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ANALYSIS OF THE POSSIBILITY OF USING ACOUSTIC EMISSION FOR MONITORING TECHNICAL CONDITION OF THE FUEL INJECTOR IN 3AL25/30 ENGINE

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Abstract. Acoustic emission method (AE) can be used for the diagnosis of machine parts such as, for example: fuel injectors. This paper presents the methodology and research results of 3AL25/30 engine fuel injector. During research was studied one injector in good condition and second with simulated failure involving closing 2 of 9 holes of the injector tip. Research was carried out on a laboratory test stand using a set of acoustic emission Vallen System. This set included: 4 channel signal recorder AMSY 6, two measurement modules ASIP-2/S, preamplifier with a frequency range 20 kHz-1 MHz and the strengthening of 34 dB, AE signal measurement sensor type VS 150M, with a frequency range 100-450 kHz. During the study, the acoustic emission (AE) generated by tested injector was recorded. The following parameters were determined: amplitude, rise time, duration time, total time, number of events – hits, the effective value of the signal (RMS). Analysis of the results showed significantly longer total time of the injection in the case of damaged injector compared to the injector in good conditions. Signal amplitude was higher, however, the RMS signal reached approximately 3-times lower value for the injector with damaged tip. This means lower quality fuel atomization. Laboratory test results were compared with signals recorded on injectors installed in the engine. Analysis of the signals allowed detection damage of the injector installed in the engine during normal operation.

Keywords: acoustic emission, diagnostics, monitoring, injector, fuel system

INTRODUCTION

Fuel injectors are exposed to destruction processes during their operation (Bejger & Drzewieniecki, 2015). Monitoring the technical condition of machines and devices is very important especially for marine applications (Murawski, 2017). One of the methods used for monitoring fuel injection process is the acoustic emission (AE) method (Dykas & Harris, 2017). According to the definition acoustic emission (AE) is an evanescent elastic wave, which is the result of rapid release of the energy stored in the material by propagating a micro-damage (increase in micro-cracks, the movement of groups of dislocations) in the material or by a process (friction, leakage, etc.) (Ziegler & Miszczak, 2007). The typical frequency range of the AE is normally determined within 20 kHz-2 MHz (Wu et al., 2016).

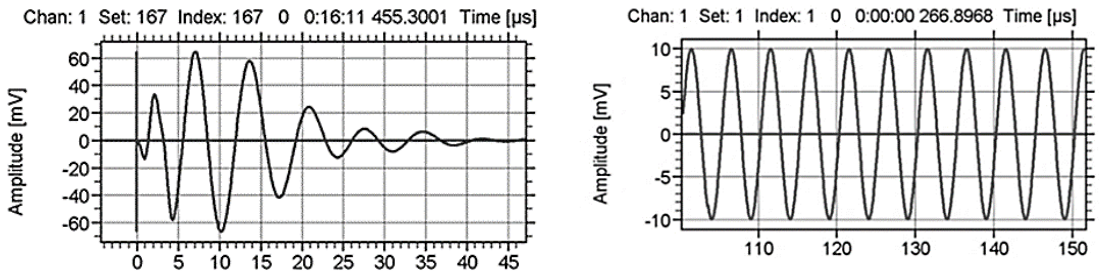
Acoustic Emission is a passive non-destructive method. Its main advantages are:

- high sensitivity,
- the possibility of continuously research ,
- the possibility to locate the source of the AE signals (damages, leaks, etc.)
- the possibility of carrying out research without having to shut down equipment out of service (Baran et al., 2007).

The stimulus causing the release of energy and the formation of elastic waves can be: load operation, environment, temperature change, and the processes which are accompanied by AE changes both at the micro and the macro scale, such as: cracks, friction, plastic deformation, corrosion, leaks, structural and phase changes, chemical reactions, delamination, cracking of the fibers and matrix in composites, etc. (Ziegler, 2007).

The acoustic waves propagate in all directions from the source, thus can be recorded by one or more sensors mounted on an object or component (Grabowski et al., 2016). During the propagation of the AE waves they are damped by several physical effects (Wu et al., 2017).

