PRELIMINARY RESEARCH OF THE DIESEL KNOCK PHENOMENON WITH USING OF THE CRANKSHAFT ACCELERATION METHOD

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Abstract

Paper presents an experimental study on the pressure variations inside of 3 – cylinder, a direct injection AD3.152 type diesel engine. The main aim of the preliminary engine test was to use of the crankshaft free acceleration method for detection of diesel knock phenomenon.

For this research, each combustion chamber was equipped with AVL cooled pressure sensor mounted at the top of engine head. Using of such sensors and special prepared at Technical University of Radom data acquisition system allow to record time histories of in-cylinder pressure variations at conditions of free acceleration of the engine crankshaft. Results presented in this paper show, that such transient engine conditions can be successfully used for detection of diesel knock phenomenon. High frequency pressure oscillations, typical for knocking were observed in the first phase of the acceleration process for selected combustion chambers. Experimental tests have been done for engine fuelled with regular diesel oil (DF) and its blend with Ethyl Tert Butyl Ether (ETBE) used as an oxygenated additive.

Engine test procedure, used methodology and data acquisition system and engine test results carried out in non-stationary conditions with using of crankshaft acceleration method are presented in the paper.

Keywords: *diesel knock, transient conditions, combustion process, acceleration method, wavelet transform, FFT analysis, alternative fuels*

1. Introduction

Vehicle engine works at transient conditions mainly. It's typical for urban traffic, where cars speed up and slow down periodically. Different research results show, that such conditions have significant and sometimes unfavorable influence on diesel engine work. It was observed, that free accelerated diesel engine works harder with higher values of in-cylinder pressure rise, than at full load in steady – state conditions. Experiments show, that it's caused by longer period of ignition delay [1-3]. This parameter is very important for engine researchers. It has significant influence on heat release immediately following autoignition process. Too long period of ignition delay impacts on engine pollution and noise emission. It's effect of abnormal course of fuel combustion process. The most dangerous phenomenon, which can occur during diesel engine operation, is a knock. It is high frequency pressure oscillations, whose amplitude decrease with time. These pressure fluctuations produce the sharp metallic sound. Knock can lead to serious piston damages, which examples are presented in literature [4].

The diesel knock phenomenon can be observed with commonly used knock sensor [5]. Acoustic signal or cylinder pressure analyses are helpful in such research too. The most of these tests are done for engines working in stationary conditions. This paper presents possibilities of using in-cylinder pressure signal which was recorded in non-stationary conditions of the engine work for research of knock phenomenon.

2. Engine test procedure, used methodology and data acquisition system

The researches were carried out in the laboratory of the Institute of Operation and Maintenance of Vehicles and Machines at Radom Technical University. The object of experimental study was direct injection AD3.152 type diesel engine. Its selected technical data are presented in Tab. 1. Rows: 7-9, which are presented in table below, contain information about: fuel injection quality, values of maximum compression pressure measured for all engine cylinders and injector opening pressures which were checked for tested engine.

Tab. 1. Selected technical information of tested engine

No.	Parameter	Engine type
		AD3.152 (direct injection)
1.	Cylinder cubic capacity, [cm^3]	980
2.	No. of cylinders, [-]	3
3.	Compression ratio, [-]	16.5:1
4.	Nominal pressure of injector opening, [MPa]	17.5
5.	Maximum torque, [Nm]	160 Nm at 1300 rpm
6.	The kind of fuel injection system	DPA rotary type fuel pump
7.	Fuel spray quality checked for: – injector mounted in cyl. #1 – injector mounted in cyl. #2 – injector mounted in cyl. #3	 good atomization good atomization excellent atomization
8.	Values of max. compression pressure in cyl.: #1 #2 #3	 3.15 MPa 3.14 MPa 3.25 MPa
9.	Values of injector opening pressure in cyl.: #1 #2 #3	 19.5 MPa 17.5 MPa 17.0 MPa
10.	Firing order	3-1-2

Tested engine was equipped with well working fuel injectors. Each of them was preliminary tested and regulated in accordance with specification of engine producer. Injector testing and necessary regulations were performed with using of PRW-3 diagnostic device. All research has been done for nominal regulation of engine fuel injection equipment. Maximum compression pressure was checked for all engine cylinders too. Obtained results show that tested engine was in excellent technical condition.

