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DIAGNOSTIC OF MALFUNCTION OF FOUR STROKE MARINE ENGINE USING HARMONIC COMPONENTS OF COMBUSTION PRESSURE WAVEFORMS

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Abstract

The paper presents results of experimental measurements and analysis of combustion pressure and fuel pressure in high-pressure line before fuel valve. The aim of conducted experiments was detection of failures of high-pressure fuel system. Both pressure signals were recorded simultaneously and subsequently processed using FFT decomposition of obtained wavelets. The idea of comparison of both fuel and gas pressures came after observations of occurrence changes of wavelets form of fuel high pressure, probably caused by malfunction of injector's sprayer. The engine from test bed is very well armoured with sensors, what enable observations of fuel and combustion pressure in real time. Unfortunately, such equipment is very unlike in real objects, what created un idea to find out whether run of combustion pressure wavelet reflects fuel pressure deviations and whether is possible to detect such kind of deviations in way of decomposition of indicated pressure wavelet. Experiment was carried out in laboratory of Gdynia Maritime University, using medium speed diesel engine. Simulation of malfunctions of fuel valve was obtained by installation of specially prepared spraying nozzles. All measurements were carried out at reference load of 75% of MCR (Maximum Continuous Rating). In order to get reliable results and avoid errors due to omitting outer atmospheric conditions, registrations were repeated several times, in days characterized by different temperature and atmospheric pressure.

Keywords: *technical diagnostics, marine engines, FFT, harmonic components, combustion pressure*

1. Introduction

Technical diagnostics is a domain of science encompassing of congregate of methods and means leading to identification of technical condition and status of mechanisms called objects of diagnosis [3]. For practical aspects of above, is very important to have possibility of continuous monitoring of critical parameters values using indicators available as standard equipment, and compare this with values given by engine's manuals. The most required situation is when analysis of available parameters enables identification of reasons of malfunctions (troubleshooting) [1, 2].

One of the most reliable ways of high-pressure fuel system's control is recording of fuel pressure characteristic in crank angle domain, but this way is not easy for implementation outside of test beds due to high price of sensors and their vulnerability [6]. Most common systems being in use on-board of ships are electronic indicators of combustion pressure [7].

The aim of conducted researches was to find the answer whether recorded values of combustion pressure reflects changes (pulsation) of pressure in high-pressure fuel pipe. For analysis purposes, it was taken an assumption that if combustion pressure signal bear any information about fuel pressure pulsation that spectrum of decomposition of pressure function shall show it by magnitude or frequency variations.

As an object for experiment was selected three cylinder diesel engine Sulzer 3Al 25/30 with turbocharger VTR 160 N, driving three phase electro generator 380 V and 50 Hz. This engine is test unit and is prepared for simulation of malfunctions of fuel valves, fuel pump and turbocharging system. In the paper were described deviations of fuel pressure pulsation caused by wear and tear of fuel valve due to normal exploitation. At indicator chart, it was observed as lack of typical pressure jump after rise of fuel valve spindle (see Fig. 1).

Implemented at test bed system of measurement of combustion and fuel pressure enables records with resolution of 0.5 degree of crank angle (CA) and record duration covers 10 subsequent revolutions (total 3600 degrees of CA).First series of measurements were conducted with wear and tear affected valve and subsequently valve was replaced by brand new one and series of measurements were repeated. During experiment, revolutionary speed of the shaft was 750 rpm and load set up was 70% of nominal. It means that power contribution of selected cylinder no. 2 was 87 kW.

2. Analysis of harmonic spectrum of in-cylinder combustion pressure in case of worn injection nozzle

During analysis of combustion pressure runs, slight deviation from standard waveform was observed. It was lack of typical jump of fuel pressure in a moment of opening (rise) of injector spindle. It is clear when compare runs presented in Fig. 1 and Fig. 5. Similar behaviour of fuel pressure wavelet occurs in the case of too low pressure of spindle opening due to weak spindle spring. That situation was simulated by unscrewing spring's hold screw and control of opening pressure at injector test stand. For experiment purposes, spindle-opening pressure was diminish by 10 MPa from manual value (see Fig. 2 and 5).

