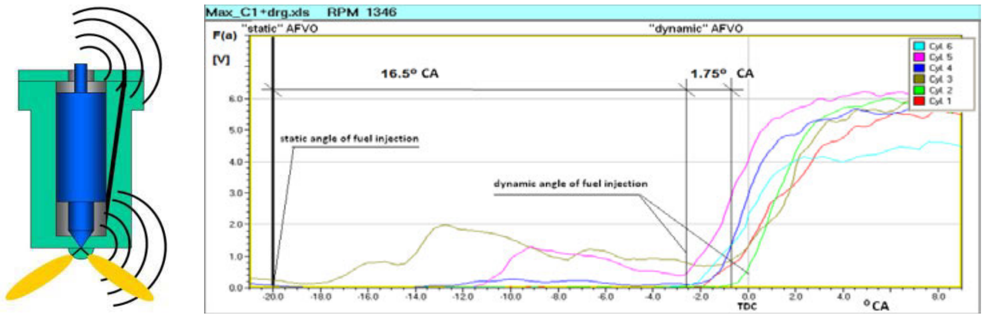

Fig. 8 Dynamic and static angles values of start of fuel injection in high-speed diesel engine type MB820 in "zoom" mode [9]

If the whole fuel delivery system works properly two sharp and strong vibrations' signals – picks – created by the fuel valve needle are usually observed in crankshaft angle domain (Figure 3), but when jamming or other malfunction occurs the signal pattern is changed. Information about fuel valve needle moving, period of fuel delivery which correlates with fuel quantity, are especially valuable. This statement is true only for low- and medium-speed engines. For high-speed engines because of the very short time window for fuelling period and vibration signal decay time it was impossible to observe vibration signal caused by closing fuel injector needle. Some results of measurements of angles of opening of fuel injectors in the form of bars for whole 12-cylinder engine are shown in Figure 9.

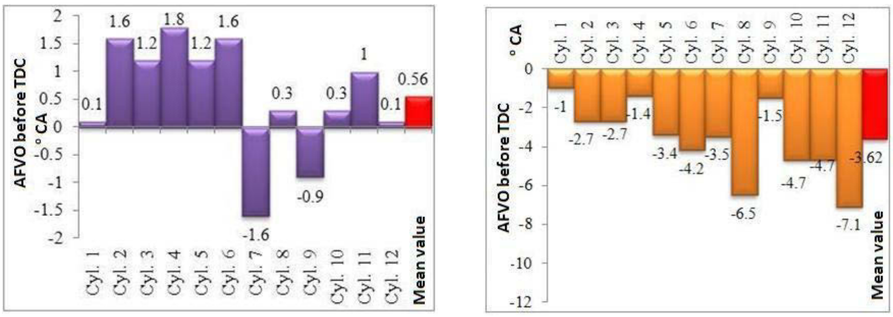

Fig. 9 Values of dynamic angles of starting the fuelling of high-speed diesel engine type MB820 when idling (left) and at nominal load (right)

There are seen differences between values of angles beginnings of fuelling in idling (left) engine and engine working close to nominal (right) load. Mean values (red) are different more than 4^{o} of CA revolution.

Valve gear mechanism

Valves strikes in valve seats during valves closing and rocker arms strikes in valve stems when they are being opened could be observed (Figure 10) in time or angle domain. Observed signals give information about valve gear mechanism timing, technical condition of valve seats, valves' steams, and other elements. In big 2-stroke diesel engines which have one hydraulically open exhaust valve, vibration sensors might be connected directly to the valve housing or to the cylinder heads. Mass of valves in such engines and cylinder head dimensions are big enough to effortless signal selection. It looks quite different in small high-speed engines where more than one relatively light valve per cylinder are installed. For example, in the MB820 engines (at 1400 rpm) one cycle (two crankshaft revolutions – 4-stroke engine) takes only ~0,12 second. Vibration signal from sensor connected to the intake manifold is strongly disturbed by vibration processes in other cylinders and engine mechanisms as it was shown in the Figure 7. But it is possible to observe some of the signals pattern with analyzer.

In the Fig. 10 signals generated by inlet valve opens in the same MB820 type engine bank are presented. It is visible that angles of valves opens differ in broad range of 5.5^{o} CA and signals patterns differ much more according to the amplitude.

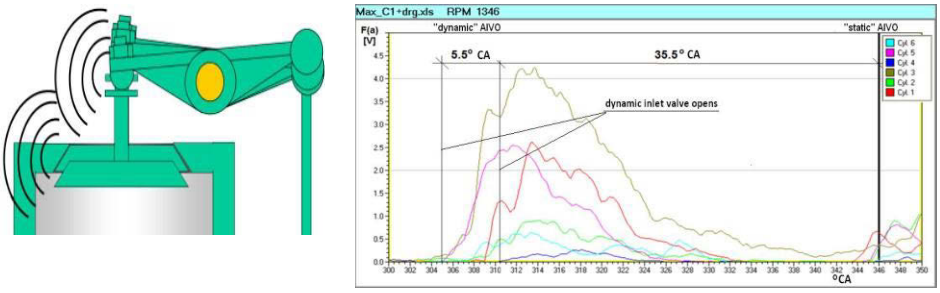

Fig. 10 Dynamic and static angles values of inlet valve opens in high-speed diesel engine type MB820 in "zoom" mode [9]

Much better than angles of valves opening are observed angles of valves closing. Using the cursor operator of the analyzer can determine the beginning of closing intake and exhaust valves of a cylinder in the engine with enough to adjust (or check the status of regulation) accuracy (Figure 11).

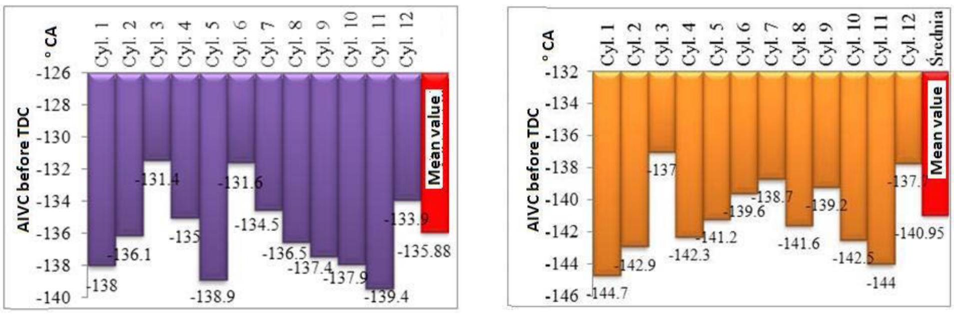

Fig. 11 Values of dynamic angles of inlet valve closing in high-speed diesel engine type MB820 when idling (left) and at nominal load (right)

There are seen differences between values of angles of beginnings of intake valves closing in idling (left) engine and engine working close to nominal (right) load. Mean values (red) are different close to 5^{o} of CA revolution. It is strongly connected with thermal load of the engine and its speed.

4. Conclusions

Marine diesel generators are responsible for the most of the ship machinery malfunctions. Most of the malfunctions in marine engines are generated by the fuel system and valve gear mechanism. Presented diagnostic method is effective in the evaluation of the technical condition of high-speed marine diesel engines. The method developed in the PNA has undergone a positive verification in the marine exploitation conditions. Values of dynamic angles of opening of the fuel injectors on the running engine can be define with using this method. The method allows determine angles of intake and exhaust valves closing on the running engine. Despite some limitations resulting from the very essence of the method and design of marine internal combustion engines, presented method can be useful for marine and not-marine high-speed engines diagnosing, especially when they are not fitted with indicating valves.

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