ARCHIWUM MOTORYZACJI
3, pp. 199 -207 (2005)

Portable system for fault diagnostics of the fuel injectors of medium power maritime diesel engine with application of acoustic signal

ARTUR BEJGER[1], JAN GUZIK[2], MIŁOSZ MARCZAK[3], SŁAWOMIR OLSZOWSKI[2], ZBIGNIEW RANACHOWSKI[4]

[1] Wyższa Szkoła Morska Szczecin, [2] Politechnika Radomska,
[3] Center of Smart Technologies IPPT PAN, [4] IPPT PAN

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

1. Introduction

Diesel motors operating as a propulsion engine of minor maritime vessels (e.g. fishing boats, yachts, barges etc.) make serious diagnostic problems especially at monitoring the combustion process or testing of fuel injection system. The similar situation is occurring during exploitation of prime mover engines of electric power generators where stub pipes to register pressure traces from the engine cylinders are not built – in. The authors' impressions are that ship owners now pay increasing attention to a problem of fault diagnostics described above. There are two reasons of a need of establishing 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 the 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 of 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 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.

When compared with different sources of vibration and acoustic emission a diesel engine can be classified as „reciprocating machinery having both rotating and reciprocating parts'' [2]. Problems of diagnostics of these machines are caused by the fact that a numerous sources of acoustic signal 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 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 ensemble to construct more reliable fault diagnostic procedures [4]. This approach requires the application if intense digital processing of the signals and yet is not completed as a final solution. The authors of this paper have performed the research to find out if the vibroacoustic signal registered in optimal frequency range (i.e.: 1000 – 10000 Hz) can be used for diagnosing of common faults of the fuel injection system of the maritime diesel engine.

Fig. 1. A 3960 kW four stroke medium speed Wartsila SW 380 diesel engine used in the investigation
Rys. 1. Silnik wysokoprężny Wartsila SW 380 (czterosuwowy, średniobieżny) użyty w badaniach

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 the registering of occurrence of fault signatures in 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 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.

Fig. 2. Vibroacoustic signal analyser, used in the investigation, connected to the USB external soundcard
Rys. 2. Analizator sygnału wibroakustycznego, stosowanego w badaniach, połączony do łącza USB zewnętrznej karty dźwiękowej

The portable equipment to register the vibroacoustic signal consisted of:

- an 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 range,
- low – noise two channel external USB soundcart of type Soundblaster 24 bit Live (visible in Fig 2 together with the amplifier),
- a laptop to register the signals in form of audio records sampled at 44.1 kHz .

The bandpass filter and amplifier was equipped with RMS converter. Measured signals were registered after a conversion to 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). Therefore a 1 V level shown in the graphs denotes a pulse of acceleration of 6.2 g. Acoustic signal was registered in two locations: on a 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.

Details of placement of the acoustic sensor are shown in Fig 3. The acoustic waveforms of the registered signals presented below and stored in location A and location B are different what is a proof that sensor placed in location A registers the signals of the operating fuel pump and placed in location B registers the signals of the working injector.

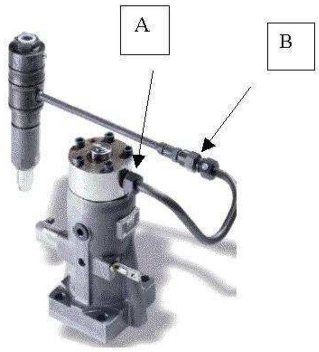

Fig. 3. Placement of the acoustic sensor for monitoring the signals generated by the fuel pump (A) and the injector (B)

Rys. 3. Umieszczenie sensora do monitorowania sygnału generowanego przez pompę (A) oraz przez wtryskiwacz (B)

3. Experimental results

A fault was recognised in one injector of the tested engine. The nozzle orifice of the injector was partially blocked with products of fuel combustion. 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 weaker pressure pulse when compared to the trace registered in healthy one (vide Fig. 4.)

