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THE WOLA MARINE HIGH-SPEED DIESEL ENGINES DIAGNOSTICS USING VIBRO-ACOUSTIC METHODS

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Abstract

In the paper, some results achieved during the tests of high-speed marine diesel engine WOLA 57H6Aa type are presented. This type of engine is still broadly use on Polish Navy vessels and on some civilian ships built in Polish shipyards, mostly as auxiliary or emergency generator. Several types of engine malfunction had been simulated especially in fuel injection system and in valve gear mechanism. The malfunctions were connected with fuel valve opening pressure, intake and exhaust valves clearances. During the tests engine speed and load had been changed in tolerant operation range. The tests were devoted to prepare some new diagnostic methods, which could be used on these types of marine diesel engines. Diagnostic methods, which based on vibration and acoustic signals analysis are usually sensitive on engine load and speed changes. During the tests, different methods based on vibration and acoustic signals processing in frequency domain were used. Set of applications possible to use by B&K PULSE system together with acoustic and vibration sensors were applied to analyse of signals changing by different types of simulated malfunctions. Aim of the research was to check if the acoustic and vibration signals generated by the engine systems and components analysed by B&K PULSE system with CPB measurement give possibility to find such parameters, which are unequivocal, strongly connected with different object structure parameters, easy to asses and measure.

Keywords: *transport, maritime transport, combustion engines, vibro-acoustic diagnostics*

1. Introduction

Internal combustion reciprocating engines are the main source of propulsion of ships. They are also the most frequently use to drive electrical generators on ships. In the case of naval vessels with smaller displacement, these are mostly medium and high-speed diesel engines. One of the types of engines widely used on the Polish Navy warships is the engine WOLA type H. This engine occurs on boards a ships in "6 – in Line" and "12 – in Vee" cylinders configurations. Due to the age, level of technology and type these engines can be considered as little susceptible diagnostically. For this reason, an attempt was made to check one of the popular vibro-acoustic signal analysis methods - CPB analysis in comparison with RMS value - in terms of its use to diagnose technical condition of fuel system and valve gear mechanism of engines family WOLA type H.

2. Object of investigations and laboratory stand

Researches took place on Polish Naval Academy laboratory stand on the WOLA engine type 57H6Aa. The WOLA engine stand is equipped with two identical hydraulic brakes connected by shaft and reduction gear with the engine. Engine test stand with hydraulic brakes is shown in Fig. 1. During the tests 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 clearances, 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 tested engine WOLA type 57H6Aa are shown in Tab. 1.

Fig. 1. WOLA engine type 57H6Aa test stand with hydraulic brakes

Values of angle parameters given in Tab. 1 are specific for "static" measuring conditions [2-5]. That means that they are measured on stopped engine and at engine temperature equal about 20^{o}C. Aim of the research was to check if the acoustic and vibration signals generated by the engine systems and components analysed by B&K PULSE system with CPB measurement give possibility to find such parameters, which are unequivocal, strongly connected with different object structure parameters, easy to asses and measure.

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

Engine type	WOLA – Henschel 57H6Aa
Turbocharger type	WSK – Holset 4MD
No. of cylinders / Configuration	*i=6 / „ L"*
Nominal output at 1500 rpm	*Pn= 155 kW*
Cylinder bore	*D= 135 mm*
Piston stroke	*S= 155 mm*
Compression ratio	*ε= 1:14,0*
Total displacement volume	*Vss= 13.3 dm*^{3}
Mean piston speed	*cśr= 8.26 m/s*
Firing order	1-5-3-6-2-4
Effective specific fuel consumption	*ge= 231 g/kWh*
Number of valves per cylinder	*z= 4*
Fuel injection pressure	*pw= 19.4 MPa*
Angle of intake valve open	*45 ± 6 deg before TDC*
Angle of exhaust valve open	*45 ± 6 deg before BDC*
Angle of intake valve close	*45 ± 6 deg after BDC*
Angle of exhaust valve close	*45 ± 6 deg after TDC*
Angle of fuel valve open	*32-36 deg before TDC*
Inlet and exhaust valves clearances	*0.3 mm*

