DIAGNOSTICS OF COURSE A WORK PROCESS IN CYLINDERS OF MARINE INTERNAL COMBUSTION ENGINES USING VIBRATION SIGNAL

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Summary

In this paper are presented a research results an applications of an acceleration vibration signals to diagnosis of the work cycle of medium-speed compression ignition engines. To take the problem was prompted a measuring errors a course of the cylinder pressures when the sensors is connected to indicator valves and the lack of these valves in some engines.

The investigations have been carried in operating conditions of the medium-speed marine diesel engines propelled a generator. In preliminary investigations for different fastenings of the acceleration vibrations sensor, an influence of relative load of the generating set on values of used diagnostic parameters was being checked. Receivers of electric energy or water resistor made the load variations of the internal combustion engine. The researches have been carried in time, amplitude and frequency domain.

In fundamental investigations an influence of the technical state on values of diagnostic parameters was tested as well and failures was localised. There have been selected the diagnostic symptom close connected at technical state and have been compared with other diagnostic symptoms.

Keywords: marine engines, work process, diagnostics.

DIAGNOZOWANIE PRZEBIEGU PROCESU ROBOCZEGO W CYLINDRACH OKRĘTOWYCH SILNIKÓW SPALINOWYCH Z WYKORZYSTANIEM SYGNAŁU DRGANIOWEGO

Streszczenie

W artykule przedstawiono metodę wykorzystania diagnostyki drganiowej do oceny obiegu w tłokowym silniku spalinowym o zapłonie samoczynnym. Do podjęcia problemu skłoniły błędy przy pomiarach przebiegu ciśnienia w cylindrach przy czujnikach mocowanych na zaworach indykatorowych oraz brak tych zaworów w niektórych silnikach.

Badania przeprowadzono w warunkach eksploatacji średnio-obrotowych okrętowym silników z zapłonem samoczynnym napędzających prądnice. W badaniach wstępnych dla różnych mocowań czujnika przyspieszeń drgań, sprawdzano wpływ obciążenia względnego zespołu prądotwórczego na wartości wykorzystywanych parametrów diagnostycznych. Zmiany obciążenia silnika spalinowego realizowano za pomocą załączania różnych statkowych odbiorników energii elektrycznej lub opornika wodnego. Badania prowadzono w dziedzinie czasu, amplitudy i częstotliwości.

W badaniach zasadniczych sprawdzano wpływ stanu technicznego na wartości parametrów diagnostycznych oraz lokalizowano uszkodzenia. Wyselekcjonowano symptomy diagnostyczne ściśle skorelowane ze stanem technicznym oraz porównano je z innymi symptomami diagnostycznymi.

Słowa kluczowe: silniki okrętowe, procesy robocze, diagnostyka.

1. INTRODUCTION

Course of in-cylinder pressure is the basic process of working in compression-ignition internal combustion engine. From the quality of this process depends on the operating effectiveness determined fuel consumption, efficiency and release of toxic exhaust constituents. This depends on the preparation of air-fuel mixture and the run of the combustion process. Both conditions show a need to develop effective methods to control the conduct of the original engine process, which is fuel combustion in the cylinder, and elaborating dynamic methods of estimation of that process.

Values of exhaust outlet temperatures from individual cylinders they are using for the

estimatation of the combustion process. Often approximation line changes of exhaust gas temperature is tilted only slightly when changing technical state, while due to injector failure conversion is undergoing burning down of piston top. Similarly difficult to identify are leaks of combustion chambers.

Diagnostics of the cylinder pressures course of marine engines uses their registration and analysis, but engine producers are not equipped with indicator valves. Pressure measurements in cylinders of engines equipped with indicator valves are affected by large errors, and indicator valves are often in the unfitness state. One of the ways acquisition diagnostic information is measurement of vibrations generated by internal combustion engine. Therefore some authors, as well as the author of this work, made an attempt to evaluate piston internal combustion engines with using vibration signals in various directions [1, 2, 3, 4], of crankshaft torsion vibrations [5], simultaneous measurement signals pressure in the combustion chamber and vibrations [1, 6] as well as vibration and noise [7]. They were carrying out tests on the research single-cylinder engines [1, 3], railway engines [1, 3] or marine engines [2, 8]. The analysis has been made in the domain of time, the amplitude, frequency, time-frequency or angle-frequency [9].