Tested engine was equipped with different sensors connected to data acquisition system. It was prepared at Technical University of Radom in cooperation with ZEPWN Company. The main element of this system is Keithley KPCI 3110 measurement card. It allows record variations of engine high-speed parameters such: injector needle lift, cylinder pressure, delivery pipe pressure, crankshaft angle position or other voltage signals. Measurement card has two D/A (Digital/Analog) output channels which can be used in different way. Prepared system use one D/A output channel for controlling of fuel pump dosing. Features of the KPCI 3110 measurement card allow prepare special application for data acquisition with programmed interface of engine work control. Such application was performed with using of the Test Point software. Some advanced mathematical calculations of different engine parameters were done with using of MathCAD. Schematic diagram of the experimental setup used in tests is shown in Fig. 1.

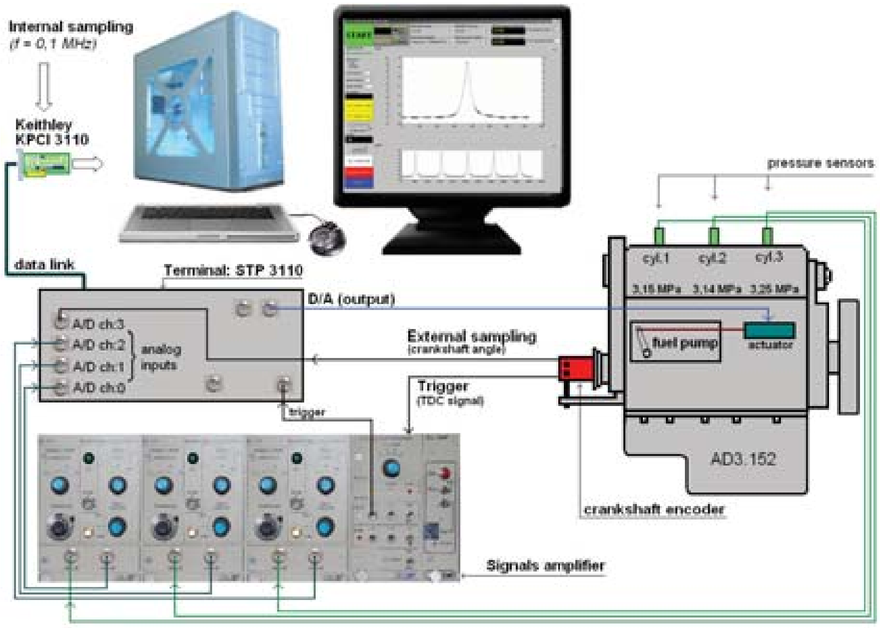

Fig. 1. View of measurement system configuration

Above presented, measurement system works in the following way. Tested engine should be thermally stabilized. For this reason the warm up procedure has to be executed first. Next, operator of measurement system has to prepare software configuration to work. Information about values of actually used internal sampling frequency and number of recorded samples are enters into dialog boxes (Fig. 2).