3. Method of investigations

In the tests Brüel & Kjær PULS system was used. For acoustic measurements additionally B&K 2250 analyser with microphone was used. This system is equipped with early fault detection tool called Constant Percentage Bandwidth (CPB) measurement. The main objective of the study was to verify whether this tool (CPB) could be used to detect defects of fuel and valve gear systems on WOLA type engines. The CPB measurement [B&K Vibro] has been developed specifically to provide early fault detection for the most common machine faults and is used in condition-based maintenance systems for reducing the life-cycle costs of many industrial machines. As yet there has never reported on the use of this CPB method in the diagnosis of internal combustion engines. The CPB is based on a constant relative bandwidth on a logarithmic scale – i.e. the bandwidth of each spectrum bar is a fixed percentage of the centre frequency, as shown in Fig. 2. This means the frequency resolution is relatively high at the lower frequencies and coarser at the higher frequencies, which is ideal for reliable, early fault detection. This method is often used in machinery monitoring systems with designated values of alarm limits – Fig. 3.

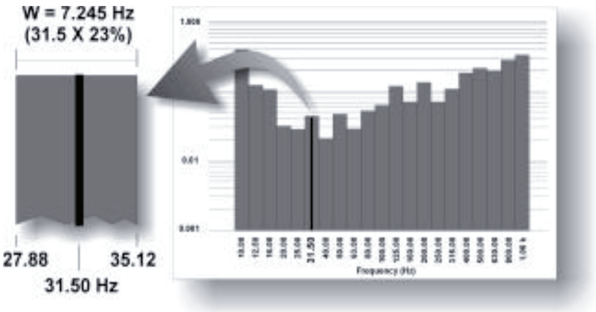

Fig. 2. A CPB23% measurement from 10 to 1000 Hz has 21 frequency bars. In this example each bar has a bandwidth that is 23% of the centre frequency[B&K Vibro]

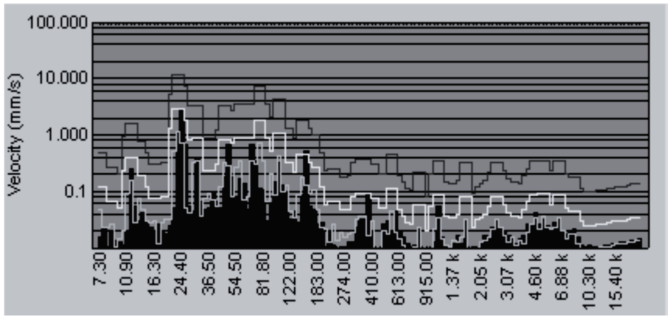

Fig. 3. CPB23% spectrum measurement with alarm limits [B&K Vibro]

During the tests, changes were made to the valve clearance and fuel injector opening pressure on one of the engine cylinders. Values of valve clearance were decrease and increased from 0.15mm, by 0.30 mm (nominal clearance value) to 0.60 mm. Similarly, around the nominal value (19.4 MPa) was changed the fuel injector opening pressure (12 MPa and 24 MPa) on one of the engine cylinders. During the study engine speed and load were also varied. During the measurements bandwidth of 6.4 kHz had been recorded, a sampling rate was 16.384 kHz. For the analysis restricted range of 1.6 kHz had been taken. At the measurement, in order to cut-off constant component, high-pass analog filter with a cut-off frequency of 0.7 Hz was enabled.

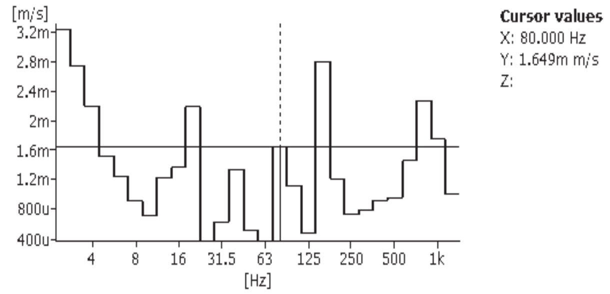

Fig. 4. An example of CPB measurement to 1 kHz 27 frequency bars – Wola engine vibration signal

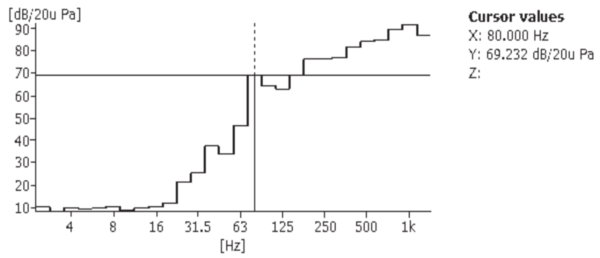

Fig. 5. An example of CPB measurement to 1 kHz 27 frequency bars – Wola engine acoustic signal

Examples of measured and analysed signals with CPB measurement are shown in Fig. 4 and 5. For further analysis and comparison with typical RMS (delta) value, for this same engine malfunctions, value of the chosen 1/3 octave band was taken. It was the band, which involved third harmonic from engine rpm connected with internal gas forces.

