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TESTS RESULTS OF NEW DIAGNOSTIC METHOD FOR WOLA MARINE DIESEL ENGINES TYPE H

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Abstract

Results of studies that aim was to develop a diagnostic method for WOLA marine diesel engines type H are presented in this paper. These engines are high-speed type units used to drive small vessels or more often to drive ship generators. Polish Navy is operating significant number engines of this type. Motors of this type do not have indicator valves, which complicates the assessment of their technical condition in exploitation. These engines also, because of their age, are relatively poorly equipped in control and measurement devices. In the era of cost reduction in operation of marine equipment there is also tendency to reduce the cost of maintenance and repair of diesel engines. One way to avoid malfunction of the motor can be systematic monitoring of the technical condition of selected critical systems using reliable diagnostic methods. Polish Naval Academy (PNA) in Gdynia for years has been doing research on methods of diagnosing marine internal combustion engines. In recent years, a diagnostic method for high-speed diesel engines based on the analysis of envelope of vibration accelerations generated by the valve gear mechanism and fuel system of WOLA type H engines has been developed. Preliminary tests were carried out on a six-cylinder WOLA engine type 57H6Aa in the Marine Power Plant Operation Laboratory in PNA. Verification tests were conducted on twelve-cylinders WOLA engines of the same type on navy vessels. The developed method allows determine the angles of opening and closing the fuel injection valves and angles of closing intake and exhaust valves during engine operation. Using this method it could not be clearly determined opening angles of intake and exhaust valves.

Keywords: *transport, maritime transport, combustion engines, diagnostics*

1. Introduction

Polish Navy operates on board ships different types of marine diesel engines. Marine WOLA diesel engines type H are used on a small vessels as propulsion prime movers. This type of WOLA engines is also very popular as source of power in marine generators in Polish Navy. Total population of these engines systematically decries as they are changed by other types of engines (for example CUMMINS K19 type) but in exploitation are still more than fifty units. WOLA diesel engines type H used in Navy have two types of configurations – six cylinders in line and twelve cylinders in "V" form. Exact parameters of these engines are given in Tab. 1. Conditions of exploitation of these engines on board the navy ships are also changed [2–4]. Crews are still less responsible for repair works and overhauls as it is more often meter of shipyards and other companies which competes for such purchase orders in public tenders. One of new tools which could be useful in everyday engines monitoring end exploitation are vibration analysis methods [1, 5, 6, 9, 10, 13]. These methods are researched in Polish Naval Academy (PNA) in Gdynia for many years and for many types of marine diesel engines. They are extremely interested in cases when engines do not have indicating valves or are purely equipped in control and signal devices. The WOLA engines family is such a case when we have high-speed traction engine adapted to maritime conditions which does not have indicating valves. So, in the paper a diagnostic method which was worked out in Technical Institute of Ship Construction and Maintenance of PNA is presented, especially for this type of engines.

Tab. 1. Basic data of the high-speed diesel engine type WOLA 57H6Aa and WOLA H12

Engine type	WOLA – Henschel 57H6Aa	WOLA – Henschel H12
Turbocharger type	WSK – Holset 4MD	—
Number of cylinders / Configuration	i = 6 / „L”	i = 12 / „V”
Nominal output at 1500 rpm	P_n = 155 kW	P_n = 235 kW
Cylinder bore	D = 135 mm	D =135 mm
Piston stroke	S = 155 mm	S = 155 mm
Compression ratio	ε = 1:14.0	ε = 1:15.6
Total displacement volume	V_{ss} = 13.3 dm^3	V_{ss} = 26.3 dm^3
Mean piston speed	$c_{śr}$ = 8.26 m/s	$c_{śr}$ = 8.26 m/s
Firing order	1-5-3-6-2-4	1-8-5-10-3-7-6-11-2-9-4-12
Effective specific fuel consumption	g_e = 231 g/kWh	g_e = 224 g/kWh
Number of valves per cylinder	z = 4	z = 4
Fuel injection pressure	p_w = 19.4 MPa	p_w = 19.4 MPa
Angle of intake valve open	45 ± 6 deg before TDC	26 ± 6 deg before TDC
Angle of exhaust valve open	45 ± 6 deg before BDC	48 ± 6 deg before BDC
Angle of intake valve close	45 ± 6 deg after BDC	38 ± 6 deg after BDC
Angle of exhaust valve close	45 ± 6 deg after TDC	28 ± 6 deg after TDC
Angle of fuel valve open	32–36 deg before TDC	32–36 deg before TDC
Inlet and exhaust valves clearances	0.3 mm	0.4 mm

2. Objects of investigations

Researches took place on PNA laboratory stands and on engines mounted on board of Polish Navy vessels. In tests two types of WOLA family engines were involved – six and twelve cylinder units – Tab. 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 for both tested engines types are shown in Tab. 1.