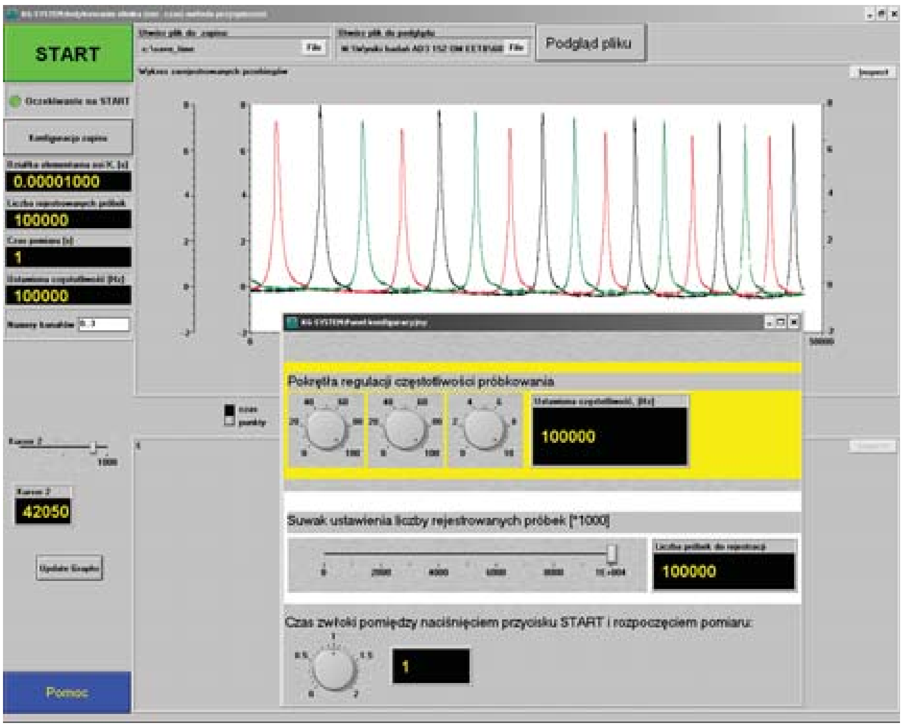

Fig. 2. View of software main window

Typical values of these parameters used in engine tests are as follows: 100 kHz and 100 000 samples respectively. For such configuration, a time of data recording equals 1 sec. only. It’s relatively small value, but long enough for engine testing with using of acceleration method.

When procedure of system configuration is completed then START button can be pushed by computer operator. Automatic procedure of engine test is initialized in this way. Computer waits for TDC signal from crankshaft encoder and when it occurs then D/A output voltage channel is used to supply of special actuator which can increase fuel pump dosing. Engine reaction on such change is rapidly process of the crankshaft acceleration (Fig. 3). In such conditions an engine works at full load and measurement system records necessary data.

