EVALUATION OF DIAGNOSTIC INFORMATION ABOUT MARINE ENGINE WORK BASED ON MESUREMENT OF THE ANGULAR SPEED DISCRETE VALUE

Mirosław Dereszewski, Adam Charchalis, Stanislaw Polanowski

Gdynia Maritime University, Mechanical Faculty
Morska Street 83, 81-225 Gdynia, Poland
tel.: +48 58 6901398, +48 58 6901347, +48 58 6901480
e-mail: deresz1@o2.pl, achar@am.gdynia.pl, stpolanowski@gmail.com

Abstract

The paper presents results of the experiment, aimed on finding the answer whether IAS (Instantaneous Angular Speed) and angular acceleration 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 electro-generator. Sulzer 3AL 25/30 is three cylinder, medium speed, four stroke marine diesel engine, with maximum output 408 kW at 750 rpm. In order to evaluate of IAS utility for diagnosis of the engine, two kinds of malfunctions of engine's fuel system were simulated. First malfunction was fuel leakage from high-pressure line; the second was partly plugged injector's nozzle. Construction of high-pressure fuel pump enables to simulate fuel leakage. The level of leakage was controlled by simultaneous measurement of pressure in the high-pressure tube. For simulation of injector malfunction, the chocked one was installed in second cylinder. The engine was running at different loads, starting from around 25% up to 70% of nominal. The IAS was measured and recorded by the measurement system ETNP-10, which mode of operation was based on perforated disc mounted at the shaft and photo-optic sensor counting laser impulses. Results of all measurement were smoothed in order to eliminate a noise. Measurement results of fault condition were compared with healthy engine measurements and with results of in-cylinder pressure diagrams, in order to detect all deviation from normal condition.

Keywords*: diagnostics, marine diesel engine, angular speed, photo optical signal, failure simulation*

1. Introduction

Marine Diesel Engines are widely used on board of vessels as a main propulsion and auxiliary engines, e.g. 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 by rough 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 functioning of subsystem such as valves and a camshaft, an injection system (high-pressure pumps and injectors), a 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 [8]. 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 [1]. 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 [2].

This work is dedicated to validation of IAS discrete measurement as a diagnostic information source. As an object of experiment was selected 3-cylinder engine driving a 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.

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 healthy engine and subsequent approach to identification of source of troubles. Simulated malfunctions were leakage from injection pump and partly plugged injector nozzle. The value of leak was adjusted proportionally to of on-line measured pressure of fuel in the injector pipe.

2. The characteristics of the engine and test rig

The experiment was fully carried out at the test bed in Mechanical Faculty Engine Laboratory. 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 electro generator GD8-500-50, 500kVA, connected to the main electric board. The load of the engine can be fluently adjusted by changing of the load of generator (adjustable resistor). The high-pressure fuel system has three injection pumps, one for each cylinder. General view of the engine is presented in Fig. 1.

Tab. 1. Engine technical particulars

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

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

2.2. Experimental rig description

The rig for carrying out the experiment consist of instantaneous angular speed measurement set and record and in-cylinder pressure measurement equipment.

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 different loads, in healthy condition, with implemented malfunction of small and significant leakage of injection pump and partly plugged injector. The level of fuel leakage was set up observing the picture of decreasing of high-pressure value at UNITEST 2008 screen (Fig. 2).

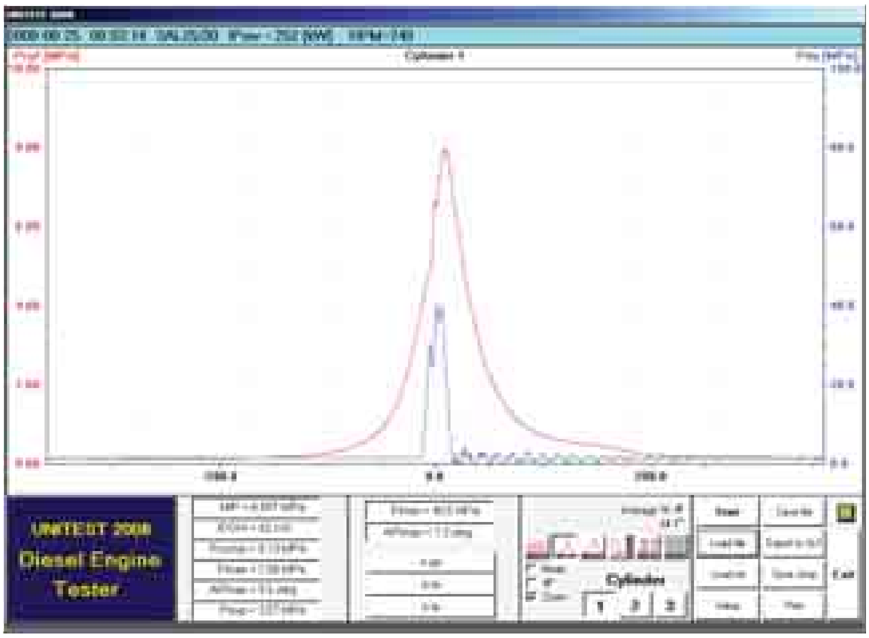

Fig. 2. Window of Diesel Engine Tester with in-cylinder and injector pipe pressure picture