Therefore the waves can only be detected within a limited distance. These distance dependents on many factors, mainly on properties of the material, the geometry of the object and the level of interference from background noise (Wu et al., 2015). According to PN-EN 1330-9:2009, AE signal can be characterized by parameters such as: amplitude, frequency, energy, rise time, duration, number of exceedances of the threshold of discrimination – hits, RMS of the signal, etc. Examples of AE signals are shown in Figure 1.



a) b)

Fig. 1. Examples of typical acoustic emission signals:
a) burst signal, b) continuous signal

THE RESEARCH METHODOLOGY

The research was carried out on the test stand placed in Maritime Engineering Faculty of Gdynia Maritime University. The stand includes: a fuel tank, a piston pump, a manometer, a high pressure fuel line and an injector. The view of the stand is shown in Figure 2. The tested injector is from the 3AL25/30 laboratory engine (Dudzik & Charchalis, 2015). Two injector tips were used during the study. The first one was completely functional, while in the other one 2 of 9 holes were closed (simulation of the limited patency of the injector).

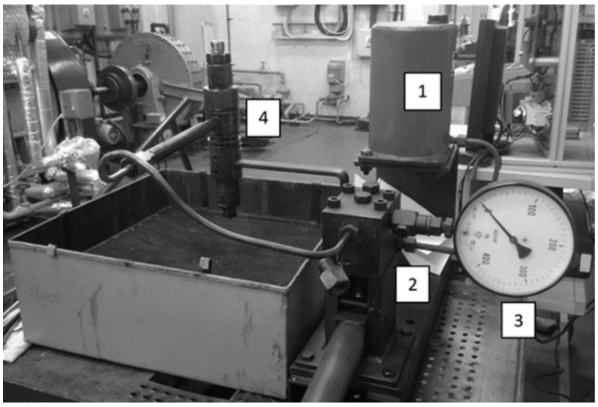
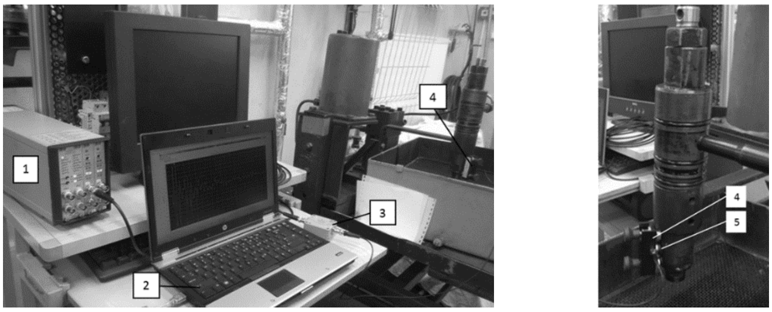


Fig. 2. The view of laboratory stand used for fuel injector testing:
1 – fuel tank, 2 – pump, 3 – manometer, 4 – injector

Research of acoustic emission (AE) accompanying the fuel injection process in testing injector was performed using a kit consisting of 4-channel signal recorder type AMSY 6 and two measuring modules ASIP-2/S from Vallen System. The kit includes pre-amplifier with a frequency range of 20 kHz-1 MHz and the strengthening of 34 dB and a sensor signal measurement AE, VS 150M, with a frequency range of 100-450 kHz. The system includes a data recording module – 8MB per channel and software for recording and analyzing AE data. The sensor was mounted on the side surface of the injector by means of a magnetic holder MAG4M – dedicated to used sensor.

Between the sensor and the surface the coupling fluid was used.

The view of laboratory stand used in research is shown in Figure 3.



a) b)

Fig. 3. The view of laboratory stand used for AE research during fuel injector testing: a) view of whole stand, b) view of fixing AE sensor on the injector; 1 – AE recorder, 2 – computer, 3 – preamplifier, 4 – AE sensor holder, 5 – AE sensor

Laboratory test results were compared with signals recorded on injectors installed in the engine during normal operation. During test 3-cylinder medium speed self-ignition engine 3AL25/30 driving electro-generator was used. View of laboratory engine used in research is presented in Figure 4.