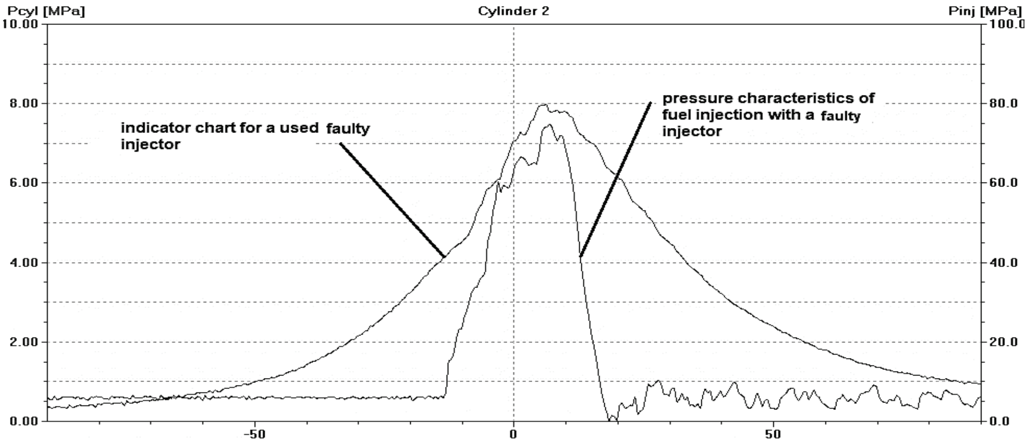

Fig. 1. Indicator chart with the injection pressure course for a load of 70% of the engine with the faulty injector

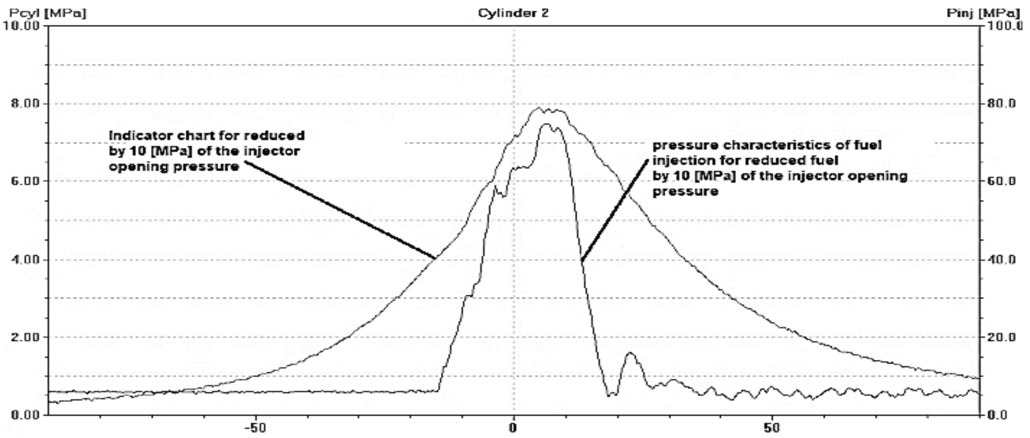

Fig. 2. Indicator chart with the injection pressure course for a 70% load of the engine with a 10 [MPa] reduced opening pressure of the injector

Subsequent step of research was relayed at collecting of information about run of combustion pressure wavelets under different outer conduction but keeping equal value of engine load [4, 5]. Data Records were carried out in several days, characterized by different atmospheric conditions and collected data were subsequently processed using Fourier transformation in order to detect expected differences in obtained spectra. Samples of results of FFT processing are shown at Fig. 3.