Simultaneously was recorded in-cylinder pressure of each cylinder using Diesel Engine Tester UNITEST 2008. This system is the 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. Fig. 3 presents a sample of in-cylinder pressure value of 3-cylinders in firing sequence.

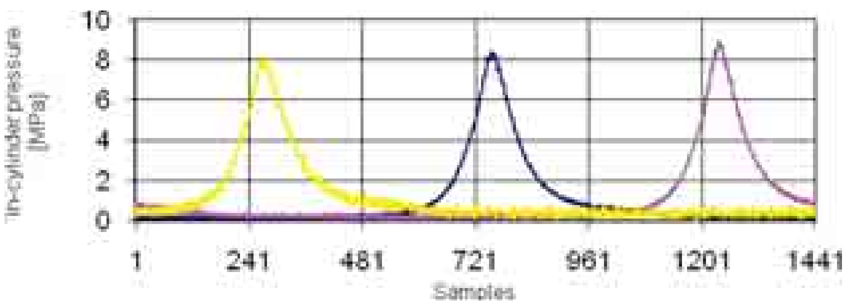

Fig. 3. In-cylinder pressure in domain of crankshaft angle (sampling interval 0.5^0)

For measurement of the angular speed variation was used the 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 the laser sensor, which emits laser beam with frequency of 16MHz, and the calculating module based on signal converter and the programmable logic controller PLC PCD3 SAIA.

Fig. 3. Calculating module ETNP-10 with PLC SAIA

The crankshaft angular speed variation signal transmitter is the perforated disc with 180 proportional slots and 180 teeth, at the 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 Fig. 4.

Fig. 4. 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 elements, was reflected by angular speed of the crankshaft. For diagnostic purposes, necessary is to distinguish three basic information: if detection of malfunction is possible, if localisation of malfunction is possible and if evaluation of severity of malfunction is possible. 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, at several engine loads.

3.1. Running healthy engine

Results of IAS measurement when the healthy engine was working, are presented below.

The measurements of healthy engine IAS at different loads were done in order to get a template picture, for further comparison with records done in malfunction conditions. It is assumed that ambient conditions have an impact at combustion process, then is necessary to determine the level of deviations between angular speed waveforms shape recorded during separate starts of the engine with time intervals. Figures below present comparison of 3-separate, independent records of IAS waveforms of healthy engine working at load 250 kW. 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. 6 presents comparison of two template runs of healthy engines at load of 250 kW. The maximum observed deviation is ± 0.1% of angular speed mean value.

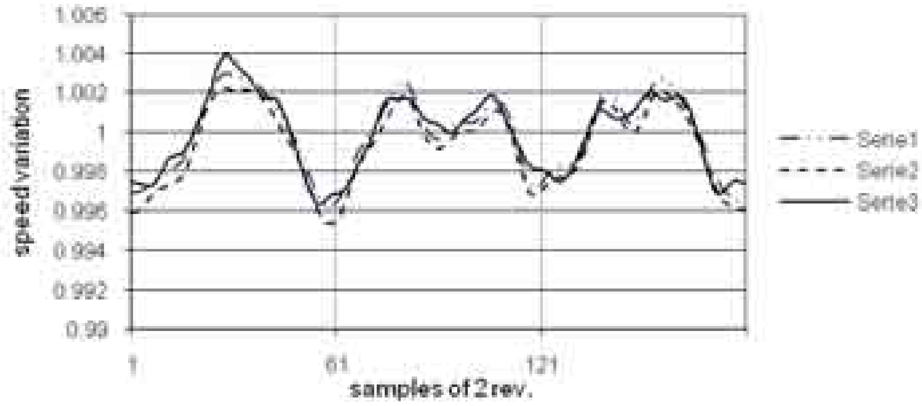

Fig. 5 Waveforms of angular speed variation of 3 runs, healthy engine, load 250 kW