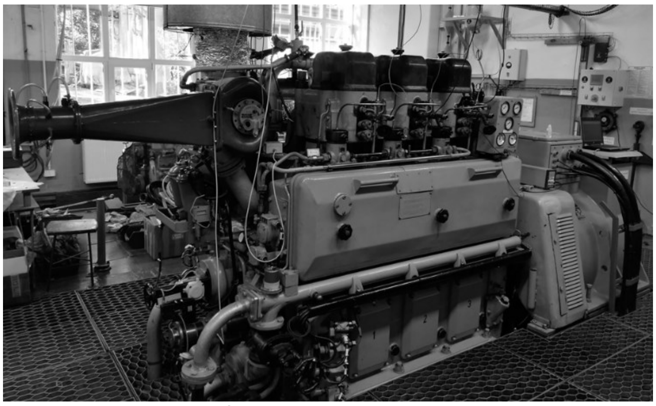


Fig. 4. The view of 3AL25/30 engine used in research.

Acoustic emission signal generated by tested injector during operation was recorded by Vallen System. The view of laboratory stand used for research of acoustic emission accompanying the fuel injection process in the injector mounted in the engine during normal work is presented in Figure 5. The AE sensor was mounted on the high pressure fuel line hose by means of a MAG4M magnetic holder. Between the sensor and the surface of the fuel line hose the coupling fluid was used.

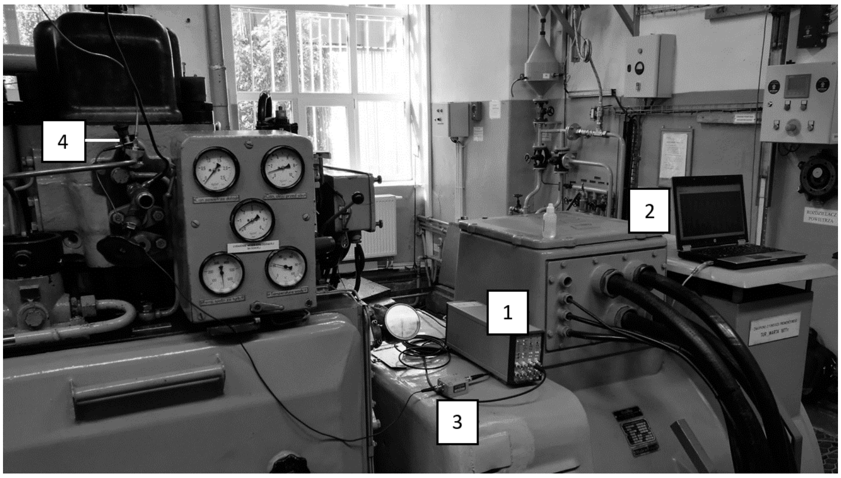


Fig. 5. The view of laboratory stand used for AE research of the fuel injection process in the injector mounted in the engine during normal work: 1 – AE recorder, 2 – computer, 3 – preamplifier, 4 – AE sensor

THE RESEARCH RESULTS

A number of parameters were analyzed during the research of the acoustic emission (AE) generated during the injection process by fuel injector of the 3AL25/30 engine carried out on the test stand. These parameters include: signal amplitude, number of events – hits, total injection time, RMS (Root Mean Square) value of the signal. Analysis of selected parameters was performed using Vallen Visual AE software. The test was repeated three times, both for the injector in good condition and for the simulated failure consisting closing 2 of the 9 injector tip holes (in the rest of the text, the abbreviation "damaged injector" is used).
Examples of graphs showing the number of events and their amplitude as a function of time, recorded during the study are presented in Figure 6.

a)
b)