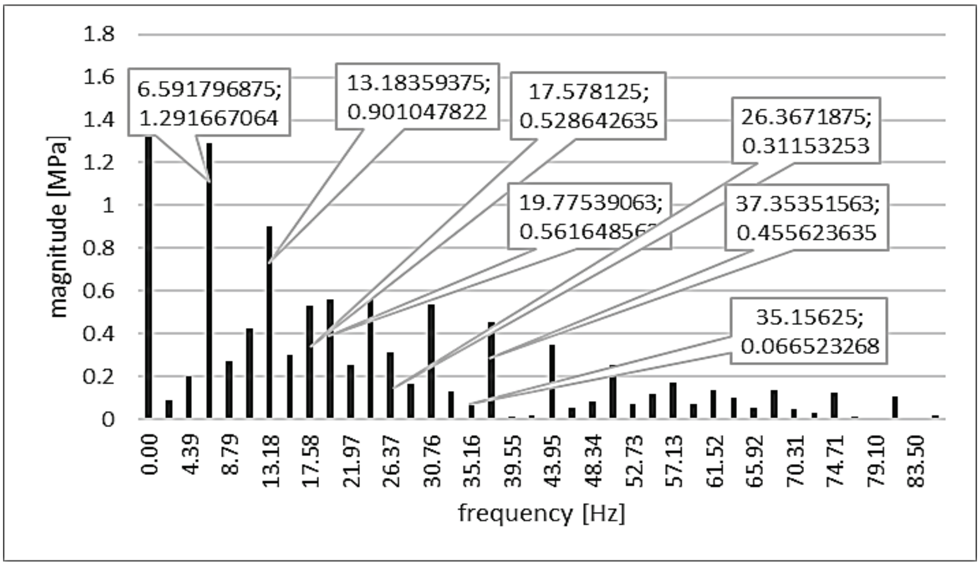

Fig. 3. Frequency spectrum of pressure values in the cylinder of the running engine for 70% load of the engine with the faulty injector

For revolutionary speed of the engine 750 rpm, injection frequency is 6.25 Hz, what is clearly presented by spectrum's straps, together with multiplications of basic frequency i.e. 12.5 Hz, 18.75 Hz, 25 Hz etc. (see Fig. 3).

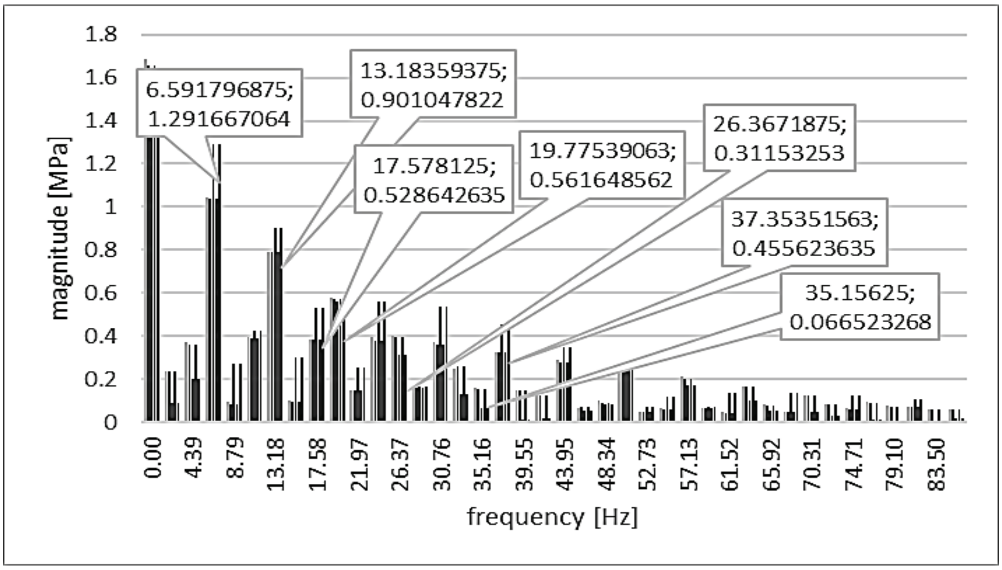

Fig. 4. Comparison of frequency spectra of pressure values in the cylinder of the running engine for 70% load of the engine with the faulty injector

Superposition of spectra of several independent record clearly shows that any differences of harmonic components does not occurs but values of magnitudes of frequency straps can be observed, what probably is caused by different combustion quality because of air temperature and pressure [8, 10].

3. Analysis of harmonic spectrum of combustion pressure in combustion chamber with brand new injection nozzle

Due to undertaken assumption that lack of fuel pressure jump can be caused by worn elements of injection valve, most probably by wear and tear of spindle seat in injector's nozzle, mentioned element was replaced by brand new one. All tests were repeated with sustaining condition of different atmospheric parameters. As result of measurements, runs of combustion pressure and fuel pressure waveform were taken. Sample of recorded values in domain of crank angle is presented in Fig. 5. Replaced nozzle caused different shape of waveform of fuel pressure, with typical jump of pressure in moment of spindle opening, what proved undertaken assumption about worn-caused deviations of pressure run.