2. RESEARCH PROGRAMME

The internal combustion engine is the object of extortion under the influence of the internal and external input. One of the extortion internal forces is gaseous power from the combustion process in the cylinder, which was observed. Research included in the different types of medium-speed marine engines which drive generators, and this work mainly manufactured under licence companies isle of MAN B & W type 6 and 7L16 / 24. Technical data of inspected engines were following:

- number of strokes = 4,
- bore = 160 mm,
- stroke = 240 mm,
- rated engine speed = 1000 or 1200 rpm,
- maximum combustion pressure = 18 MPa,
- cylinder power = 88,9 or 90,8 kW.

These engines are not equipped with indicator valves, and have in the system of monitoring of the outlet exhaust temperatures [10]. Engines have been tested in exploitation conditions repeatedly, in different technical states: before the maintenance, after maintenance, before and after failure and during acceptance tests. Diagram of the measuring system is shown in figure 1.

The sampling frequency was 100 kHz and an analog and digital filtration was applied. During data acquisition process, the rotating speed of the engine was kept at a constant rpm. In figure 2 shows the in-cylinder pressure course and time course of vibration acceleration signal perceived on bolt of the coupling cylinder head 6AL20/24D engine equipped with indicator valves. The maximum combustion and impetus vibration accelerations from combustion process are appearing in the same time.

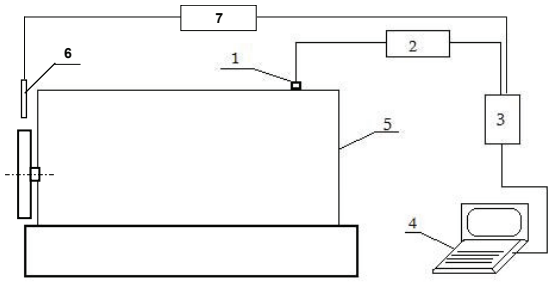


Fig. 1. Diagram of the measuring system: 1 – vibration acceleration sensor, 2 – preamplifier, 3 – terminal connection, 4 – portable computer, 5 – investigated internal combustion engine, 6 – location of the crankshaft sensor, 7 – power pack

3. RESULTS OF PRELIMINARY INVESTIGATIONS

For the selection of rational place of signals trapping have been used planning of the experiment, in which the influence of the direction and the place of fixing the sensor on the values of diagnostic parameters were applied. The cylinder head cover is fixed by 5 screws. In figure 3 summarises the impact of the 3 seats anchorages sensor on the value of the root-mean-square values of amplitudes accelerations vibration in one-third octave frequency bands. With the figure 3 shows that the most favourable fixing of sensor is on the screw no 1, as the values of the root-mean-square values of amplitudes in third octave frequency bands are highest. In preliminary investigations were also examined the influence of engine load on the values of the diagnostic symptoms, for 2 constant engine speeds.

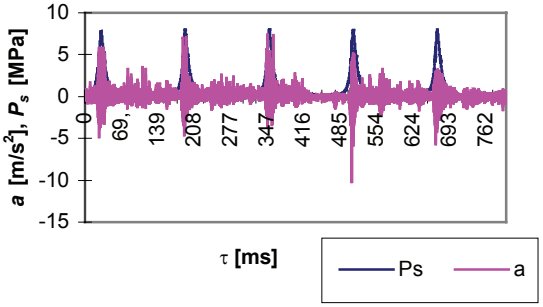


Fig. 2. Time courses: of accelerations vibration signal processed on the screw of the cylinder head and in-cylinder pressure of marine engine by the pressure sensor fastened on the indicator valve: a – acceleration vibration, P_s – in-cylinder pressure, τ – time