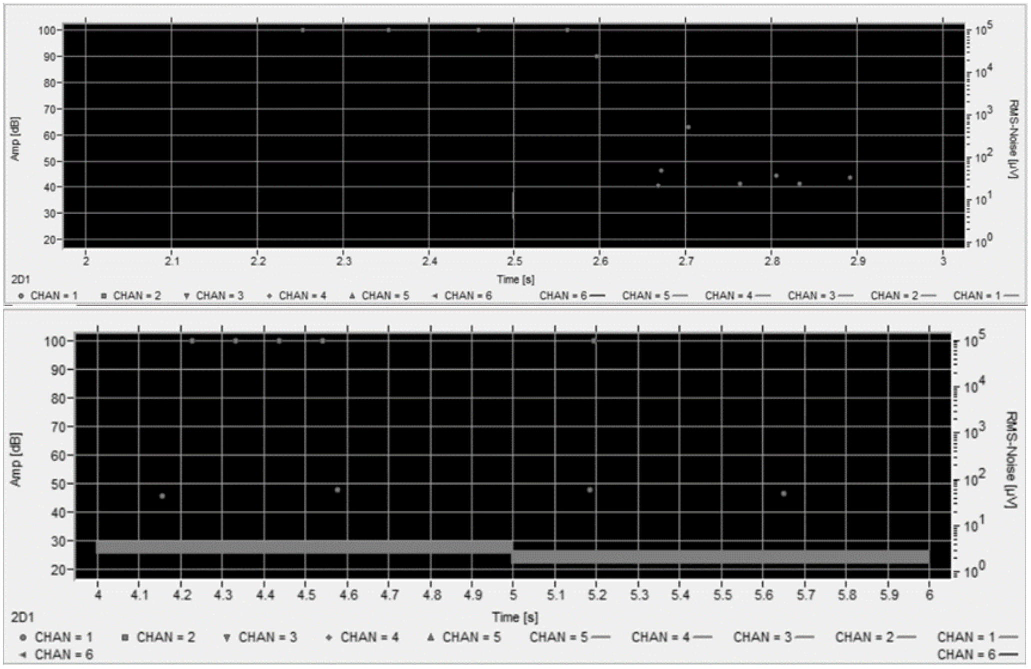


Fig. 6. Chart of number of hits and their amplitude changing as a function of time during injection: a) good injector, b) damaged injector

During injection process, in case of the injector in good conditions, the signal amplitude was maximum when the needle is opened and then the amplitude of the signal is reduced to the threshold value. In case of the damaged injector, the initial injection phase is identical to the good injector, and the differences occur at the end of the injection phase – a characteristic increase in amplitude is reached to the maximum value, followed by a decrease to the threshold value of the AE.
The results of the acoustic emission test of the good and damaged injector, in the form of average values of chosen parameters indicative of AE signals, are presented in Table 1.

Table 1.
Average value of chosen parameters recorded during test on laboratory stand.

Fuel injector	A [dB]	RMS [µV]	T [s]
Good, test 1	59.7	8.76	0.878
Good, test 2	67.56	8.63	0.638
Good, test 3	55.38	8.58	0.846
Good, average	**60.88**	**8.65**	**0.787**
Damaged, test 1	76.36	3.22	1.492
Damaged, test 2	84.5	2.87	0.96
Damaged, test 3	77.67	2.71	0.926
Damaged, average	**79.51**	**2.93**	**1.126**

The amplitude of the signals recorded in both cases is greater in the case of the damaged injector. This may be due to an increase in fuel pressure at the injector tip due to the limited patency of the spray channels. Total injection time was shorter in case of good injector compared to damaged one.

The efficiency of the injection process is best determined by the RMS value of the signal. The analysis of this parameter shows that the values achieved for the good injector are close to three times bigger then in case of the damaged injector. This applies to both, average and maximum values recorded during the test.

The next step of the research was comparing the recorded signals for the injectors on a laboratory stand and mounted into the engine.

Analysis of recorded signals after FFT (Fast Fourier Transform) allows to compare the frequency of these signals. Comparison of the characteristic frequencies of signals recorded on injectors mounted in the engine during normal operation with those obtained at the test stand allows to determine their technical condition.

Figures 7 and 8 show exemplary amplitude signals as a function of time and amplitude as a function of the frequency recorded during research of good injector.

a)

b)