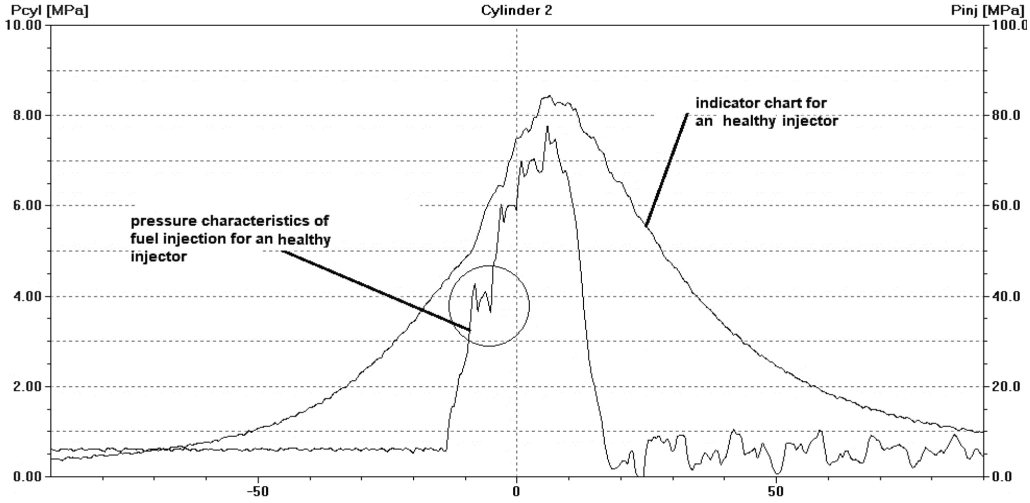

Fig. 5. Indicator chart developed along with the injection pressure course for 70% load of the engine with the healthy injector nozzle

Wavelets of records of combustion pressure with new nozzle were processed using FFT in order to find out possibility of detection of malfunction basing on spectrum components comparison. In Fig. 6 is presented sample of frequency spectrum.

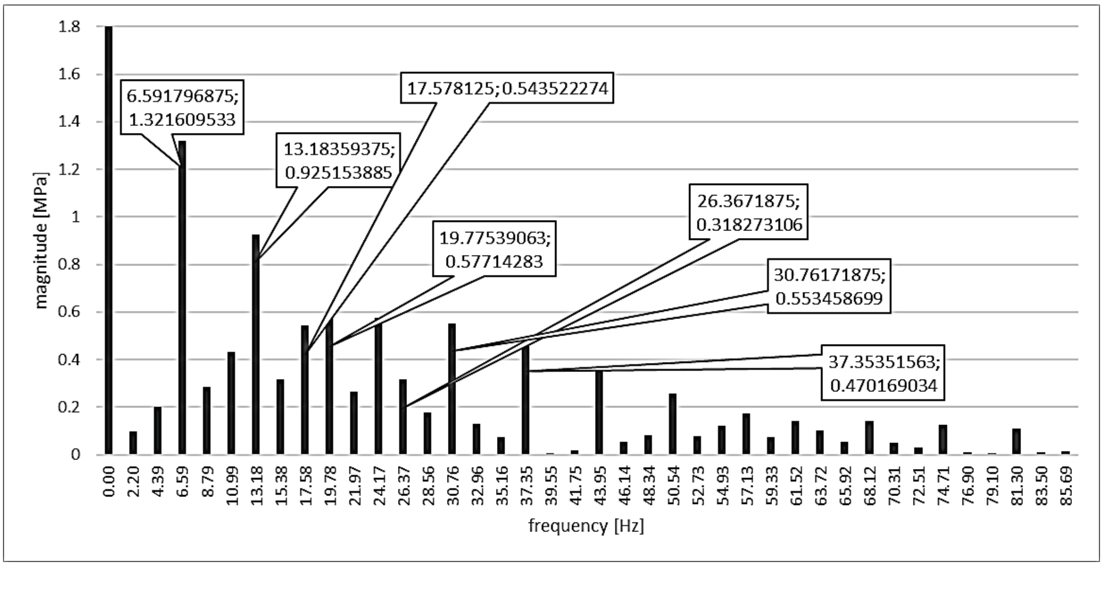

Fig. 6. Frequency spectrum of combustion pressure values in the cylinder of the running engine for 70% load of the engine with the healthy injector

For revolutionary speed 750 rpm, basic harmonic order frequency is 6.25 Hz what is clearly pointed in spectrum, also multiplications of basic frequency are presented (see Fig. 6) one can observed all frequency straps' magnitudes going down with increasing of frequency.