At work have tried to find a model between the course of the pressure in a combustion chamber and with course accelerations vibrations processed on the screw fixing the head. Such a model can be written in the form:

$$a = f(P_s) \tag{1}$$

Since values of the accelerations vibration signal represented the in-cylinder pressure course are matrices, it is possible to fill it with writing in the matrix form:

$$A(\tau) = \{a_1(\tau), a_2(\tau), \ldots, a_n(\tau)\} \tag{2}$$

$$P_s(\tau) = \{p_{s1}(\tau), p_{s2}\tau), \ldots, p_{sn}(\tau)\} \tag{3}$$

$$A = f(P_s) \tag{4}$$

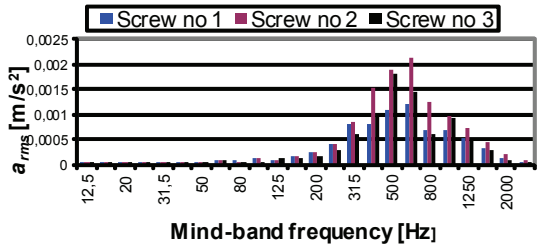


Fig. 3. Influence of the sensor location on root-mean-square values of amplitudes in third octave frequency bands

Signal analysis measuring was making in the time domain, the amplitude and the frequency, seeking frequency bands of analysis and diagnostic symptoms about the greatest usefulness. In figure 4 provides time course of accelerations vibration signal for one cylinder and of the position of the top dead centre of piston (TDC) processed by means of the photo-optical sensor. The time selection allowed distinguished pulses from the combustion process and functioning of the valves in the cylinder head. This way selected signals are characterized by a small level of interference and repeatability.

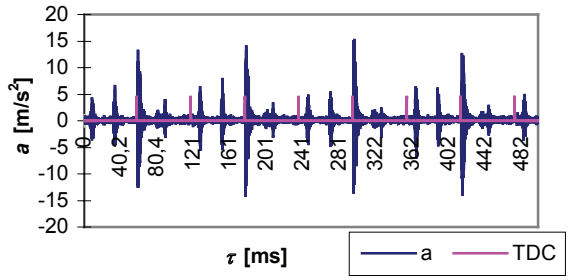


Fig. 4. Time course of acceleration vibration signal delivered on the screw fixing the cylinder head cover of medium-speed shipping engine 6L16/24 type do not have indicator valve together with the TDC positions

In figure 5 gives examples of the spectrum of signal accelerations vibrations, where there are growth amplitudes for frequencies proportionate to rotational of crankshaft.

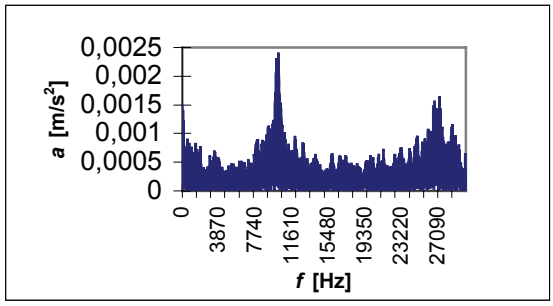


Fig. 5. Examples of the amplitude spectrum of accelerations vibration signal in the 0–30 000 Hz frequency band: rated engine speed 1200 rpm, f – frequency

Seeking useful methods of the signal analysis they used among others windowed time scope (fig. 6). Many temporary differing windows exist of baulk with one self with shape, from which every have been properties characteristic of oneself. You can see that the function of the window on scratches 6. Has maximum in the middle of the period and symmetrically is falling on both ends of the scope.

Was also applied a wavelet analysis in order to find a useful of signals processing. As a promising it was considered a decomposition of vibration signal using different digital low-pas and high-pas filters (fig. 7).