Values of angle parameters given in Tab. 1 are specific for “static” measuring conditions. That means that they are measured on stopped engine and at engine temperature equal about 20°C. For such measurements values of clearances are also changed to get exact values of angles. Engine monitoring or diagnostic system needs values of these parameters characteristic for operating and loaded engine. Aim of the research was 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. Engine in laboratory, with 6 cylinders, is a unit for small ship propulsion system but engines tested on board a ship are typical units for generators. Some of their powers and tuning parameters are different as they are prepared to different operation conditions.

3. Method and results of investigations on laboratory stand

To assess proper and efficient diagnostic parameters on the base of vibration signal analysis some basic and more advanced research were made. At first with using of Brüel & Kjær PULS system on the test bed with 6-cylinder WOLA engine accelerations of vibration signal in time domain was registered as it is shown in Fig. 1 and Fig. 2. Vibration sensor was mounted on cylinder head number 2. During engine operation one section of fuel high-pressure pump number 2 which delivers fuel to the cylinder number 2 was suspended in upper position what results in vibration signal pattern as it is shown in Fig. 1. For normally operated engine (and fuel pump) vibration signal pattern was as in Fig. 2.

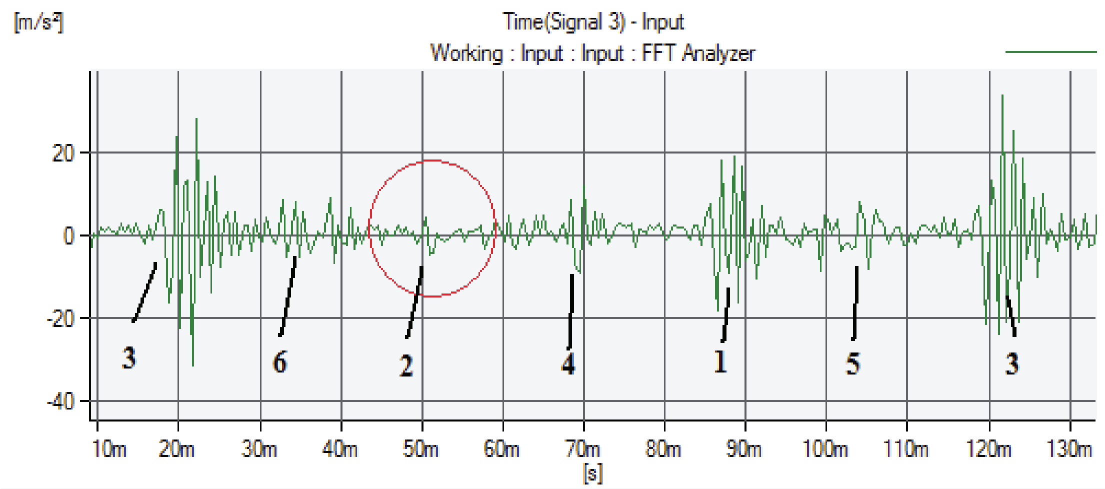

Fig. 1. Acceleration vibration signal measured on cylinder head number 2 in time domain. Engine firing order 1-5-3-6-2-4, plunger of the second section of fuel pump is blocked in upper position

