EXPERIMENTAL METHOD OF EVALUATION OF DIAGNOSTIC VALUE OF THE ANGULAR SPEED DISCRETE SIGNAL FROM FREE END OF THE CRANKSHAFT

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Summary

The paper presents the method of the experimental way of finding the answer whether IAS (Instantaneous Angular Speed) of the crankshaft is carrying information about quality of combustion in cylinder of the diesel engine. The experiment was carried out at laboratory stand in Gdynia Maritime University, equipped with diesel engine Sulzer 3AL 25/30 driving the electro-generator. Sulzer 3AL 25/30 is three cylinder, medium speed, four stroke marine diesel engine, with maximum output 400 kW at 750 rpm. In order to evaluate of IAS utility for diagnosis of the engine, the healthy engine run was recorded and malfunction of engine's fuel system were simulated. The malfunction was fuel leakage from high pressure line and bad condition of the injector. The IAS was measured and recorded by perforated disc mounted at the shaft and photo-optic sensor.

Keywords: diagnostics, marine diesel engine, combustion control, angular speed variation.

EKSPERYMENTALNA METODA OCENY PRZYDATNOŚCI DIAGNOSTYCZNEJ DYSKRETNEGO SYGNAŁU PRĘDKOŚCI KĄTOWEJ Z WOLNEGO KOŃCA WAŁU KORBOWEGO

Streszczenie

W artykule zaprezentowano eksperymentalną metodę sprawdzenia czy chwilowa prędkość kątowa wału korbowego jest nośnikiem informacji o jakości procesu spalania w cylindrze silnika z zapłonem samoczynnym. Eksperyment przeprowadzono na stanowisku testowym w Akademii morskiej w Gdyni, wyposażonym w silnik wysokoprężny Sulzer Al. 25/30, napędzający prądnicę. Sulzer 3Al 25/30 jest trzycylindrowym, średnioobrotowym, czterosuwowym silnikiem o mocy maksymalnej 400 kW, pry prędkości obrotowej 750 obr./min. W celu oceny przydatności sygnału prędkości kątowej do celów diagnostycznych przeprowadzono pomiary na silniku w stanie wzorcowym bez usterek, a następnie powtórzono pomiary symulując usterki systemu paliwowego. Symulowane usterki to przeciek na pompie wtryskowej oraz zły stan techniczny wtryskiwacza. Do pomiarów prędkości Katowej zastosowano laserowy czujnik fotooptyczny.

1. INTRODUCTION

Marine Diesel Engines are widely used on board of vessels as a main propulsion and auxiliary engines, mostly diesel generators. Majority of them are low or medium speed engines, within revolutionary speed span from 90 up to 800 rpm (revolutions per minute). Due to importance of such mechanisms for ships operation and safety, and obvious fact that reparation on board is complicated and limited by sea state and limited spare parts supply, to ensure reliability of these engines is primary importance. Engine's condition monitoring helps predict and avoid failures of equipment.

Many malfunctions of diesel engines are related to the combustion process. The process can be disturbed because of wrong function of subsystem such as valves and camshaft, injection system (high pressure pumps and injectors), turbocharger, or piston and cylinder liner wear. The in-cylinder pressure contains many data about the combustion process. However, direct measurement of in-cylinder gas pressure is impractical and quite expensive. For every cylinder installation of a transducer is necessary, but these tend to have limited lifetime due to exposure at high temperature and pollutants.

Analysis of the crankshaft instantaneous angular speed (IAS) variation has been in focus of attention for several years. Convenience of that method is non-invasive measurement and relatively easy mounting of measurement system elements. According to some authors, analysis of the lowest harmonics can even point the faulty cylinder, other methods are focused on indicated torque.

This work is dedicated to validation of IAS measurement as a diagnostic information source. As an object of experiment was selected 3-cylinder engine driving an electro- generator. The implemented measuring method uses photo-optic sensor emitting with high frequency a laser beam received by photodiode. The system counts number of signals passing through slots of perforated disc, mounted at free end of a crankshaft. In order to preliminary predict the engine behaviour under condition of different malfunction, the simplified dynamic model of the crankshaft rotation has been elaborated. Results of healthy engines run were a backup of model's correction.

As the method of evaluation of the IAS utility, has been undertaken comparison of records done under different but known malfunctions of fuel system with the model and subsequent approach to identification of source of troubles. Simulated malfunction was a leakage from injection pump. The value of leak was adjusted proportionally to of on-line measured pressure of fuel in injector pipe.

2. THE CHARACTERISTICS OF THE ENGINE AND TEST RIG

The experiment was carried out at the test bed with the electro – generator driven by the engine Sulzer AL 25/30. Short description of the engine and test equipment is presented below.