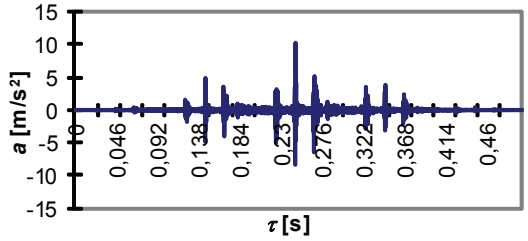


Fig. 6. Windowed time scope of acceleration vibration signal

4. EXAMPLES OF THE FUNDAMENTAL RESULTS OF INVESTIGATIONS

In fundamental examinations they were aspiring to the evaluation of the technical state of individual cylinders of inspected engines at with constant load. In figure 8 shows values amplitude estimates and exhaust outlet temperature from the individual cylinders. An important role to the dynamics of growth in the cylinder pressure, and consequently burden of piston-crank system, has the state of the injection – mainly of injector valve. Differences value of symptoms in the individual cylinders had been caused by the state of injection apparatus,

which also assessed using accelerations vibration signals.

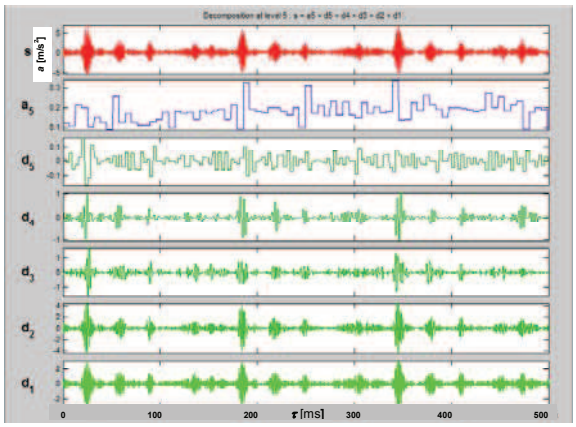
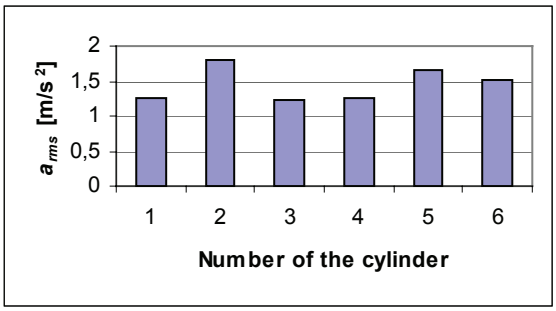


Fig. 7. Wavelet analysis of the accelerations vibration signal: s – registered basic signal, a_5 – low-pas filter, d_4–d_1 – high-pas filter

Were also made measurements accelerations vibrations of engine before the longer exclusion from the use during the shipyard maintenance (figure 9). In the cylinder no 1 was very small values of global measurement of accelerations vibration. After restart the engine was extensive failure in this basic subsystem: the cylinder head, valves, cylinder liner and the piston. Large resistances to motion of valves in the head and their collision with piston, which in these types of engines are often, have caused failure.

a)



b)

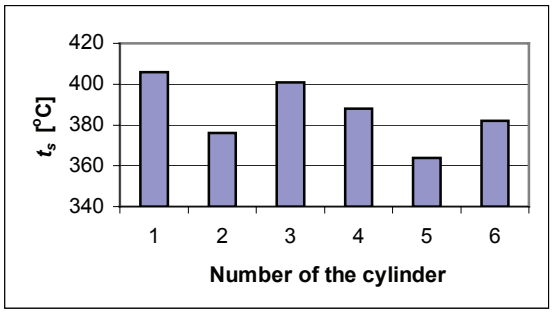


Fig. 8. The root-mean-square values accelerations vibrations a_{rms} (a) interdependent with the maximum combustion pressure in the individual cylinders and value of the exhaust outlet temperature t_s (b) for the individual cylinders