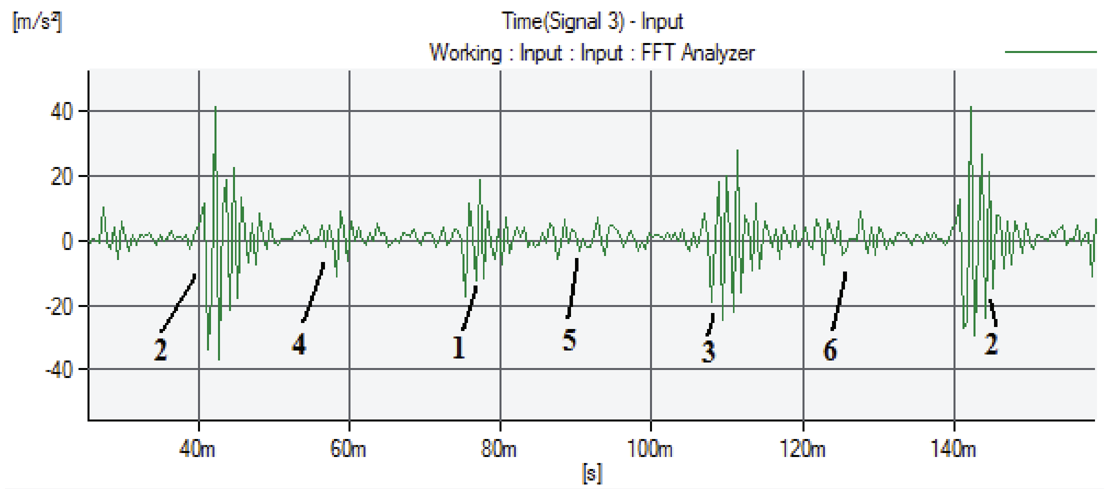

Fig. 2. Acceleration vibration signal measured on cylinder head number 2 in time domain. Engine firing order 1-5-3-6-2-4, plunger of the second section of fuel pump in normal operation

On the basis of that tests and other researches made on test engine in PNA it was shown that observerd vibration signal is sensitive enough to observe malfunctions in engine fuel system.The special method and dedicated engine analysier has been constructed [7, 8, 11, 12]. The method based on envelope of aceleration vibration signal followig which is automatically or manually analised in engine crank angle domain – Fig. 3. Obsevered signals of vibration acceleration envelopes measured on engine six cylinders are medium values from several followed traces. To add the signals and calculate and show their mean value vibration signals are triggered by the signal from pressure curve which was measured only on cylinder number 2. These envelope curves represents signals which are simultanously measured and averaged from several folloved vibration cycles closed by the trigger (marker) on the pressure curve. In Fig. 3 signals from cylinders 1, 6 and 3, 4 and 5 are moved respectively by 120, 240 and 360 cranck angle degree to achieve the same location of the signals according to TDC of cylinder number 2 on which pressure sensor was mounted.