2.1. Description of the engine

The main engine particulars are reported in Tab.1. It is turbocharged medium speed diesel engine designed by Sulzer. This 3- cylinder in row engine develops 408 kW at rotational speed of 750 rpm. The engine drives alternate current generator, connected to the main electric board. The load of the engine can be fluently adjusted by changing of the load of generator. The high pressure fuel system has three injection pumps, one for each cylinder. General view of the engine is presented in Phot.1.

Tab.1. Engine technical particulars

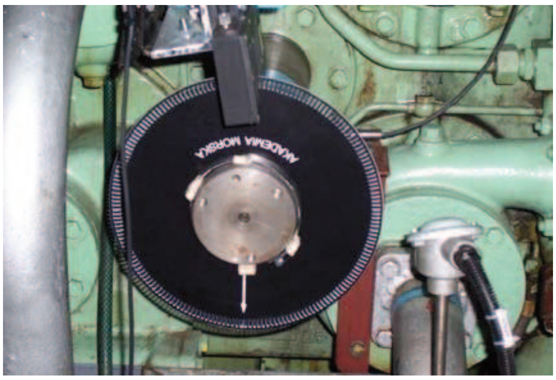
Manufacturer	HCP Cegielski/Sulzer
Type	3 AL 25/30
Rated power (kW)	408
Cylinder number	3
Cylinder swap capacity (cm^3)	4922
Rotational speed (rpm)	750
Compression ratio	13:1

Phot. 1. General view of the Sulzer 3 AL 25/30

2.2. Experimental rig description

The crankshaft angular speed variations were measured at the crankshaft free end. Measurements were carried out at different loads, i.e. 150, 200, 250 kW and idle run. IAS measurement was conducted under every load in healthy condition and with implemented malfunction of significant leakage of injection pump and with installed out of order injector. Simultaneously was recorded in-cylinder pressure of each cylinder using Diesel Engine Tester UNITEST 2008. This system is permanent equipment of the laboratory test bed and enables measurement of in-cylinder pressure and high pressure fuel pipe pressure in every cylinder in the same time.

For measurement of angular speed variation was used laser photo optical system ETNP-10 produced by ENAMOR Ltd. Gdynia. The system originally dedicated for torque measurement at ship's propulsion shaft, consist of laser sensor which emits laser beam with frequency of 16 MHz, and calculating module based on signal converter and programmable logic controller PLC SAIA. The speed variation signal transmitter is a perforated disc with proportional slots and teeth at disc's circumference. Number of impulses going through the slot or "blind" due to tooth, depends on instantaneous angular speed. The picture of the disc and the sensor is presented in Phot. 2.



Phot. 2. Measurement disc and laser sensor mounted at crankshaft free end

3. RESULTS OF EXPERIMENT

The aim of the experiment was to find the answer whether disturbances of combustion process caused by malfunction of high pressure fuel system and injector, would be reflected by the angular speed of the crankshaft. For diagnostic purposes, necessary is to obtain three objectives: detection of malfunction, localisation of malfunction, evaluation of severity of malfunction. Answers for all above questions shall come from one source – angular speed deviation analysis.

Results of the experiment are presented in parts according to introduced malfunction.

3.1. Running with leak from the injection pump of 2nd cylinder

The introduced malfunction was the leakage from injection pump number 2. The level of leakage was adjusted basing on observation of high pressure fuel decreasing, at UNITEST display, and was established at 30% max. pressure down. The angular speed is presented as "instant-to-mean" ratio. Very important factor for further detecting and identification of malfunctions is the shape and the magnitude of difference value of compared runs' waveforms.

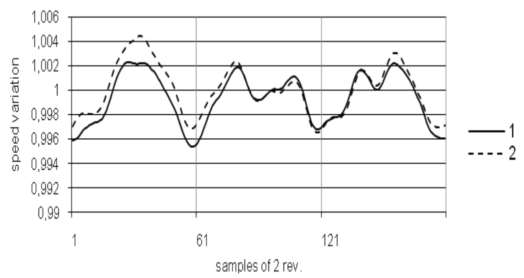


Fig. 1. Angular speed variations of healthy engine (1) and fuel leakage (2), load 250 kW

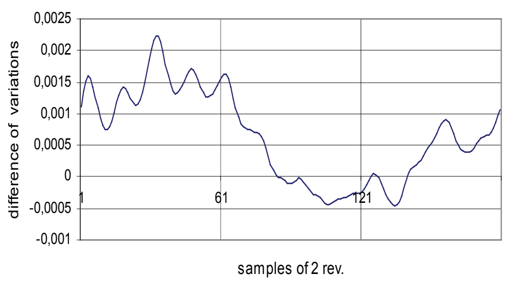


Fig. 2. Angular speed variations difference between healthy engine and fuel leakage, load 250 kW

3.2 Running with low injector pressure in 2nd cylinder

In order to get records of impact of an injector malfunction, specially prepared injector with lowered injection pressure from 250 to 150 bar was installed in 2nd cylinder's head. The engine was working at load of 250 kW. Simultaneously with angular speed recording, in-cylinder pressure and injection pressure were measured. The waveform of disturbed combustion in comparison with healthy one is presented in Fig.3.