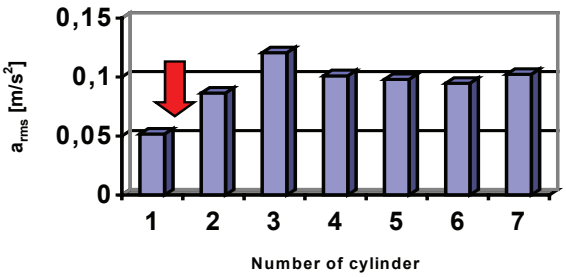


Fig. 9. Root-men-square values of accelerations vibrations signal by the sensor fastened on the cylinder head cover screws for 1–7 cylinders of 7L16/24 engine: ↓ – failed of piston-cylinder group after restart the engine

Between took valves and guides collect deposits, which increase the resistance significantly when the temperature node grating is low. Deposits are substances vibrations damping.

4. Conclusions

Experimental investigations carried out in the operating conditions have shown the possibility of working process diagnosis of marine combustion engines, which not equipped with indicator valves using signal accelerations vibration. Acceleration sensors well are attached to the pins clamping on the cylinder head or cylinder head cover with the thread.

Through the selection of the time course of the vibration signal a possibility of the identification of basic processes exists, as opening and closing of inlet and outlet valves, fuel injection and pressure course in the cylinder. Symptoms of accelerations vibrations signal shall contain information about the course of the combustion process, technical state of piston-cylinder group, valves in the cylinder head, injection apparatus, etc. The wavelet decomposition lets also allocate basic processes from the complex vibratory signal.

Further research will be reduced to choose the most useful diagnostic symptoms from among many in various domains.

References

[1] B. Czerycha, G. M. Szymański, F. Tomaszewski, *Odwzorowanie procesu spalania w sygnale drganiowym tłokowego silnika spalinowego o zapłonie samoczynnym*. Diagnostyka 2004 nr 1, pp. 123–124.

[2] T. Lus, *Diagnostics research of high-speed marine diesel engines using envelope vibration method*. Combustion Engines 2011 nr 3 (146), s. 83, cd. pp. 1–6.

[3] J. Merkisz, M. Waligórski, *Ocena diagnostyczna poprawności przebiegu procesu spalania w silnikach ZS w oparciu o wybrane*

metody analizy sygnału drganiowego. Combustion Engines 2009-SC2, pp. 275–284.

[4] B. Żółtowski, *Badanie struktury sygnału wibroakustycznego procesu spalania w silnikach tłokowych*. Silniki Spalinowe 1980 nr 2, pp. 17–19.

[5] P. Charles, J. K. Sinha, F. Gu, L. Lidstone, A. D. Ball, *Detecting the crankshaft torsional vibration of diesel for combustion related diagnosis*. J. Sound and Vibr. 2009, № 3–5, pp. 1171–1185.

[6] M. Flekiewicz, H. Madej, G. Wojnar, *Wykorzystanie selekcji przestrzenno-fazowej (kątowej) sygnału WA w diagnozowaniu złożenia tłok – cylinder silnika ZS*. Journal of KONES Powertrain and Transport 2007 Vol. 14, No 2, pp. 133–144.

[7] J. A. Drallmeier, W. Eversman, D. McAdams, *Indication of cylinder pressure rise rate by means of vibration and acoustic emissions of an internal combustion engine*. Missouri University of Science and Technology 2008, pp. 1–148.

[8] J. Monieta, P. Waleriańczyk, *Diagnozowanie przebiegu ciśnienia w komorach spalania okrętowych silników spalinowych z wykorzystaniem sygnału drganiowego*. Diagnostyka 2008 nr 2, pp. 157–163.

[9] H. Madej, B. Łazarz, G. Peruń, *Application of the wavelet transport in SI engine valve fault diagnostis*. Diagnostyka 2008 nr 4, s. 97–101.

[10] Power to the worl fleet. MAN B&W Diesel A/S. Reg. No. 39 66 13 14, Holeby, Denmark 2000.

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