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FAULT DIAGNOSTICS OF THE FUEL INJECTION SYSTEM OF A MEDIUM POWER MARITIME DIESEL ENGINE WITH APPLICATION OF ACOUSTIC SIGNAL

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The possibilities of application of a portable system for registration of the acoustic signal in the frequency range of 1000–10000 Hz for diagnosing common faults of the fuel injection system of the maritime diesel engine are presented. Clear differences in the registered waveforms are occurring when the records of the working fuel injector are compared with the other ones recorded in the injector with blocked nozzle orifice and when insufficient amount of fuel is delivered. Signal signatures of the operating fuel pump at three operating conditions are also presented. A procedure of comparing the acoustic signals registered on the stub of similar faulty and good engine elements is recommended by the authors as efficient and easy for application.

Key words: Diesel engine fault diagnostics, vibration analysis, marine accidents.

1. Introduction

Diesel motors operating as a propulsion engines of minor maritime vessels (e.g. fishing boats, yachts, barges etc.) make a serious diagnostic problems, especially at monitoring the combustion process or testing the fuel injection system. A similar situation is occurring during exploitation of prime mover engines of electric power generators where the stub pipes to register pressure traces from the engine cylinders are not built–in. The authors' impressions are that ship owners pay now increasing attention to the problem of fault diagnostics described above. There are two reasons for the need of establishing the fault detection systems in naval machinery. The first one is related to economical losses caused by the machinery breakdown, especially when the vessel operates in a remote region, but also an important matter is to keep the crew out of danger of marine accidents.

European Agency for Safety and Health of Work [1] has issued a guide for European fishing boats shippers focused on safety and health prevention. The data submitted in the guide estimate the number of death accidents among fishermen worldwide to 24,000 per year and also thousands of other events are leading to serious injuries and illnesses. Machinery failure remains one of the significant categories of the accidents. Passenger ferry transportation also suffers from lack of the proper machinery diagnostics. The modern ferryboats are designed to navigate in any weather conditions. Down-time and breaking of operation for a ferry implies losses of thousands of US$ a day. Also lowering of combustion effectiveness causes reasonable costs when larger propulsion engine consumes 10–20 tons of fuel per day. International Maritime Organisation and government regulations are introducing the need of reduction of the amount of polluting gases produced by the marine engines. Appendix VI to the international pollution convention, MARPOL, issued in January, 2000, obliges all the ship owners to reduce the NO_x and SO_x in combustion products of newly introduced diesel engines, what also implies the need of engine fault diagnosis development.

For the purpose of vibration and acoustic emission measurements, a diesel engine can be classified as the “reciprocating machinery having both rotating and reciprocating parts” [2]. Problems of diagnostics of such machines are caused by the fact that numerous sources of acoustic signals are operating simultaneously in them. The major signal sources in engines in-service are [3]: combustion and piston slapping, clashing of the valves, operation of the fuel injectors. The low frequency vibroacoustic signal alone (unfortunately propagating between the neighbouring engines) is too complex to perform the effective fault diagnostics. Some authors propose to combine three diagnostic signals: cylinder pressures, low frequency vibration and high frequency acoustic emission into an ensemble to construct more reliable fault diagnostic procedures [4]. Proper methods of processing the ensembles mentioned above are not completed yet as a final solution. The authors of this paper have performed the research to find out if the acoustic signal registered in optimal frequency range (i.e.: 1000–10000 Hz) can be used for diagnosing common faults of the fuel injection system of the maritime diesel engine.

2. Experimental details

The following common methods are now in use in diagnostics of diesel fuel injection systems: aural and visual inspection, cylinder temperature measurements, cylinder pressure monitoring and conventional vibration analysis – including registering the occurrence of fault signatures in the frequency range of 25–10000 Hz [5]. The latter method was chosen by the authors of the paper to make the experimental work, however the analysed frequency range was modified to suppress the low frequency components generated by the crank vibrations and combustion pulses. The object of examination was a 6-cylinder 3960 kW four-stroke medium speed Wartsila diesel engine presented in Fig. 1. A custom–made portable signal monitoring equipment has been used. The equipment consisted of:

- a Brüel and Kjær broadband accelerometer of type 4371 and sensivity of 0.8 mV/m s^{-2},
- bandpass filter and amplifier operating in frequency range of 1–10 kHz,
- low – noise two-channel external USB soundcart of type Soundblaster 24 bit Live,
- a laptop to register the signals in the form of audio-records sampled at 44.1 kHz.