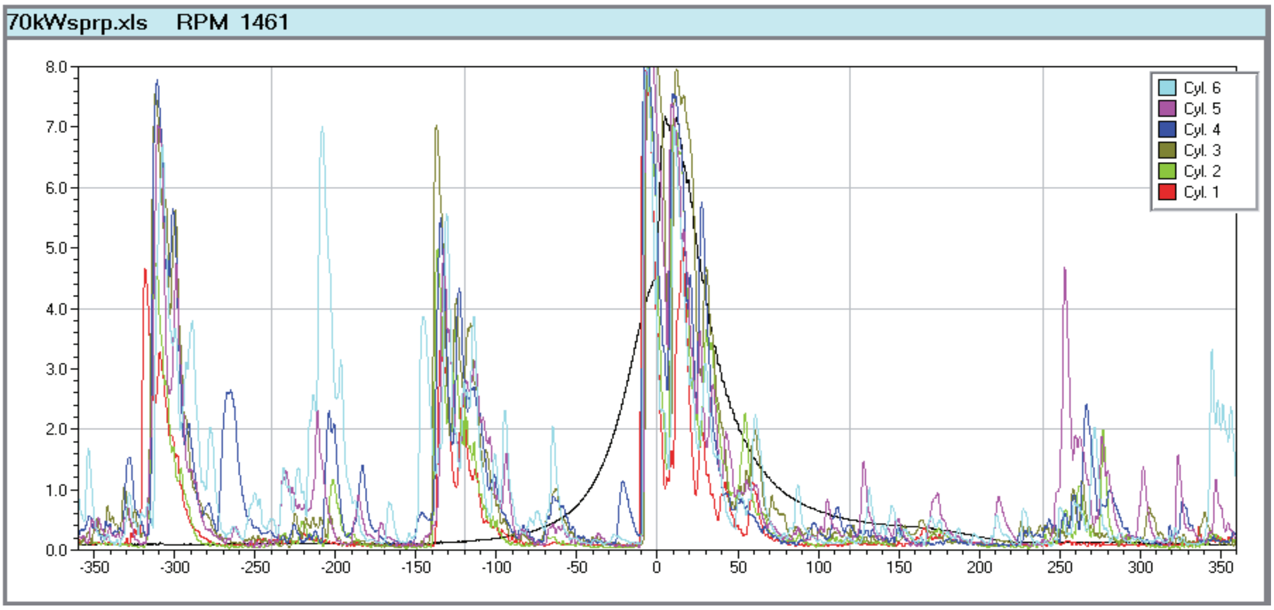

Fig. 3. Envelopes of vibration acceleration signals registered on the laboratory six cylinders diesel engine WOLA type 57H6Aa; engine speed =1461 rpm, engine load = 70 kW = 50% of nominal load

Special analyser software solution enables to enlarge parts of the diagrams and make easier for the operator to assess accurate values of angles characteristic for fuel valve and exhaust and intake valves opennig and closing. Possibilities of analyser "zoom" mode are shown in Fig. 4, where angles of openning for six engine fuel valves are marked. As it is seen values of angles varies from 12 to 8 degree before TDC.

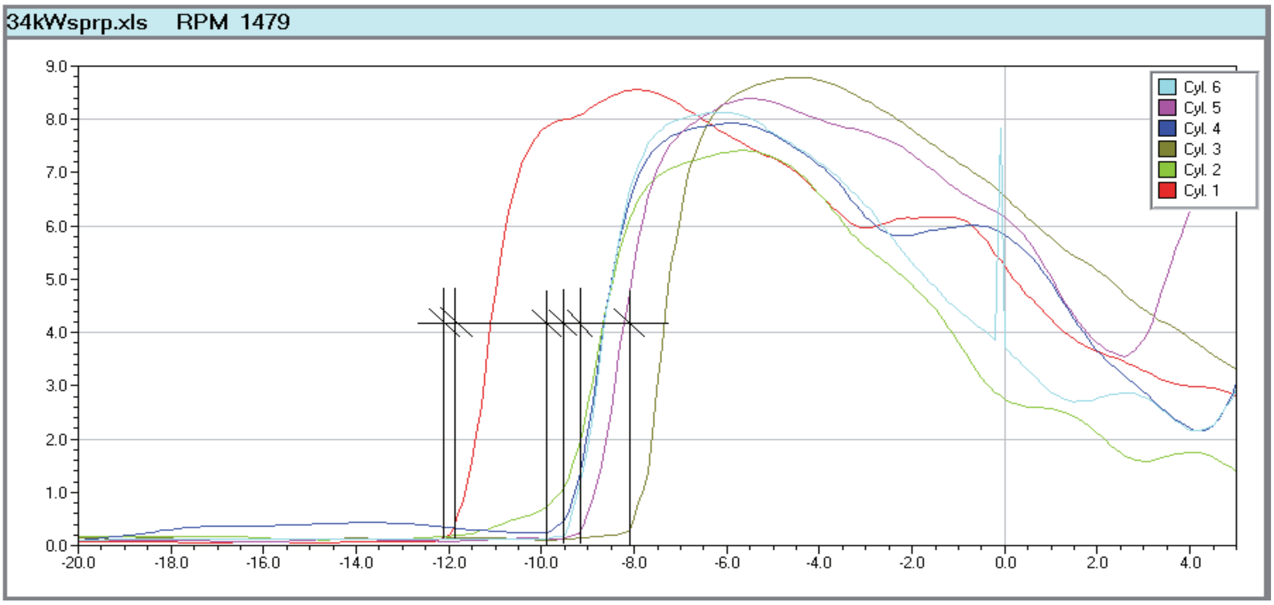

Fig. 4. Envelopes of vibration acceleration signals registered on the laboratory six cylinders diesel engine WOLA type 57H6Aa in „zoom" mode – angles of fuel velves opens; engine speed =1479 rpm, engine load = 34 kW = = 25% of nominal load

During the laboratory tests some engine malfunctions have been simulated. In Fig. 5 and Fig. 6 results of such simulation are presented. Fig. 5 presents situation when fuel valves on cylinders number 2 and number 5 have set nominal pressure value which opens fuel valves. In Fig. 6 fuel injector on cylinder number 2 has set lower fuel pressure value equal to 13.0 MPa, not 19.4 MPa which is a proper value.