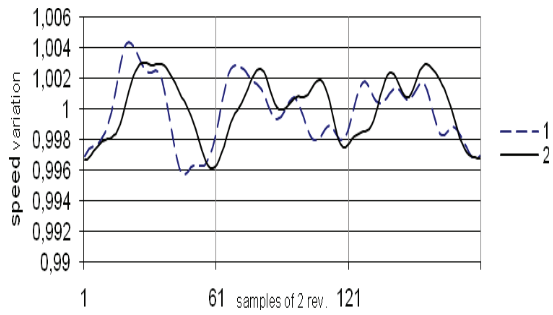


Fig.3. Comparison of healthy engine (1)and low injection pressure (2),load 250 kW

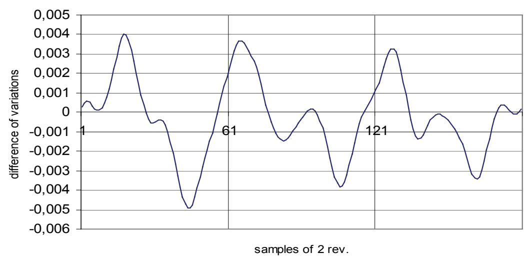


Fig.4. Angular speed variations difference between healthy engine and low injection pressure , load 250 kW

3.3 RUNNING WITH ENLARGED INJECTOR'S NOZZLE HOLES IN 2nd CYLINDER

In order to simulate above malfunction, special injector with enlarged holes of the injector nozzle was prepared. That situation can occur due to unprofessional repair of the injector and results with deviations of injection pressure and change of fuel spray drops. Results of measurement are presented in Fig.6. and 7.

4. MODELLING OF THE CRANKSHAFT SPEED VARIATIONS

The crankshaft was modelled as a simple system balanced dynamically. As the engine is large and masses of pistons and connection roads cannot be omitted, a model with flexible crankshaft has been developed. It takes under consideration the torsional vibrations creating twisting of main journals of the crankshaft. The torsional vibrations creating torsional twisting of main journals of the crankshaft.

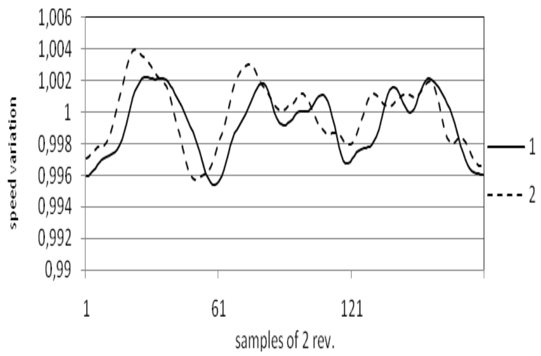


Fig. 5. Comparison of healthy engine (1) and enlarged injector nozzle holes (2),load 250 kW

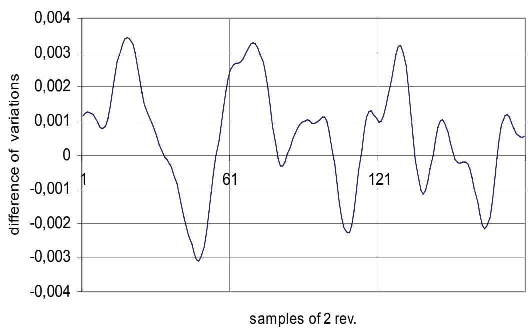


Fig. 6. Angular speed variations difference between healthy engine and enlarged injector nozzle holes, load 250 kW

The torsional vibrations were superimposed with the rotational motion of the rigid crankshaft. In-cylinder pressure consists of two elements, the combustion pressure and compression pressure. For modelling purposes, the results of in-cylinder pressure records of the run of healthy engine at 250 kW load, were taken as the basis.Inertia forces were calculated basing on masses and dimensions of crankshaft-connecting rod-piston system.

Finally the theoretical waveform of crankshaft angular speed oscillation was elaborated, and compared with results of healthy engine measurement (Fig. 7).