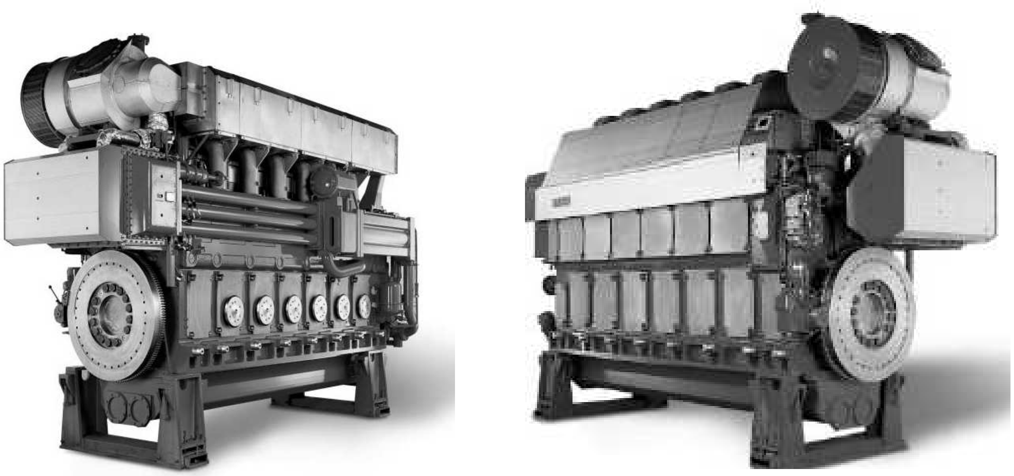

Fig. 1. A 3960 kW four-stroke medium speed Wartsila SW 380 diesel engine used in the investigation.

The bandpass filter and amplifier was equipped with a RMS converter. Measured signals were registered after conversion to the RMS value in a form of a signal envelope. The waveforms shown in the paper are presented under a system voltage gain set to 26 dB (20 X). Acoustic signal was registered in two locations: on the stub outlet of the injection pump (A) for monitoring the signals generated by the pump and on the stub inlet to the injector (B) for monitoring the signals generated by the operating injector. Placement of the acoustic sensor is shown in Fig. 2.

The acoustic waveforms of the registered signals presented below and stored in location A and location B are different, what is a proof that a sensor placed in location A registers the signatures of the operating fuel pump and that placed in location B registers the signatures of the working injector.

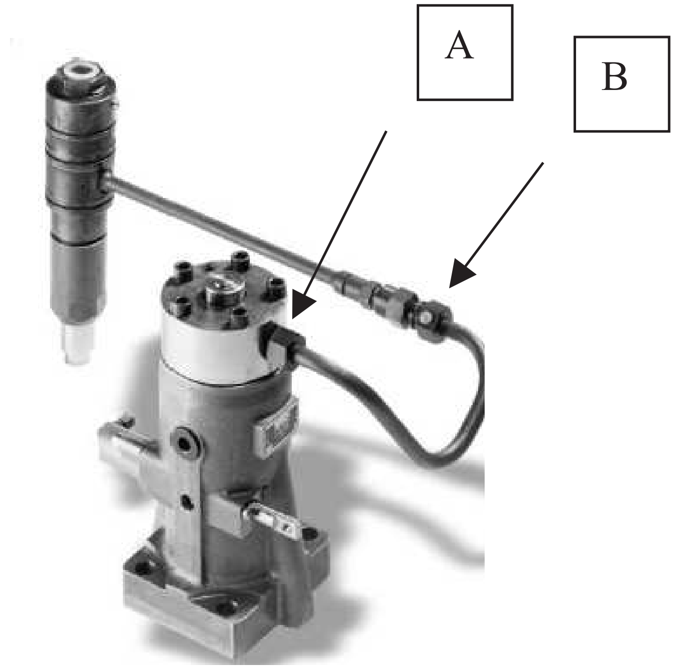

Fig. 2. Placement of the acoustic sensor for monitoring the signals generated by the fuel pump (A) and the injector (B).

3. Experimental results

A fault was recognised in one injector of the tested engine. The nozzle orifice of the injector was blocked with products of fuel combustion – the obstruction exceeded 50% of the orifice area. This fault had no effect on the operation of the entire engine because its governor section would attempt to increase the fuel supply to the remaining cylinders in order to produce the same amount of power. That procedure disadvantageously rises the overall engine fuel consumption. A pressure trace from the faulty cylinder demonstrates the pressure pulse delayed in time domain when compared to the trace registered in the healthy one (vide Fig. 3).