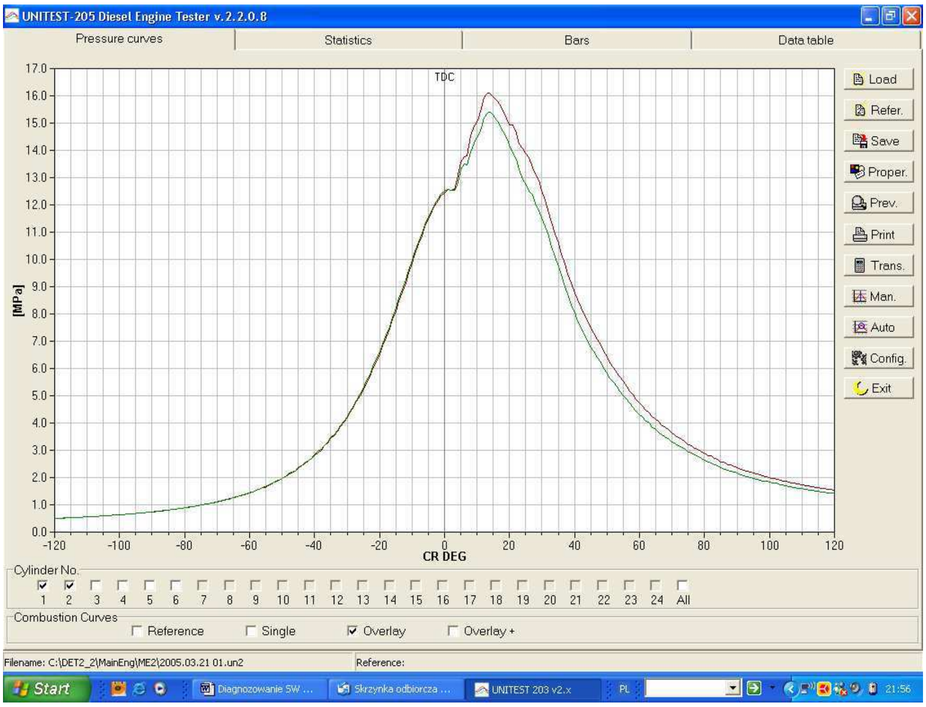

Fig. 4. A pressure trace registered in the faulty injector (lower curve) and the trace registered at correct injector operation (upper curve). The records produced with application of UNITEST 205 diesel engine tester

Rys. 4. Przebieg ciśnienia zarejestrowany dla uszkodzonego wtryskiwacza (górna krzywa) oraz przebieg ciśnienia dla dobrego wtryskiwacza (dolna krzywa). Wyniki otrzymano stosując tester silników wysokoprężnych UNITEST 205

Figures 5. and 6. 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. Signal amplitude of the injector with blocked nozzle orifice is 30 % lower than that shown in Fig 5. The strategy of finding this engine fault requires to complete the capturing the acoustic signals at all working injectors and detection the faulty one emitting a weaker signal. Acoustic signal generated by a fuel injector consists of 3 segments representing the following engine events: (1) onset of opening, (2) full open position and fuel injection (3) return of the injector needle to seat position. Recognition of these three segments might be an useful tool for finding wear effects occurring in injector. 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 7. and 8. present the comparison of the acoustic signals registered on the stub outlet of the pump feeding the injector working correctly and the other one on the stub outlet of the pump feeding a blocked injector. The effect of a contraction of the fuel flow cross-section causes a readable increase of the pulses seen in Fig. 8.

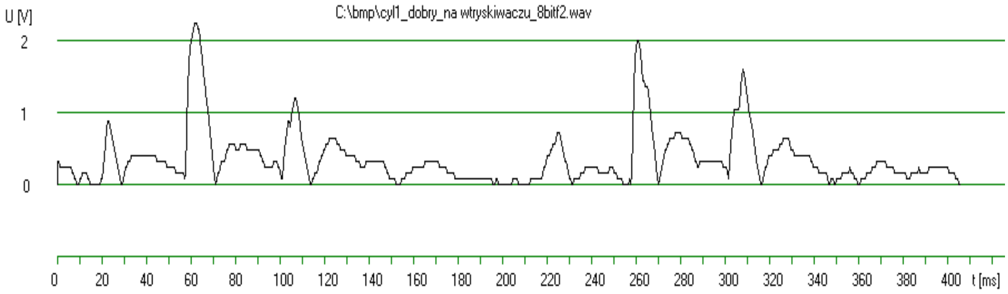

Fig. 5. Two consecutive waveforms of acoustic signal registered on the stub inlet to the injector working correctly

Rys. 5. Dwa kolejne okresy sygnału akustycznego zarejestrowane na wejściu do wtryskiwacza prawidłowo pracującego