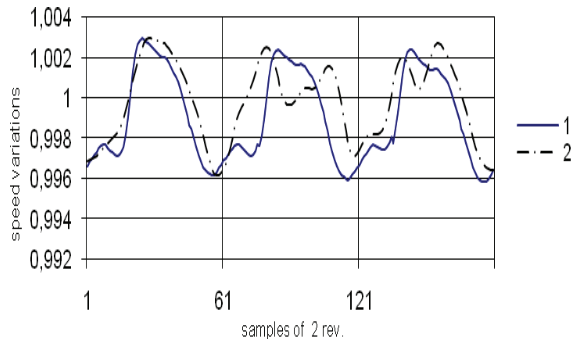


Fig. 7. Comparison of calculated (1) and measured (2) waveforms of speed variations

5. DETECTION OF MALFUNCTION PRESENCE, SOURCE AND MARKING OF THE AFFECTED CYLINDER

Analysis of healthy and disturbed waveforms of IAS leads to the conclusion that simple comparison of waveforms is not sufficient for definition of the malfunction. Better picture of disturbances is given by comparison of waveforms presenting difference between angular speed of healthy and faulty condition, at the same load value [6]. Analysis of tendencies and magnitudes can give the information about malfunction presence and its character. Samples of measured angular speed differences between: two healthy, healthy - leakage fault, and healthy – plugged injector are presented at Fig. 8. and Fig. 9.

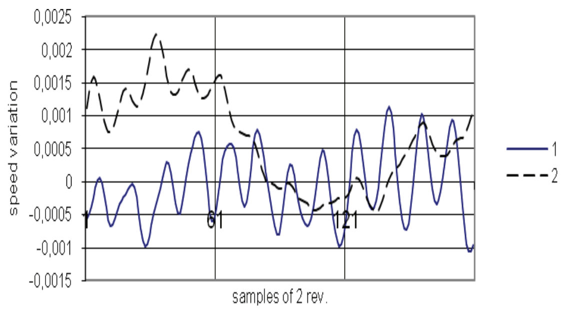


Fig. 8. Angular speed variation difference comparison: two runs healthy engine (1;) healthy and fault of fuel leaking (2), domain of samples of 2rev., 250 kW

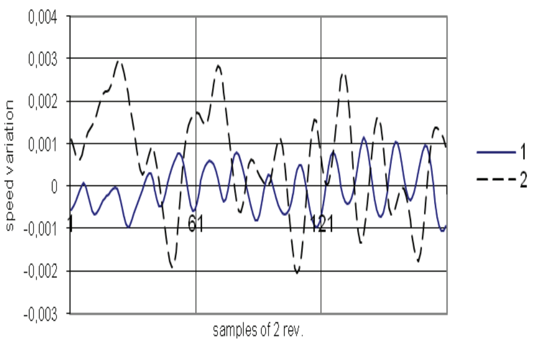


Fig. 9. Angular speed variation difference comparison: two runs healthy engine (1;) healthy and fault of plugged injector (2), domain of samples of 2rev., 250 kW

Occurring of the malfunction is shown due to magnitude amplification. Detection of faulty cylinder in the case of fuel leaking can be done in the way of span analysing, between maximum and minimum value of variation's difference, in every interval (240^0) between TDC's of the work stroke of each cylinder (Fig. 8). In the case of partly plugged injector, simple analysis of amplitude span is insufficient (Fig. 9).

6. CONCLUSION

The results of conducted experiment showed that malfunctions of fuel system were the source of angular speed deviations. The level of deviations is strong enough to be detected by photo-optical measurement system. The signal obtained from the perforated disc after decomposing of noise, is a base for diagnostic analysis focused on identification and definition of reason of faulty condition. The way to receive diagnostic information is comparison of healthy and faulty condition IAS waveforms. The conclusion coming from above is that for detection and localisation of malfunction, necessary is having template measurements of a healthy engine. From diagnostic practice is known that collecting of healthy engine data can be difficult, especially for engines being in permanent exploitation. To avoid that inconvenient limitation, a template in a form of healthy engine measurements shall be replaced by very accurate mathematical dynamic model of a crankshaft movement. Construction of such model should enable easy adjustment to any type of diesel engine by setting changeable factors related to certain technical parameters of an engine.

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Adam CHARCHALIS, born in 1944 in Przemyśl. In 1968 he accomplished engineering course in Polish Navy University and subsequently followed master studies in Gdansk University of Technology, in Faculty of Shipbuilding. Finally graduated to Msc. Eng. in 1971. In years 1968 - 1971 was appointed as a chief engineer on board a mine sweeper ORP „Krogulec". Since 1971 had been working in Polish Navy Academy. In 1979 was appointed in substitution as a Commander of Institute of Ships Construction and Propulsion. From 1990 to 2003 was performing the duty of Institute Commander. From 1994 to 2003 was appointed as a Dean of Mechanical -Electrical Faculty of Polish Navy Academy. Since 1999 has been a professor in Maritime Academy in Gdynia. Promoted to Phd. of Engineering in 1978, professor since 1994. Zone of scientific interest is Marine Propulsion, Marine Power Plants, Gas Turbine Propulsion and Diagnostics of Marine Mechanisms.. Author of 3 monographs, 8 handbooks and more than 250 articles.

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