In Fig. 7 is presented comparison of three selected spectra of combustion pressure decomposition, after processing of records, which were done under different outer conditions. Similar to picture given by decomposition of records with faulty injector, any deviations of frequency components cannot be observed, all basic frequencies are presented. For all frequency straps, slight differences of magnitude can be spotted. One has to assume that magnitude differences are caused by not equal working conditions, what by the way, was intentionally arranged.

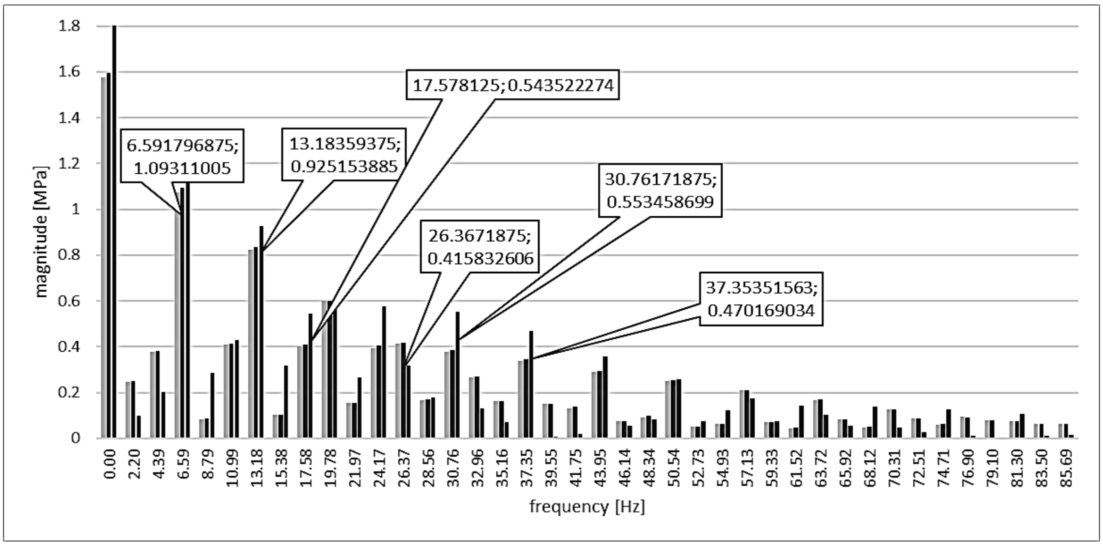

Fig. 7. Comparison of frequency spectra of pressure values in working cylinders of the running engine for 70% load of the engine with the healthy injector nozzle

4. Conclusions

Conducted experiments and their subsequent analysis showed that diagnosis of wear and tear deriving malfunctions in way of FFT decomposition of compression and combustion pressure wavelet does not giving expected results. In range of basic harmonic orders commonly considered for compression ignition engines i.e. from ½ up to 14th order any specific signals or phenomena giving chance to detect malfunction does not occur. Looking at Fig. 8 is clearly visible that either frequencies or magnitudes related to them are similar for healthy and worn injector, and differential value is at range of changes due to outer conditions variations.

It can lead us to the conclusion that phenomena of damming and pulsation occurring in high-pressure fuel pipe does not affect strongly enough the process of pressure rise. Quick rise of pressure during initial phase of combustion can mask potential deviation. Second phase of combustion process is much more stabilized and smooth then can hide low amplitude signal. Moreover, the frequency of single cylinder injection (6.26 Hz) is double of revolutionary speed frequency (12.5 Hz). According to [2] maximum magnitude of the frequency spectrum is for half of revolutionary frequency of the engine (6.25 Hz) what can be reason of masking coming from high pressure fuel system signals.Different picture can be observed when higher frequency straps are taken in focus. Analysis of spectrum in range of 400 Hz to 950 Hz, 1.9 MHz to 2.2 MHz and 6 MHz to 6.4 MHz shows that some magnitude differences between healthy and worn out system's elements can be observed. To enhance differential magnitude picture all values were raised to 5th power, what eliminate very small values, which can be omitted. Results are presented in Fig. 9-11.