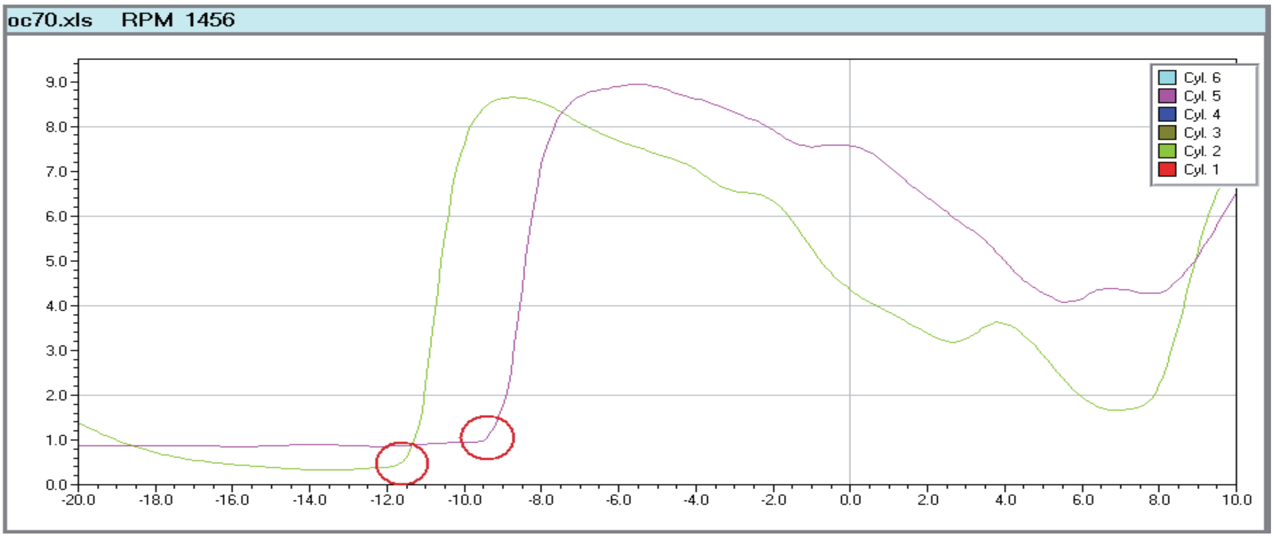

Fig. 5. Envelopes of vibration acceleration signals registered on the laboratory six cylinders diesel engine WOLA type 57H6Aa in „zoom“ mode circles – angles of fuel velves opens; engine speed = 1456 rpm, engine load = = 34 kW = 25% of nominal load