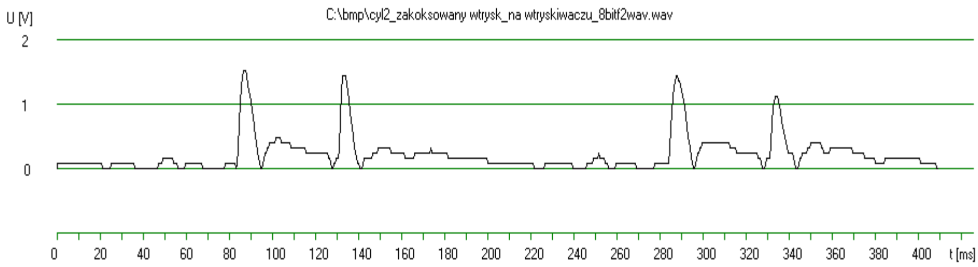

Fig. 6. Two consecutive waveforms of acoustic signal registered on the stub inlet to the injector with nozzle orifice partially blocked with products of fuel combustion. Signal amplitude is 30 % lower than that shown in Fig 5, first of three pulses seen above in Fig. 5. is missing.

Rys. 6. Dwa kolejne okresy sygnału akustycznego na wejściu do wtryskiwacza z otworem dyszy częściowo zablokowanym zanieczyszczeniami paliwa. Amplituda sygnału jest 30% mniejsza, niż na rys. 5, brakuje pierwszego z trzech impulsów pokazanych powyżej na rys. 5.

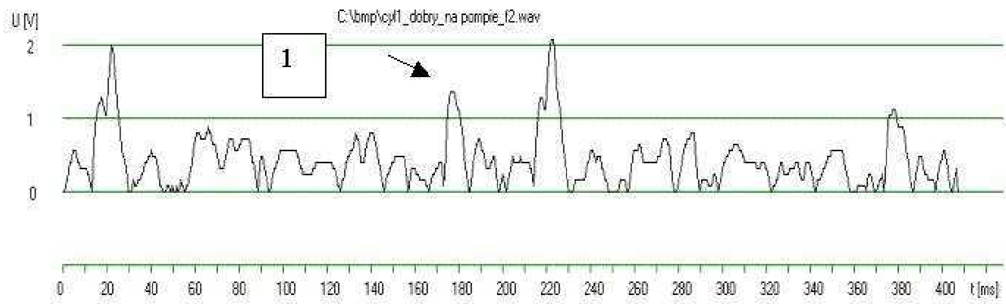

Fig. 7. Acoustic signal registered on the stub outlet of the pump feeding the injector working correctly. Mark „1" denotes a pulse to compare with a missing one shown in Fig. 10
Rys. 7. Sygnał akustyczny zapisany na wyjściu z pompy zasilającej wtryskiwacz prawidłowo pracujący. Znak „1" oznacza impuls porównawczy do sygnału bez impulsu pokazanego na rys. 10

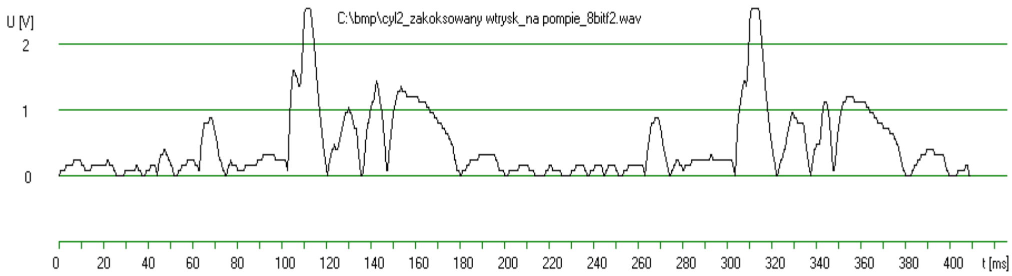

Fig. 8. Acoustic signal with increased amplitude registered on the stub outlet of the pump feeding a blocked injector
Rys. 8. Sygnał akustyczny z podwyższoną amplitudą zapisany na wyjściu pompy zasilającej zablokowany wtryskiwacz

Figures 9. and 10. present acoustic signals registered in location (A) and (B), shown on Fig. 3., in the situation when the fuel pump delivers less fuel into injector.