4. Results of investigations – valve gear mechanism – vibrations

Tab. 2. Results of RMS analysis for 1100 rpm and 10 kW

RMS for 1100 rpm and 10 kW $[m/s]^2$						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
3.23	1.49	3.72	1.29	2.93	1.52	Mean value

Tab. 3. Results of RMS analysis for 1500 rpm and 25 kW

RMS for 1500 rpm and 25 kW $[m/s]^2$						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
5.43	1.50	4.81	1.45	4.50	1.34	Mean value

Tab. 4. Results of RMS analysis for 1500 rpm and 100 kW

RMS for 1500 rpm and 100 kW $[m/s]^2$						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
5.87	1.89	6.05	1.75	5.52	1.81	Mean value

Tab. 5. Results of RMS analysis for idling engine

RMS for idling engine $[m/s]^2$						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.87	0.47	2.39	2.11	2.78	2.36	Mean value

Tab. 6. Results of CPB analysis for 1100 rpm and 10 kW

CPB for 1100 rpm and 10 kW [mm/s]						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.10	0.19	0.27	0.05	0.87	0.20	Mean value

Tab. 7. Results of CPB analysis for 1500 rpm and 25 kW

CPB for 1500 rpm and 25 kW [mm/s]						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.08	0.35	1.65	0.69	1.21	0.32	Mean value

Tab. 8. Results of CPB analysis for 1500 rpm and 100 kW

CPB for 1500 rpm and 100 kW [mm/s]						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.47	0.58	1.31	0.50	1.88	0.71	Mean value

Tab. 9. Results of CPB analysis for idling engine

CPB for idling engine [mm/s]						
Valve clearance 0.6 mm (to big)		Valve clearance 0.3 mm (nominal)		Valve clearance 0.15 mm (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
0.11	0.04	0.16	0.14	0.43	0.09	Mean value

5. Results of investigations – fuel injection system – vibrations

Tab. 10. Results of RMS analysis for 1100 rpm and 10 kW

RMS for 1100 rpm and 10 kW $[m/s]^2$						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
3.18	1.39	3.72	1.29	3.15	1.38	Mean value

Tab. 11. Results of RMS analysis for 1500 rpm and 25 kW

RMS for 1500 rpm and 25 kW $[m/s]^2$						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
4.59	1.36	4.81	1.45	6.24	2.02	Mean value

Tab. 12. Results of RMS analysis for 1500 rpm and 100 kW

RMS for 1500 rpm and 100 kW $[m/s]^2$						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
5.86	1.92	6.05	1.75	4.28	1.52	Mean value

Tab. 13. Results of RMS analysis for idling engine

RMS for idling engine $[m/s]^2$						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
2.45	1.26	2.39	2.11	2.70	1.80	Mean value

Tab. 14. Results of CPB analysis for 1100 rpm and 10 kW

CPB for 1100 rpm and 10 kW [mm/s]						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
0.60	0.17	0.27	0.05	0.99	0.33	Mean value

Tab. 15. Results of CPB analysis for 1500 rpm and 25 kW

CPB for 1500 rpm and 25 kW [mm/s]						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.65	0.83	1.65	0.69	1.21	0.37	Mean value

Tab. 16. Results of CPB analysis for 1500 rpm and 100 kW

CPB for 1500 rpm and 100 kW [mm/s]						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
1.17	0.39	1.31	0.50	1.78	0.95	Mean value

Tab. 17. Results of CPB analysis for idling engine

CPB for idling engine [mm/s]						
Fuel injection pressure 24 MPa (to big)		Fuel injection pressure 19.4 MPa (nominal)		Fuel injection pressure 12 MPa (to small)		
Cylinder head	Engine block	Cylinder head	Engine block	Cylinder head	Engine block	
0.18	0.11	0.16	0.14	0.61	0.13	Mean value