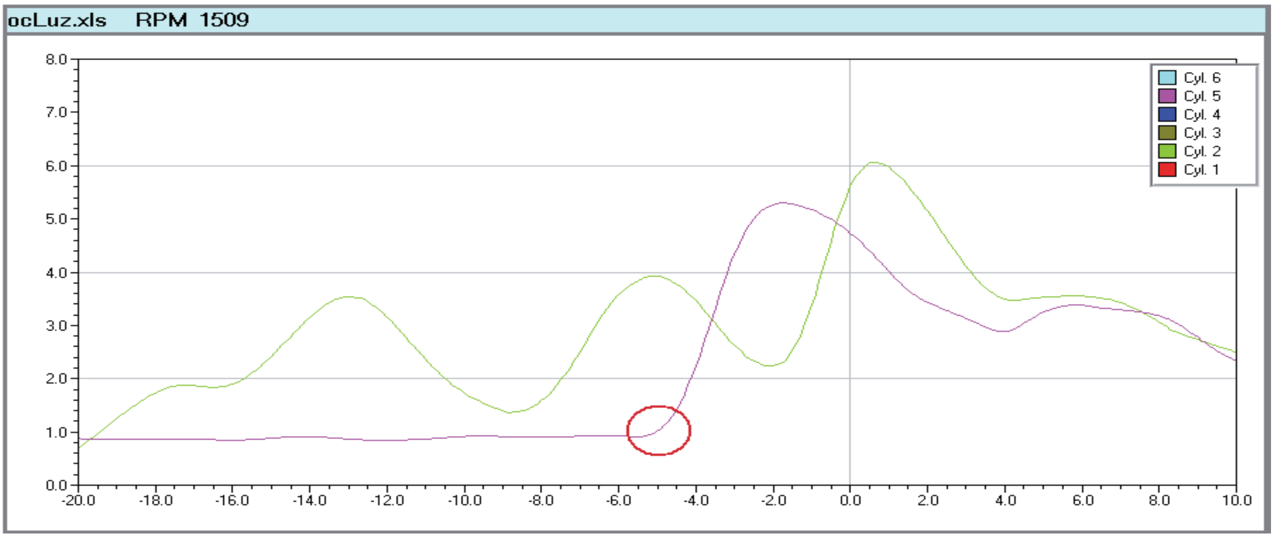

Fig. 6. Envelopes of vibration acceleration signals registered on the laboratory six cylinders diesel engine WOLA type 57H6Aa in „zoom“ mode circle – angle of fuel velves open; engine speed = 1509 rpm, engine load = = 34 kW = 25% of nominal load

It is seen that when fuel valve settings are changed the character of whole vibration curve is changed and momentum of fuel valve opening and fuel valve closing are not clearly seen (Fig. 6). Circles in Fig. 5 and Fig. 6 shows places when fuel valves becoming be opened during engine operation. In case of fuel valve which has lower fuel opening pressure (Fig. 6 – green line) this point is not easy to determine.

4. Results of investigations which were made on board a ship

Next part of the research was made on 12-cylinder diesel-generator units on the one of the Polish Navy vessels. Engines were loaded up to 50% and 100% of the nominal load during the tests. Observed on analyzer's screen patterns of envelope of vibrations for one bank of cylinders are shown in Fig. 7. To achieve better signal visualization followed signals are moved-up by a few volts. In signal pattern at 100% nominal engine load opening and closing points of fuel valves are seen. Also angles of intake and exhaust valves closing are easy to observe.

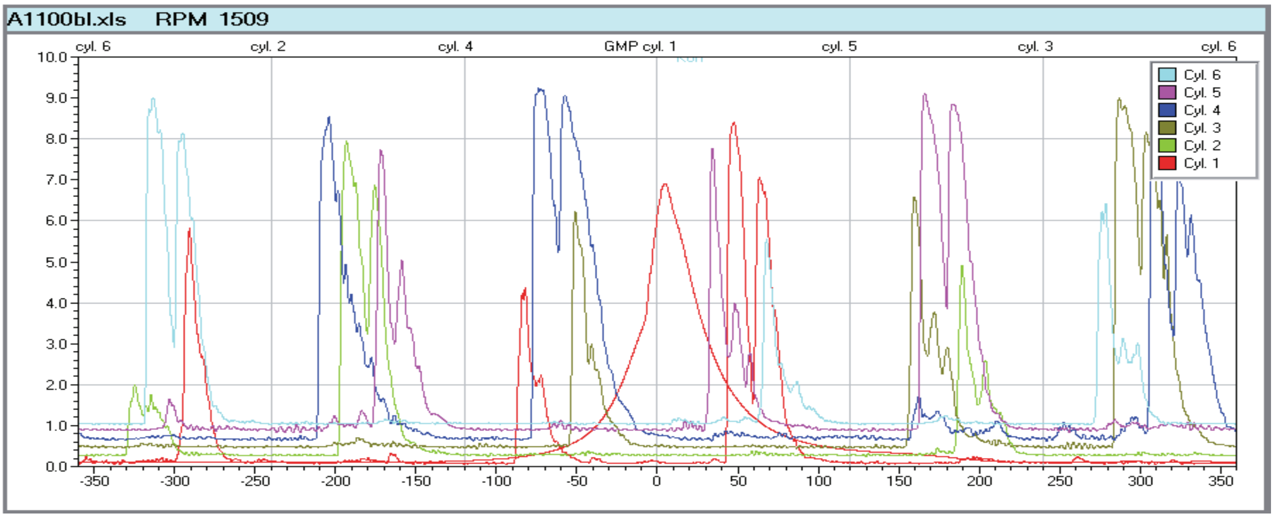

Fig. 7. Envelopes of vibration acceleration signals registered on one of the banks with six cylinders auxiliary diesel generator engine WOLA H12; engine speed = 1509 rpm, engine load = 100% of nominal load