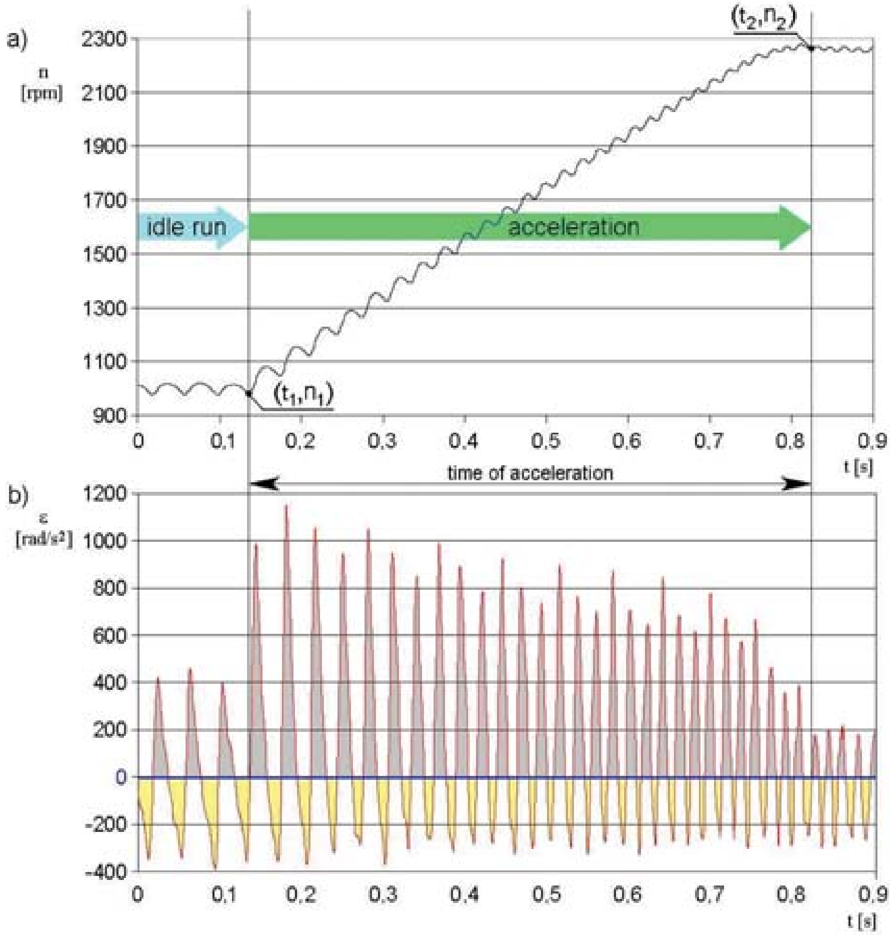

Fig. 3. Instantaneous variations of: a) rotational speed, b) angular acceleration of AD3.152 engine crankshaft obtained with using of acceleration method

Engine tests were carried out with using regular diesel oil (DF). Next, its blend with 40% vol. of Ethyl Tert Butyl Ether (ETBE) as oxygenated additive was prepared and used for research.

3. Test results

Engine tests were carried out in non-stationary conditions with using of crankshaft acceleration method. Example view of recorded, in-cylinder pressure variations are shown in Fig. 4. Tested engine starts accelerate at firing of cylinder no. 2. Next one is cylinder no. 3 and finally cylinder no. 1. Directly analysis of presented figure shows that in each cycle the maximum cylinder pressure is characterized for cylinder no 2. The lowest value of maximum pressure was observed for cylinder no. 1. The most interesting for researcher was cylinder no. 3. Knock phenomenon was detected just in this cylinder only. Fig. 5 presents in-cylinder pressures variations which were recorded in the first cycle of crankshaft acceleration process. High – pressure oscillations, typical for knock are visible in Fig. 5b and 5e. It should be noted, that in this case an engine was fuelled with regular diesel oil.

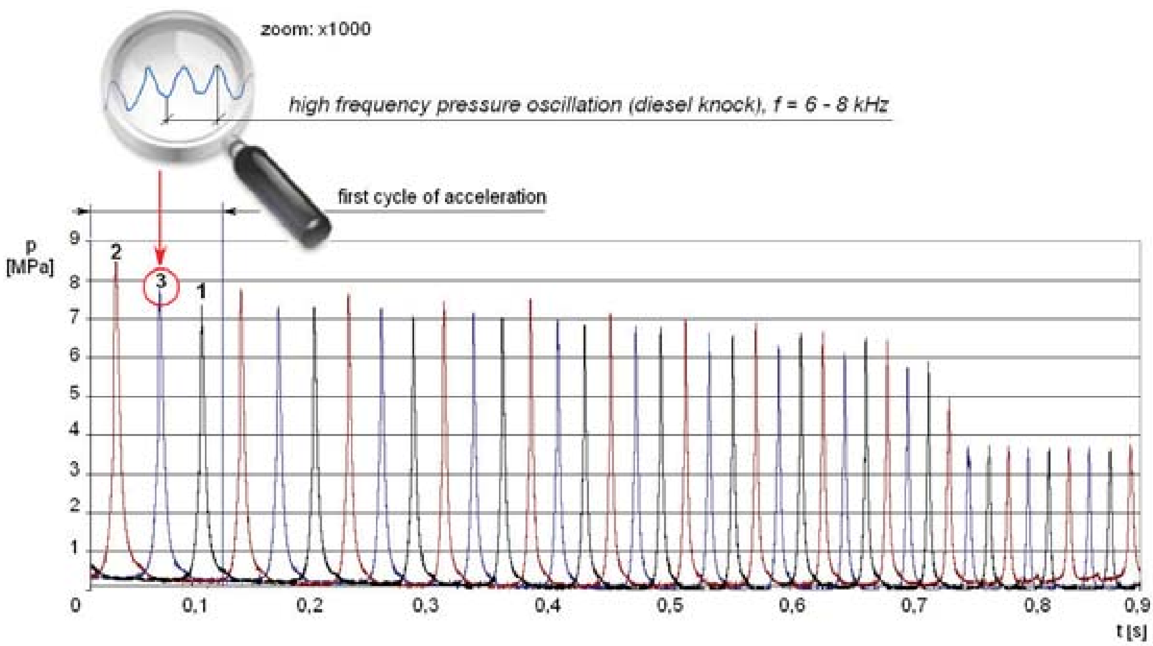

Fig. 4. Example variations of in-cylinders pressure recorded for accelerated AD3.152 engine fuelled with regular diesel oil