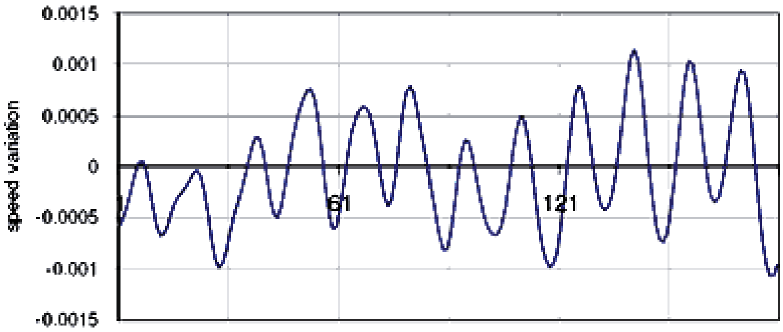

Fig. 6. Difference between angular speed variations of two healthy states in domain of samples, load 250 kW

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

First 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.

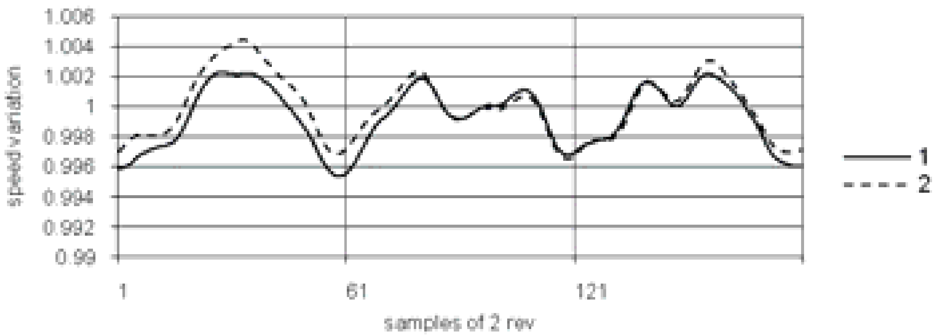

Fig. 7. Angular speed variations of healthy engine (1) and fuel leakage (2), load 250 kW

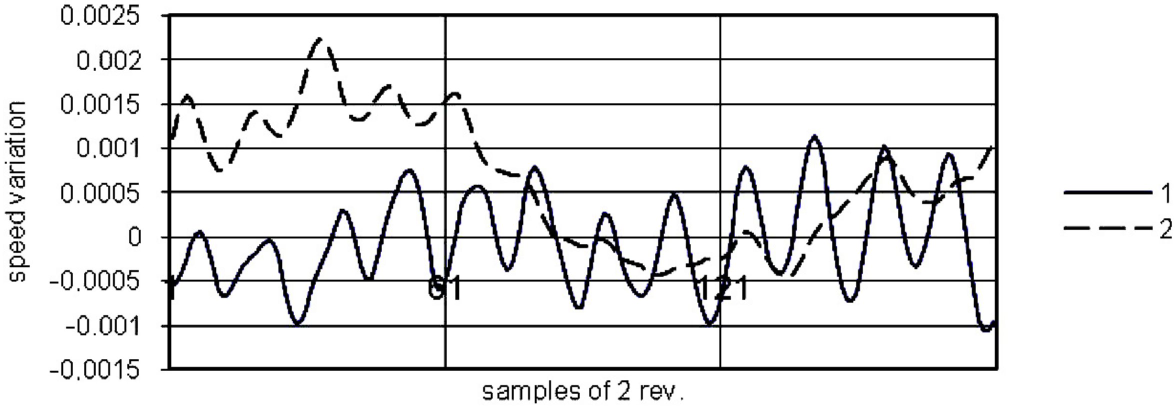

Fig. 8. Angular speed variations of healthy engine (1) and fuel leakage (2), load 150 kW

3.3. Running with partly plugged injector nozzle in 2nd cylinder

In order to get records of impact of an injector malfunction, specially prepared injector with plugged 30% of nozzle openings was installed in 2nd cylinder's head. The engine was working at different loads. 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. 9.