Figures 4 and 5 present the comparison of the acoustic signals registered on the stub inlet to the injector working correctly and on the injector affected with the fault described above. Two sets of a burst consisting of three distinct pulses are visible in Fig. 4. They represent four revolutions of the crank, i.e. two complete combustion cycles. The authors of the paper have made identification of the crank angular position using the method of inserting an optical marker on the shaft surface. These tests have revealed that the first two pulses are caused by inlet and exhaust valve closing operations. The last pulse arises during fuel injection and combustion. The latter pulse (generated during fuel injection and combustion) is missing in Fig. 5. The average signal RMS level

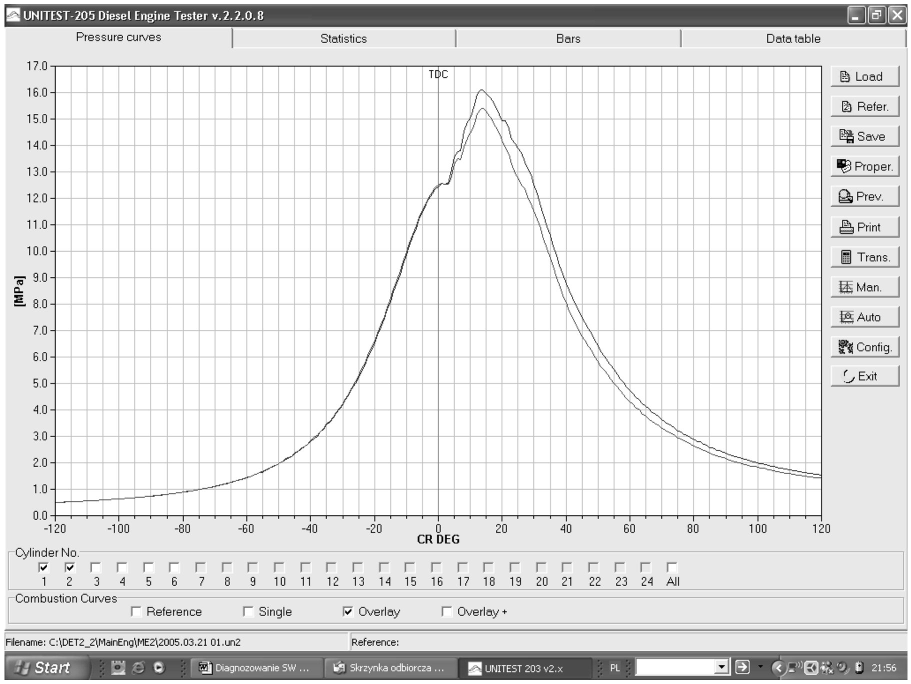

Fig. 3. A pressure trace registered in the faulty cylinder (upper curve) and the trace registered at correct injector operation (lower curve). The records produced with application of UNITEST 205 diesel engine tester.

is therefore by circa 30% weaker when the nozzle orifice is blocked than that shown in Fig. 4. The strategy of finding this engine fault requires to complete capturing of acoustic signals at all working injectors and detection the faulty one emitting a weaker signal. Additional confirmation of the recognition of the blocked injector is possible when acoustic signals registered on the stub outlet of the fuel pump are compared. Figures 6 and 7 present the comparison of the acoustic signals registered on the stub outlet

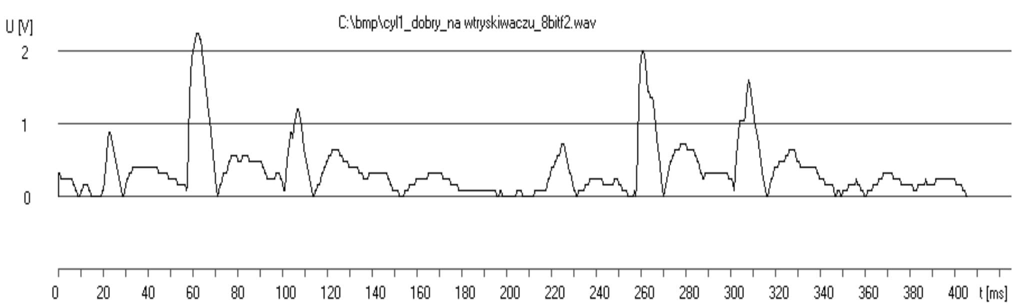

Fig. 4. Two consecutive waveforms of acoustic signal registered on the stub inlet to the injector working correctly – generated at two complete engine combustion cycles.

Fig. 5. Two consecutive waveforms of acoustic signal registered on the stub inlet to the injector with nozzle orifice partially blocked with products of fuel combustion. Signal amplitude is 30% lower than that shown in Fig. 4, the last one of the three pulses shown in Fig. 4 is missing.