Values of fuel injectors angles of opening and closing for 12-cylinder WOLA H12 engine are shown in "bar" form in Fig. 8. Average value of fuel valve opening angle for 12 cylinders at 100% engine load in operation mode is about –17°CA ("–" means before TDC). Average value of fuel valve closing for the same engine operation mode is about –1°CA. Differences between cylinders are less than ±2°CA. Fuel injection period at engine full load has about 16°CA. At this same engine working mode values of intake valves closing angles were read out and registered. Results of these measurements are shown in Fig. 9. Values of intake valves closing angles are varying from –152°CA to –143°CA before TDC. Values of differences are lower than acceptable margin of error given by engine manufacturer (±6°CA).

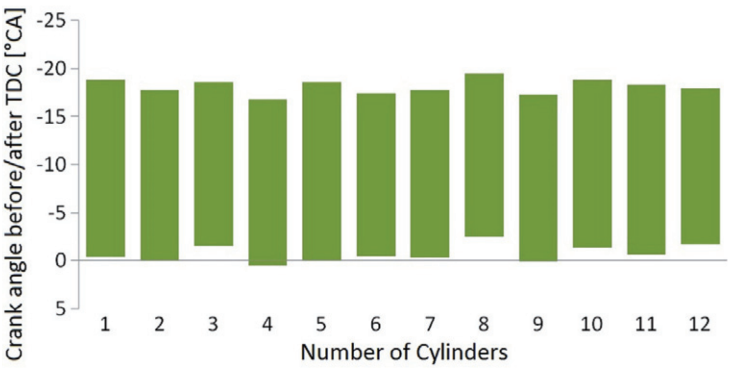

Fig. 8. Values of fuel injectors angles of opening and closing for auxiliary diesel-generator engine WOLA H12; engine speed = 1500 rpm, engine load = 100% nominal load

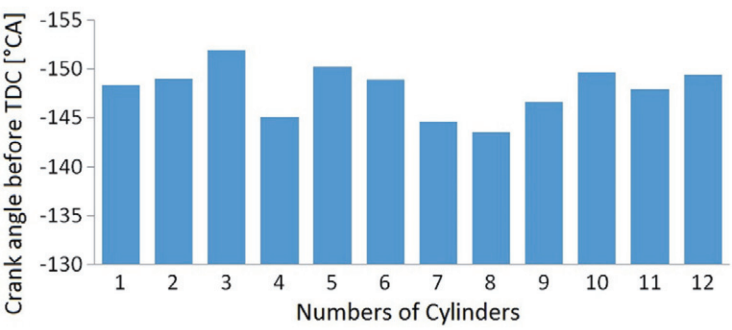

Fig. 9. Values of intake valves angles closing for auxiliary diese-generator engine WOLA H12; engine speed = 1500 rpm, engine load = 100% of nominal load

During engine tests on the one of diesel generators situation as shown in Fig. 10 has occured. On the cylinder number 9 angle of intake valve closing was about 16°CA earlier than on other cylinders. It is sugesting situation when after valve timing control valve clearence on that cylinder was not changed on value 0.4 mm from 1.0 mm.