6. Results of investigations –fuel injection system – acoustic - chosen results

Tab. 18. Results of CPB analysis for 1500 rpm and 100 kW

CPB for 1500 rpm and 100 kW [dB/uPa]			
Fuel injection pressure 24 MPa (to big)	Fuel injection pressure 19.4 MPa (nominal)	Fuel injection pressure 12 MPa (to small)	
70.1	67.1	60.0	Mean value

Tab. 19. Results of CPB analysis for 1500 rpm and 25 kW

CPB for 1500 rpm and 100 kW [dB/uPa]			
Fuel injection pressure 24 MPa (to big)	Fuel injection pressure 19.4 MPa (nominal)	Fuel injection pressure 12 MPa (to small)	
67.6	69.2	62.6	Mean value

Tab. 20. Results of CPB analysis for 1100 rpm and 10 kW

CPB for 1100 rpm and 10 kW [dB/uPa]			
Fuel injection pressure 24 MPa (to big)	Fuel injection pressure 19.4 MPa (nominal)	Fuel injection pressure 12 MPa (to small)	
56.5	52.5	66.2	Mean value

Conclusions

From the diagnosis point of view, for this type of malfunctions, acceptable effects gives a accelerometer CPB measurements on the cylinder head and the measurement using a 1/3 octave band analysis (velocity) and 1/3 band value reading of which contains the 3-harmonic but only for idling and 1100 engine rpm. At higher speeds, the differences between the states of operational/faulty are ambiguous. Similarly, the ambiguous results are recorded on the engine block. What more, the ambiguous results are recorded during the acoustic measurements.

Presented signal processing CPB method could be effective for overall evaluation of the technical condition of WOLA high-speed marine diesel engines type H but only at specific engine load and speed conditions.

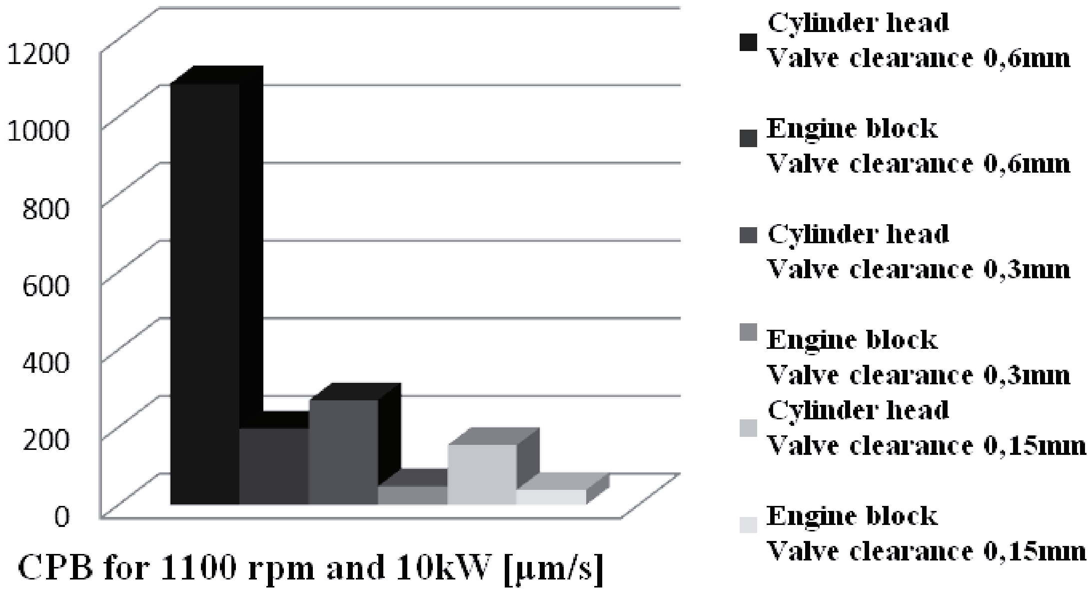

Fig. 6. An example of CPB measurement results – WOLA engine – valve gear - vibrations

The Institute for Construction and Maintenance of Ships of Polish Naval Academy is working on further improvement of other methods, which could be more effective in high-speed marine diesel engines diagnostics, especially when it concerns the indication of a damaged engine sub-system or component.

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