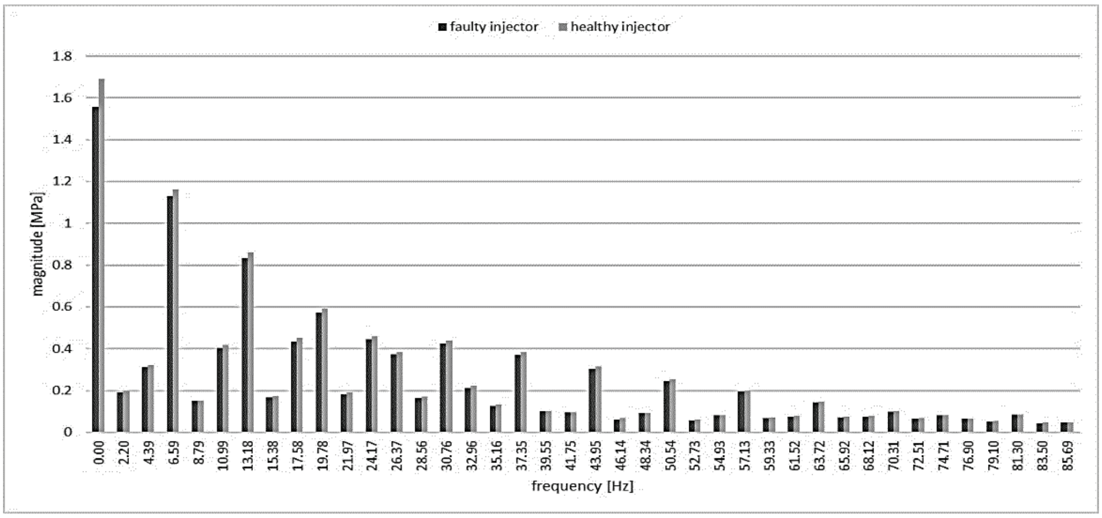

Fig. 8. Comparison of mean values of amplitude spectra of pressures in working cylinders of a running engine for 70% load with healthy and faulty injector nozzle

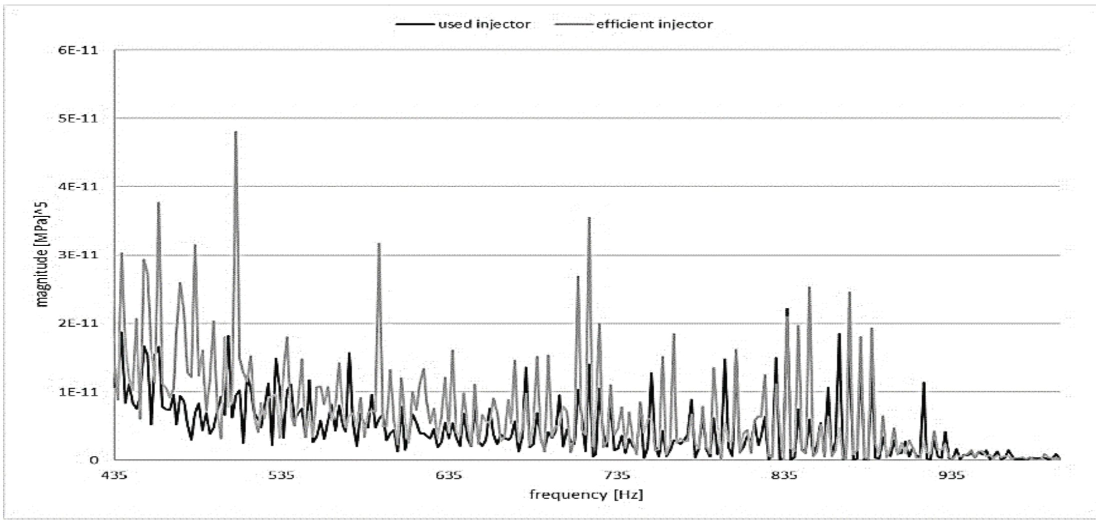

Fig. 9. Comparison of average values of magnitude for healthy worn injector in domain of frequency range 430-950 Hz