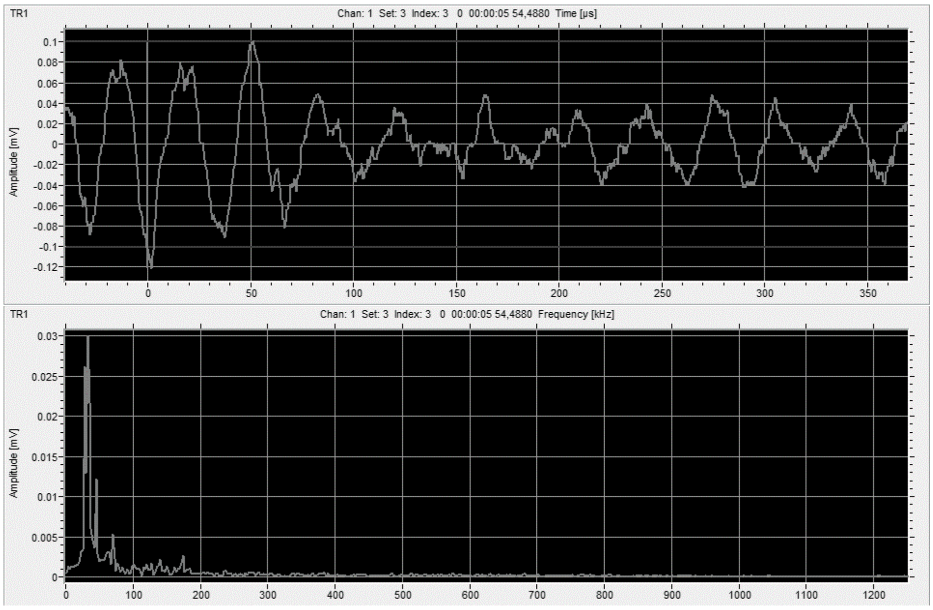


Fig. 7. An example of the signal recorded during injection of good injector on laboratory stand: a) AE sampled signal, b) signal after FFT analysis.

a)

b)

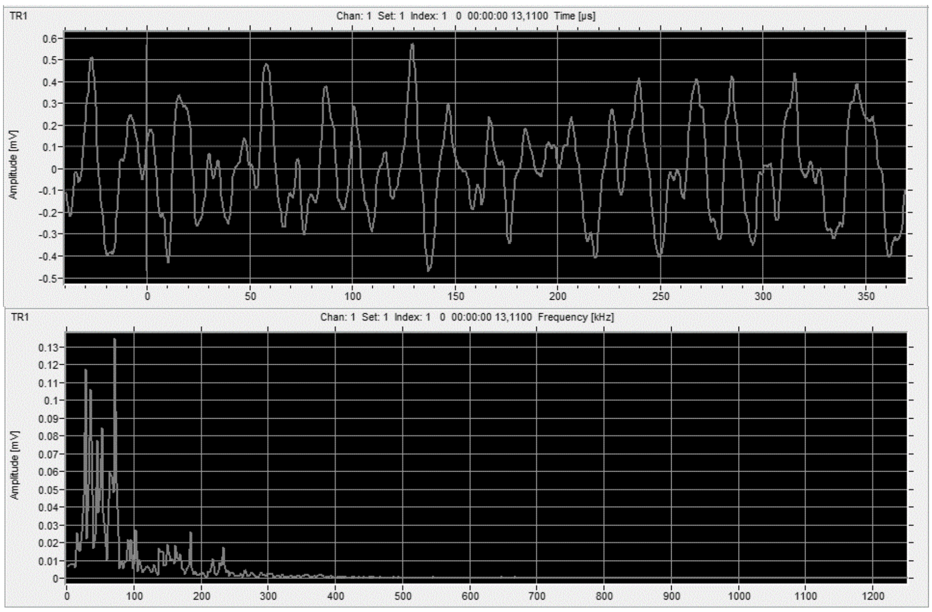


Fig. 8. An example of the signal recorded during injection of good injector installed in the engine: a) AE sampled signal, b) signal after FFT analysis.

Figures 9 and 10 show exemplary amplitude signals as a function of time and amplitude as a function of the frequency recorded during research of damaged injector.

a)

b)