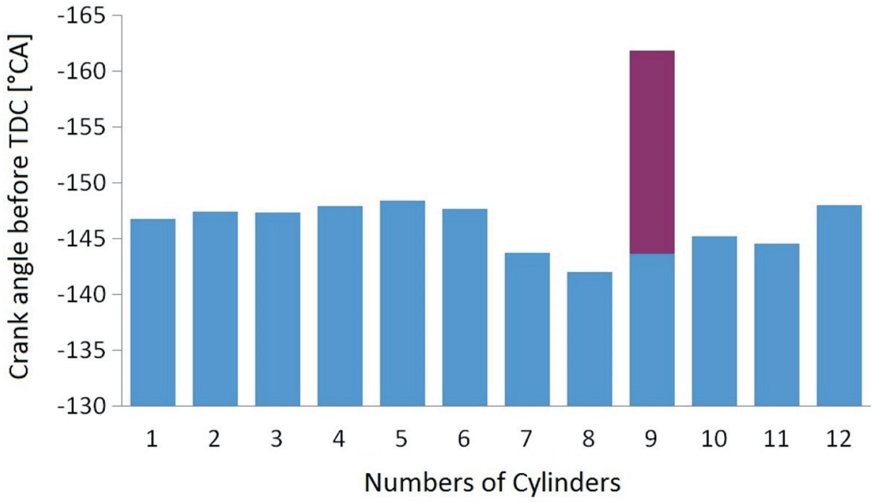

Fig. 10. Values of intake valves angles closing for auxiliary diese-generator engine WOLA H12; engine speed = 1500 rpm, engine load = 100% of nominal load

5. Conclusions

Presented diagnostic method is effective in the evaluation of the technical condition of a high-speed marine diesel engines WOLA type H. Engines devoid of indicator valves can be tested using this method. The method developed in the laboratory has undergone a positive verification of the marine exploitation conditions. Values of dynamic angles of opening and closing of the fuel injectors on the running engine can be define with using this method. Other malfunctions to the fuel system can be detected with this method, as shown in Fig. 6. The method allows determine angles of intake and exhaust valves closing on the running engine. How to hitherto to determine the opening angles intake and exhaust valves when using this method has failed. In order to accurately generate the angle axis of crankshaft rotation the method requires the removal one of an air starter valve on the motor. The Institute for Construction and Maintenance of Ships of Polish Naval Academy is working on further improvement of the method.

References

[1] Batko, W., Dąbrowski, Z., *Nowoczesne metody badania procesów wibroakustycznych*, Wydawnictwo i Zakład Poligrafii Instytutu Technologii Eksploatacji – PIB, Radom 2006.

[2] Bengtsson, M., *Condition Based Maintenance System Technology – Where is Development Heading?*, Euromaintenance 2004 – Proceedings of the 17th European Maintenance Congress, AMS (Spanish Maintenance Society), Barcelona, Spain 2004.

[3] Kennedy, R., *Examining the Processes of RCM and TPM*, The Plant Maintenance Resource Center, The Centre for TPM (Australasia), 2005.

[4] Klockars, T., Eykerman, A., Mayr, I., *Making the Most of Perfect Maintenance Timing, in Detail*, Wärtsilä Technical Journal, 01.2010, pp. 57-60, Finland 2010.

[5] Lus, T., *Vibro-Acoustic Methods in Marine Diesel Engines Diagnostics*, Journal of KONES Powertrain and Transport, Vol. 18, No. 3, pp. 203-210, 2011.

[6] Lus, T., *Tuning Method for High-Speed Marine Diesel Engine MB820 Type*, Journal of KONES Powertrain and Transport, Vol. 17, No. 2, pp. 277-284, 2010.

[7] Lus, T., *Marine High-Speed Reciprocating Internal Combustion Engines Investigations Using Envelope Vibration Method*, Journal of KONES Powertrain and Transport, Vol. 19, No. 3, pp. 263-269, 2012.
[8] Lus, T., Łutowicz, M., *Marine Diesel Engines Diagnostics*, Research Papers of Lithuanian University of Agriculture, Vol. 42, No. 2-3, p. 8, 2010.
[9] Lus, T., *Envelope Vibration Method in Diesel Engine Dynamic Tuning*, Explo-Diesel & Gas Turbine'01, Gdańsk – Międzyzdroje – Copenhagen 2001.
[10] Madej, H., *Diagnozowanie uszkodzeń mechanicznych w silnikach spalinowych maskowanych przez elektroniczne urządzenia sterujące*, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – PIB, Radom 2009.
[11] Łutowicz, M., *Analysis of Application of Chosen Methods for TDC Determination in Marine Diesel Engines*., Journal of KONES Powertrain and Transport, Vol. 16, No. 4, 2009.
[12] Polanowski, S., *Errors of Piston TDC Reference to Zero Points of Cylinder Pressure Derivatives of Marine Engines*, 27th International Scientific Conference on Combustion Engines KONES2000, Nałęczów Journal of KONES, Poland 2000.
[13] Polanowski, S., Lus, T., *Monitoring and Diagnostic Systems of Marine Diesel Engines*, 9th TC-10 IMECO Conference, Wrocław, Poland 1999.