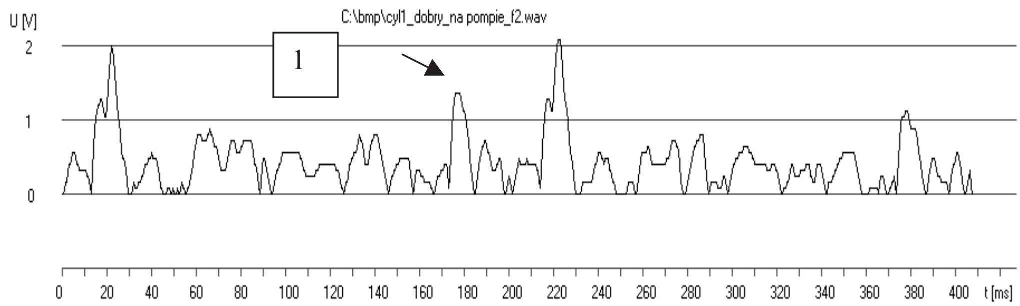

Fig. 6. Acoustic signal registered on the stub outlet of the pump leading to the injector working correctly. Mark “1” denotes a pulse to compare with that shown in Fig. 9, generated during the beginning of the fuel compression process.

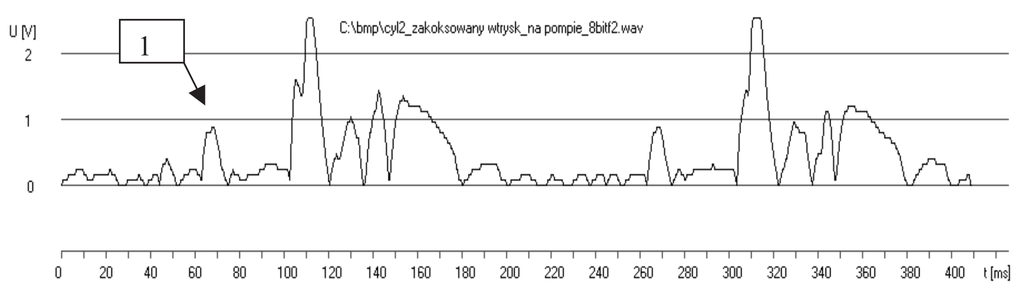

Fig. 7. Acoustic signal with increased amplitude registered on the stub outlet of the pump leading to a blocked injector. The effect of a contraction to the fuel flow causes a readable (30%) increase of the pulse generated in the fuel pipeline system when the pump delivers the highest injection pressure.

of the pump leading to the injector working correctly and the other one on the stub outlet of the pump leading to a blocked injector. The pulse marked “1” in Fig. 6. is caused during the beginning of the fuel compression process and the other remarkable pulse arising 40 milliseconds later is generated in the fuel pipeline system when the pump delivers the highest injection pressure. The effect of a contraction of the fuel flow causes a readable (30%) increase of that second pulse seen in Fig. 7.

Figures 8 and 9 present acoustic signals registered in locations (A) and (B) in the situation when the fuel pump was out of trim and supplies the injector with insufficient fuel volume.

Fig. 8. Acoustic signal registered on the stub inlet to the injector in the situation when the fuel pump was out of trim and supplies the injector with insufficient fuel volume. The signal amplitude is smaller than that shown in Fig. 4.

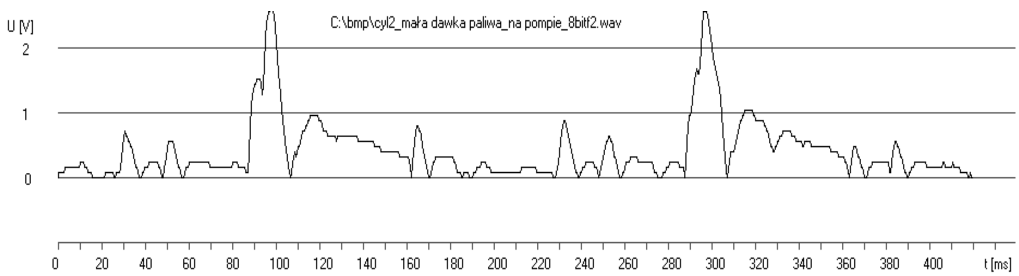

Fig. 9. Acoustic signal registered on the stub outlet of the pump in the situation when the fuel pump was out of trim and supplied the injector with insufficient fuel volume. A pulse marked “1” in Fig. 6 does not appear in this faulty situation.

4. Conclusions

The experimental results presented above allow the authors to state that certain faults of high power diesel fuel injection system can be localised using the method of registering and comparing of acoustic signals in the frequency range of 1000–10000 Hz. The engine operation events identified by the authors are:

- inlet and exhaust valve closing operation,
- fuel injection and combustion,
- beginning of the fuel compression process in the pump,
- onset of the highest injection pressure delivery.

The amplitude of the vibroacoustic pulses generated by these events are modified by the engine faults described in the paper what makes the faults detection possible. The presented method is non-invasive and therefore convenient to apply in the objects being in service. Both the software and experimental results reside in a lightweight laptop computer enabling to improve the controlling procedure.

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