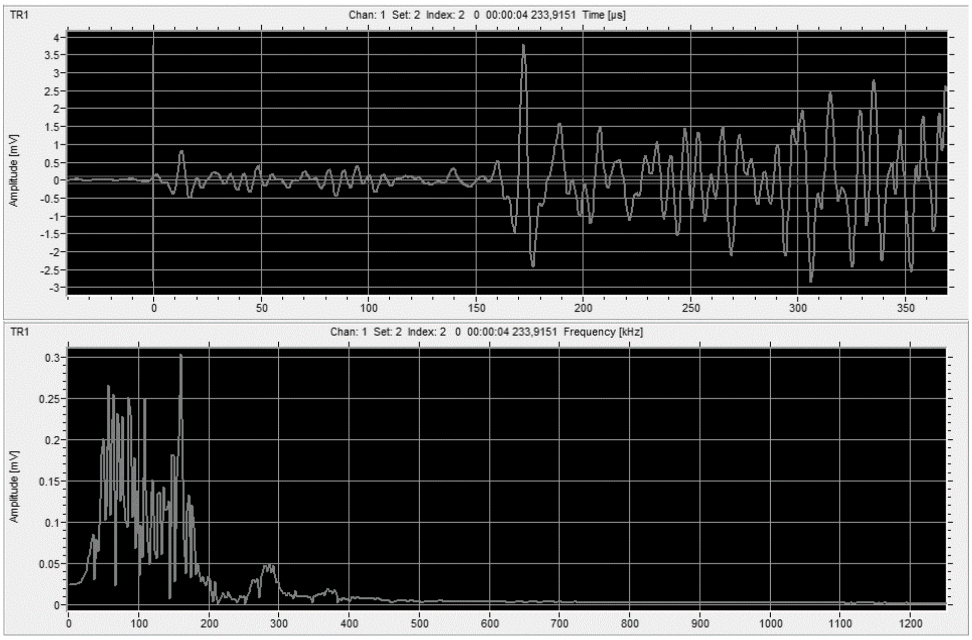


Fig. 9. An example of the signal recorded during injection of damaged injector on laboratory stand: a) AE sampled signal, b) signal after FFT analysis

a)

b)

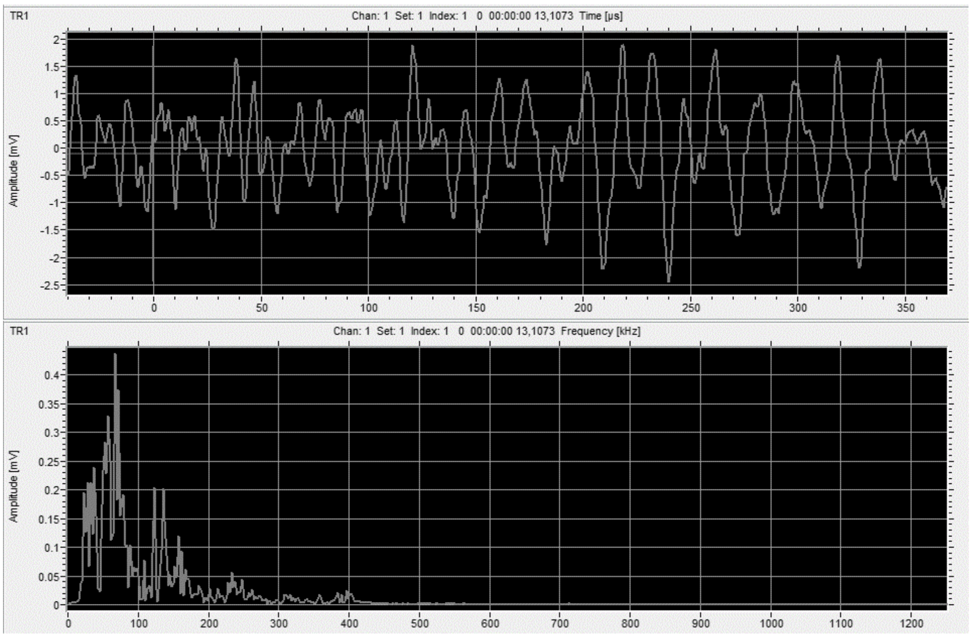


Fig. 10. An example of the signal recorded during injection of damaged injector installed in the engine: a) AE sampled signal, b) signal after FFT analysis

For a good injector, the signal frequency range is between 25-75 kHz. In case of the injector with simulated 2-hole shutdown caused the signal frequency range to be between 35-185 kHz.

CONCLUSIONS

The analysis of the research results of the acoustic emission generated during the injection process in a good injector and with simulated damage in the form of closed 2 of 9 holes allowed to draw the following conclusions:

- the damaged injector tip increases the signal amplitude during the injection. The increase of amplitude during injection is due to increase of fuel pressure and interference of elastic waves in both, the fuel and the material of injector tip,
- the damaged injector tip causes increasing of total injection time,
- the fuel flow on all 9 holes of the good injector nozzle compared to the damaged injector (only 7 open holes) results in a noticeably higher value of the recorded RMS value – both, mean and maximum values,
- damaged injector tip extends the frequency range of the generated signal – additional (approximately twice) the frequency of the signal is generated as compared to the good injector,
- Comparison of the signals recorded at the test stand with the signals obtained during monitoring of the technical condition of the injectors mounted in the engine during normal operation, allows to detect their damage.

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