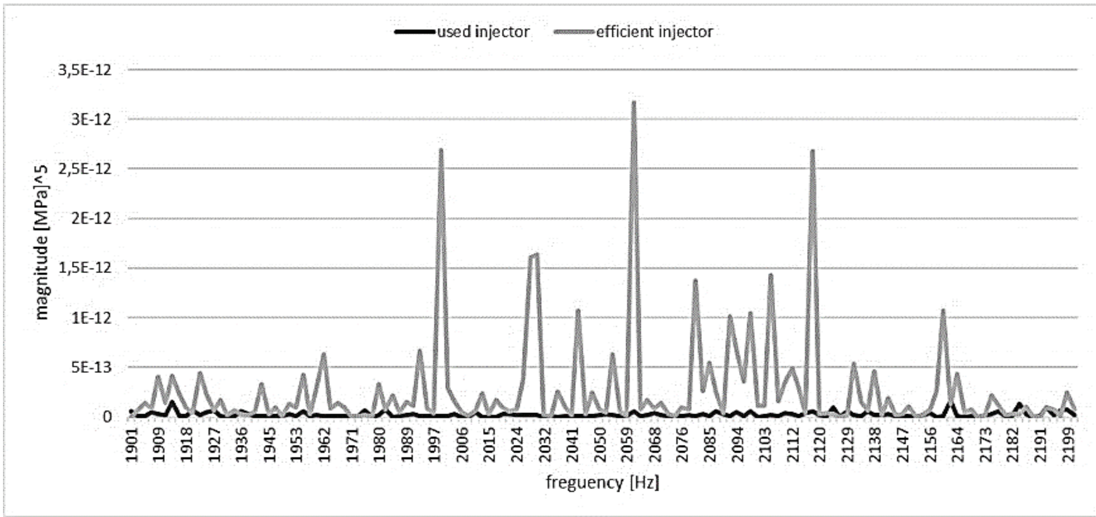

Fig. 10. Comparison of average values of magnitude for healthy worn injector in domain of frequency range 1.9-2.2 MHz

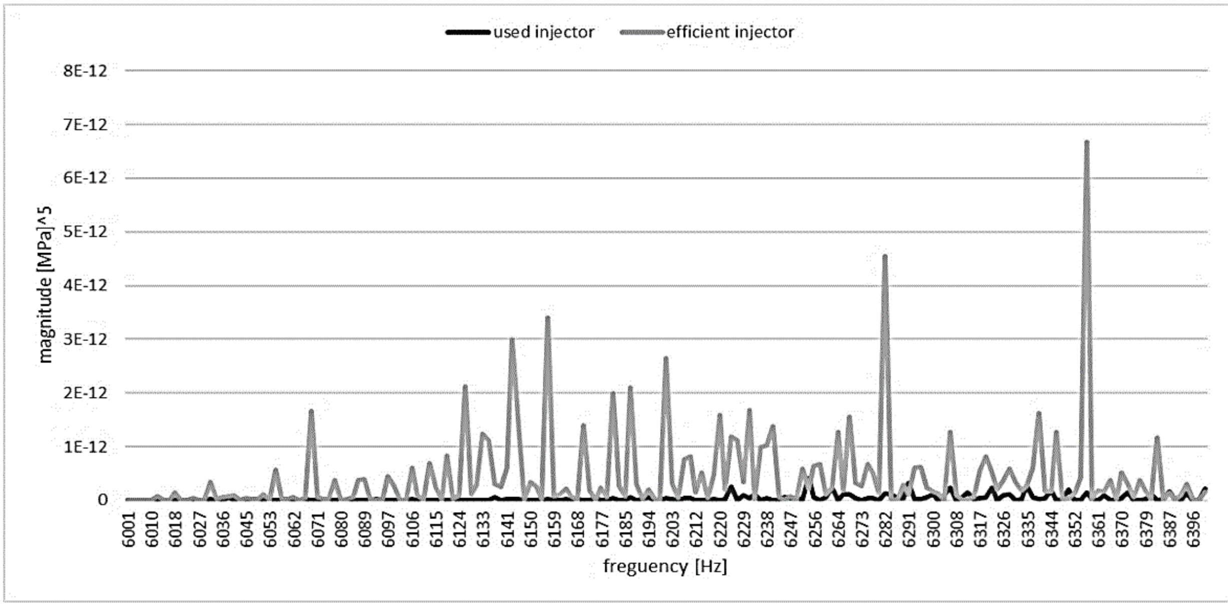

Fig. 11. Comparison of average values of magnitude for healthy worn injector in domain of frequency range 6-6.4 MHz

Above presented results of analysis cannot be basis of assumption of diagnostic value of high frequency components. It only shows that some kind of deviation can be observed and shall be verified. Continuation of experiments seems to be justified and requires implementation of other kinds of high-pressure malfunction. If exist any detectable relation between pulsations in high-pressure pipe and deviations of combustion pressure course, it would be interesting source of diagnostic signal.

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