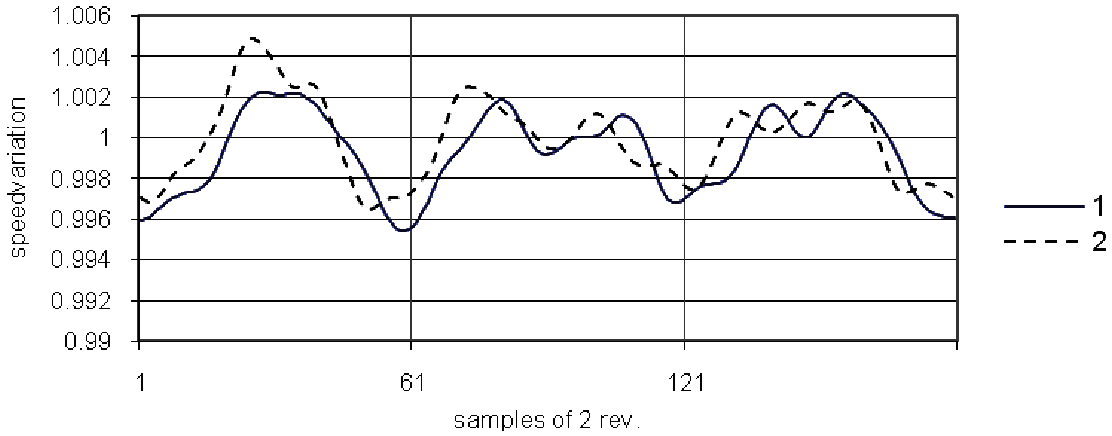

Fig. 9. Comparison of healthy engine (1)and partly plugged injector's nozzle (2),load 250 kW

4. Detection of malfunction presence, source and marking of affected cylinder

After analysis of healthy and disturbed waveforms of IAS, became obvious that simple comparison is not sufficient for definition of the malfunction. Better picture of disturbances is given by comparison of waveforms presenting angular speed difference between 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. 10. and Fig. 11.

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 (240º) between TDC's of the work stroke of each cylinder (Fig. 10). In the case of partly plugged injector, simple analysis of amplitude span is insufficient (Fig. 11).

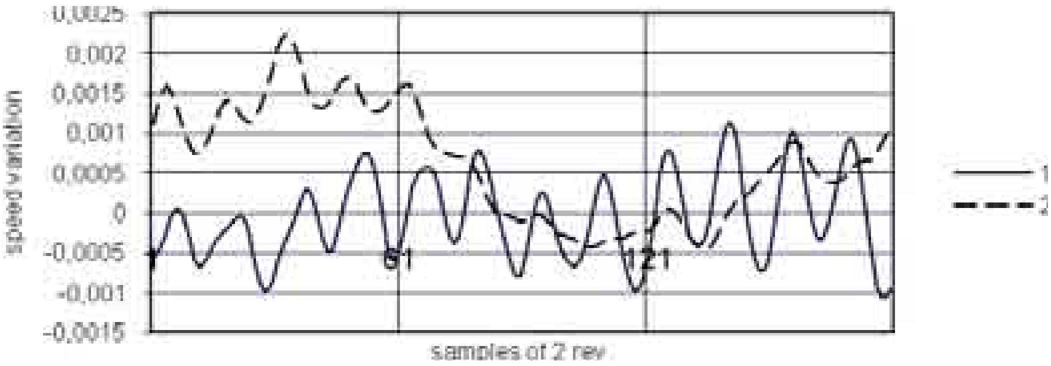

Fig. 10. Angular speed variation difference comparison: two runs healthy engine (1;) healthy and fault of fuel leaking (2), domain of samples of 2rev.,250 kW

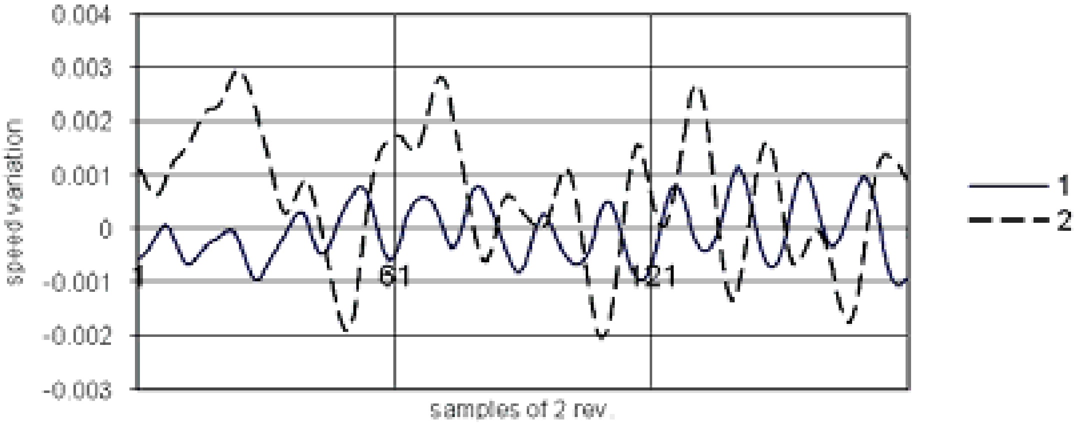

Fig. 11. Angular speed variation difference comparison: two runs healthy engine (1) healthy and fault of plugged injector (2), domain of samples of 2rev. 250 kW

5. 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 a 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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