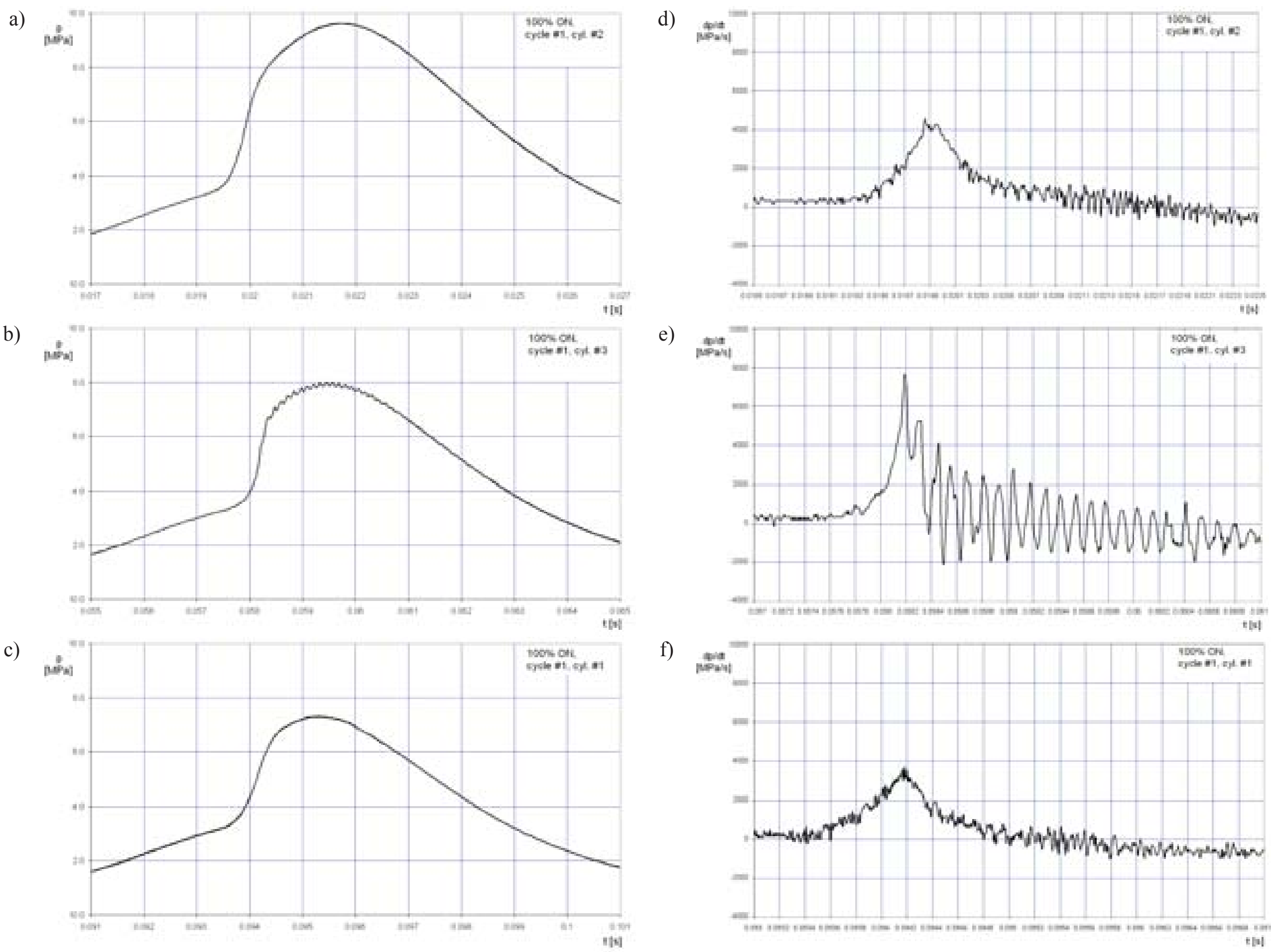

Fig. 5. View of in-cylinder pressures variations and calculated pressure rise rate in a first cycle of acceleration process for: a), d) cylinder no. 2; b), e) cylinder no. 3; c), f) cylinder no. 1 (engine fuelled with regular diesel oil)

Engine acceleration tests were repeated with using of DF-EETB fuel blend. Results are very similar (Fig. 6) in comparison with earlier presented in Fig. 5.