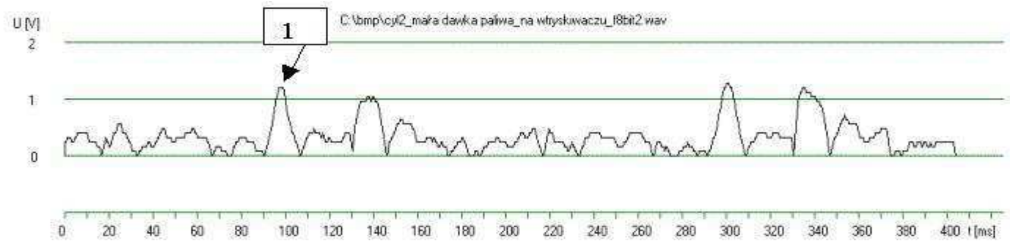

Fig. 9. Acoustic signal registered on the stub inlet to the injector in the situation when the fuel pump is out of trim and delivers less fuel into injector. The signal amplitude is smaller than that shown in Fig. 5. Mark „1" denotes the needle lift

Rys. 9. Sygnał akustyczny zapisany na wlocie do wtryskiwacza, gdy pompa paliwowa działa nieprawidłowo i zasila wtryskiwacz zbyt małą objętością paliwa. Amplituda sygnału jest mniejsza, niż na rys. 5. Znak „1" oznacza otwarcie zaworu iglicowego

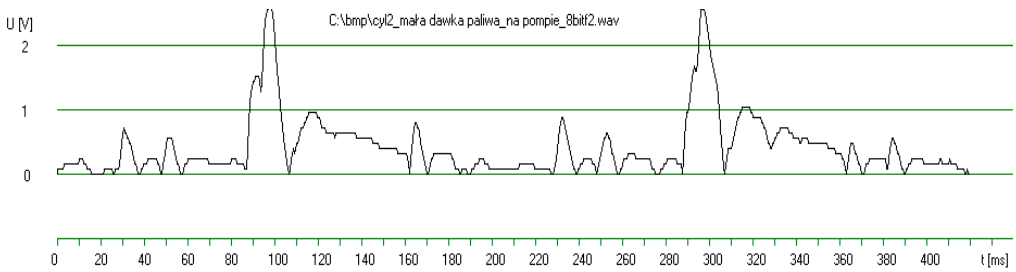

Fig. 10. Acoustic signal registered on the stub outlet of the pump in the situation when the fuel pump is out of trim and delivers less fuel into injector. A pulse marked „1" in Fig. 7. does not appear in faulty situation shown in this Figure

Rys. 10. Sygnał akustyczny zapisany na wyjściu pompy w sytuacji jej nieprawidłowego działania i zasilania wtryskiwacza zbyt małą objętością paliwa. Impuls ze znakiem „1" na rys. 7. nie występuje w tej nieprawidłowej sytuacji pokazanej na tym rysunku

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 of the frequency range of 1000 – 10000 Hz . The described method is non - invasive and therefore possible to apply in the objects being in service. The operator needs about 5 minutes for inspection and visualisation of stored data at a single location. Both software and experimental results reside in a lightweight laptop what makes the procedure of diagnostics and data analysis convenient.

References

[1] A website http://agency.osha.eu.int
[2] MAEDEL P.H.: *Vibration standards and test codes [in] Shock and vibration handbook*. Mc Graw – Hill, 19.1 – 19.11, 1995.
[3] CHANDROTH G.O. et al.: *Cylinder pressures and vibration in internal combustion engine condition monitoring.* Proceedings of Comadem 99. Sunderland, UK, 1999.
[4] CHANDROTH G.O.: *Diagnostic classifier ensembles: enforcing diversity for reliability in the combination*. PhD Thessis submitted at Department of Computer Science, University of Sheffield, 1999.
[5] GRAY C.: *Noise and vibration research applied to diesel engines*. Technical Report 329, Diesel Engineers and Users Association, 1970.

Przenośny system diagnostyki uszkodzeń wtryskiwaczy paliwa do morskich silników wysokoprężnych średniej mocy

Streszczenie

W pracy przedstawiono dane techniczne i przykład zastosowania praktycznego przenośnego systemu do rejestracji sygnału akustycznego w zakresie częstotliwości 1000 – 10000 Hz, przeznaczonego do diagnostyki typowych uszkodzeń układu zasilania w paliwo morskich silników wysokoprężnych. Jako przykłady zarejestrowanych sygnałów przedstawiono przebiegi uzyskane na wtryskiwaczu działającym poprawnie, wtryskiwaczu zakoksowanym oraz przy podaniu zbyt niskiej dawki paliwa. Dla porównania pokazano przebiegi dla tych samych sytuacji diagnostycznych uzyskane na króćcu wylotowym z pompy paliwowej. Diagnostyka detekcji uszkodzenia polega na porównaniu przebiegu zmierzonego na wtryskiwaczu uszkodzonym z przebiegami zmierzonym na wtryskiwaczach sprawnych, biorąc pod uwagę charakterystyczne zniekształcenia przebiegów opisane w tekście.