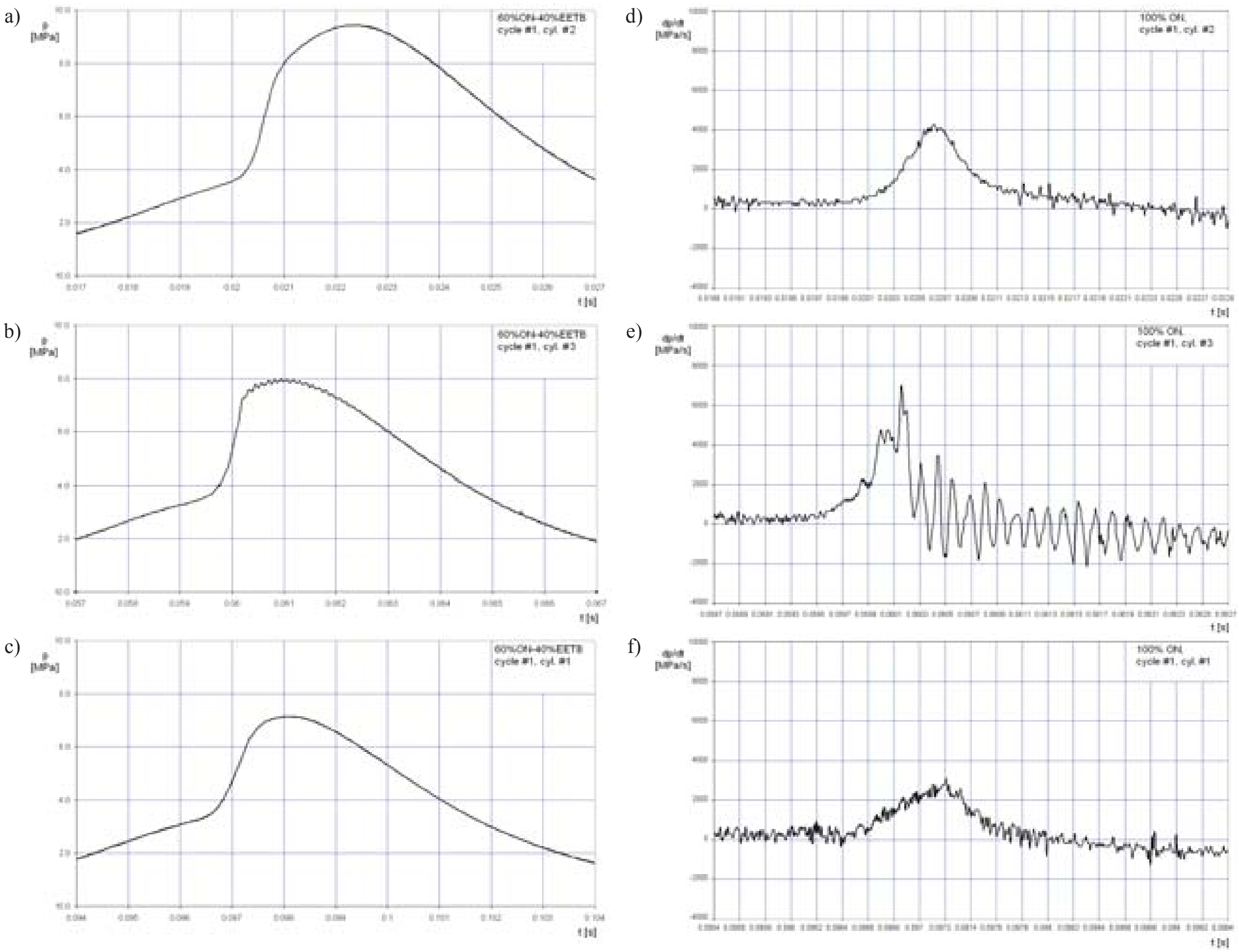

Fig. 6. View of in-cylinder pressures variations and calculated pressure rise rate in a first cycle of acceleration process for: a), d) cylinder no. 2; b), e) cylinder no. 3; c), f) cylinder no. 1 (engine fuelled with blend contained 60% vol. of regular diesel oil and 40% addition of EETB)

Knock was observed in the first two cycles recorded during acceleration process for cylinder no. 3. Example pressure oscillations recorded in the first cycle are shown in Fig. 6b. In each case, knock was preceded by rapid increase in value of pressure rise.

4. Conclusions

This paper describes preliminary experiment results, where tested engine was fuelled with two kinds of fuels: diesel oil and its blend with 40% vol. addition of ETBE. In case of such research, where alternative fuels are used for diesel engine fuelling, the knock problem should be an important part of investigation. Detection of such, abnormal combustion process can be realized with using of in-cylinder pressure analysis. For this reason, each combustion chamber of tested engine was equipped with cooled pressure sensor. Its signal can be recorded in relationship to crankshaft angle position or in domain of time. Data acquisition with using of crankshaft angle encoder is unfavorable because obtained sampling rate is usually to low for knock detection. Acquisition system should record pressure signals in domain of time, where sampling frequency should be adequately higher than knock frequency (typical range: 4-10 kHz) [5-6].

The most of researchers use Fast Fourier Transform (FFT) for spectral analysis of signals recorded from engines operated in stationary conditions. Test procedure is laborious in this case usually. Presented in this paper the acceleration method can significantly decrease a test time. Crankshaft acceleration period equals about 1 second only. Moreover, crankshaft acceleration procedure don't require engine brake. Using of acceleration method allows record necessary data from tested engine working at full load and full range of crankshaft rotational speeds. Above presented advantages of acceleration method show, that it should be helpful in engine research.

Pressure data recorded in above presented non-stationary conditions can not be analyzed with using of FFT, because it is designed for analysis of stationary processes. In case of non-stationary processes Short – Time Fourier Transform (STFT) can be used, but it has some unfavorable properties too. STFT allows analyze a short periods of recoded signal at domain of time with using a window of fixed-size and then sliding the window along of time. Because STFT uses a fixed-size window, that at high periodicities it has a poor frequency resolution, while at low periodicities the time resolution has to low value usually. For this reason, STFT may give an incorrect estimation of the periodicities and their instantaneous variations for a signal with multiple frequencies. Probably the best way of signals analysis recorded in non-stationary processes depend on using wavelet transform and it will be presented in next publications. Examples of pressure signal analysis with using of wavelet transform are presented in literature [7].

This paper focuses on the detection of knocking features in the combustion process based on conventional analysis of the in-cylinder pressure rise. Research show, that knock phenomenon can occur not in all cylinders at the same time, but can be characteristic for selected cylinder/cylinders. It is important information for all researchers which tests are done with using of multicylinder engines where only one cylinder is indicated. In case of tested engine the knock was detected in cylinder no. 3. It was observed only in the first phase of crankshaft acceleration process. In two other cylinders the combustion process was devoid of any disturbing symptoms. Although cylinder no. 3 was equipped with well working injector it was replaced on a new one. Next, engine tests were repeated, but knock was detected again only in cylinder no. 3. It seems that knock wasn't caused by injector failure, but reason should be found somewhere else. It is interesting that maximum combustion pressure wasn't recorded in cylinder no. 3, but regularly in cylinder no. 2. Analysis of in-cylinder pressure oscillation show, that knock phenomenon was preceded by rapid pressure rise. Its maximum value was about twice higher than in case of normal combustion.

In this research two kinds of fuels were used: regular diesel oil and its blend with 40% addition of ETBE. It has been observed, that amplitude of pressure oscillation in knock condition is higher not for tested fuel blend, but for pure diesel oil. It is suggest that ETBE can be an interesting oxyganted addition for diesel oil and it should be tested in the future.

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