IRREGULARITY OF ROTATIONAL SPEED OF DIESEL ENGINE WITH MODIFIED FUEL INJECTION SYSTEM

Damian Kowalski, Andrzej Bieniek, Sebastian Brol

Opole University of Technology
Faculty of Mechanical Engineering, Department of Road and Agricultural Vehicles
Mikolajczyka Street 5, 45-271 Opole, Poland
tel./fax: +48 77 400 6272
e-mail: d.kowalski@doktorant.po.edu.pl
a.bieniek@po.opole.pl, s.brol@po.opole.pl

Abstract

The operation of diesel engine is closely connected with controlling the process of injecting the fuel into the cylinder. It influences proper combustion process, which translates directly into irregular engine operation resulting in dumping and noise. It is related to improper control of fuel injection which is connected with improper completion of expected control strategy that can be a result of defective injection system. Irregular engine operation can also be caused by total lack of initiated combustion process in specific cylinder of the engine or in several cylinders, described as misfire, or ca be a result of differences in combustion process in individual operation cycles / engine cylinders. The effect is an engine working irregularly (there is instability of rotational speed) and emitting increased amount of pollutants. As a consequence the secondary fuel purification systems located in the exhaust system can be damaged. Therefore, it is required to choose the fuel injection control parameters in a way that enables detecting and correcting the process of fuel injection in order to minimize effects resulting from improper process of fuel combustion in individual cylinders or even lack thereof. It is useful to suggest diagnostic parameter that can be used to detect engine faultiness or elements of the accessories such as e.g. injection system. Ability to apply such control and correction of injection dose is provided by modified mechatronic in-line injection pump. The study shows results of researches on modified injection system with mechatronic in-line injection pump that enables identification of misfire and preventing irregular operation of diesel engine.

Keywords: *injection pump, pollutant emission, electric valves, transport, off-road*

1. Introduction

Correct combustion process in diesel engines is related to proper fuel delivery to the engine cylinders. As a consequence, the whole process of fuel injection has to be supervised, while in currently used systems it is based on electronic control. Despite numerous advantages, those systems are expensive to produce, highly damageable and have lower resistance to the quality and type of fuel used. In the engines of vehicles that are used outside of paved roads and in the units supplying industrial machines, mechanically controlled in-line injection pump, where the control system enables maintaining even engine operation and precise regulation of doses of fuel injected into the cylinders is frequently used. The solution offers good reliability and opportunity to use alternative fuel [1]. Hence, in the engines of researched types of vehicles and machines operating in difficult conditions, described as “off-road”, it is necessary to undertake research works that would enable adjusting the type of vehicles to comply with fumes emission standards as well as improving the whole process of fuel injection control in order to reach favourable indicators of engine operation, such as power or torque. Moreover, the engine must still be highly reliable and easy to operate, which in the case of vehicles described is particularly important. Each time when the defective engine is preventing further operation, it generates great costs resulting from vehicle or machines stoppage. Optimization of engine operation with regard to improved control of fuel injection is connected with irregularity of its

work, because correct process of fuel injection ensures stable work, decreased engine noise and dumping. It also translates directly into the performance, emissions and fuel use indicators. Uneven operation of engine is often caused by misfire in engine cylinders or premature or overdue start [6]. It can result in the unconsumed fuel penetrating into the exhaust system, which causes increased emission, damage of engine operation regulation systems and combustion gas treatment systems. This issue is very important due to the large number of reasons that can cause such occurrence, therefore, detecting the so called misfire can also be important diagnostic information concerning technical condition of the engine [5]. Signal detecting misfires, which should be transferred to the ECU allows for correction of injection system operation parameters.

2. Modernization of injection system

Injection system that went under research was built basing on the in-line injection pump, which was additionally provided with two sensors: rotational speed and location of injection pump camshaft. Injection sections have been extended by additional valves controlled electromagnetically. The valves include piston and housing along with internal fuel channels opened by an electromagnet located inside the section's housing. The view of modernized injection pump has been presented on Fig. 1a, and its section made in CAD on Fig. 1b.

a) b)

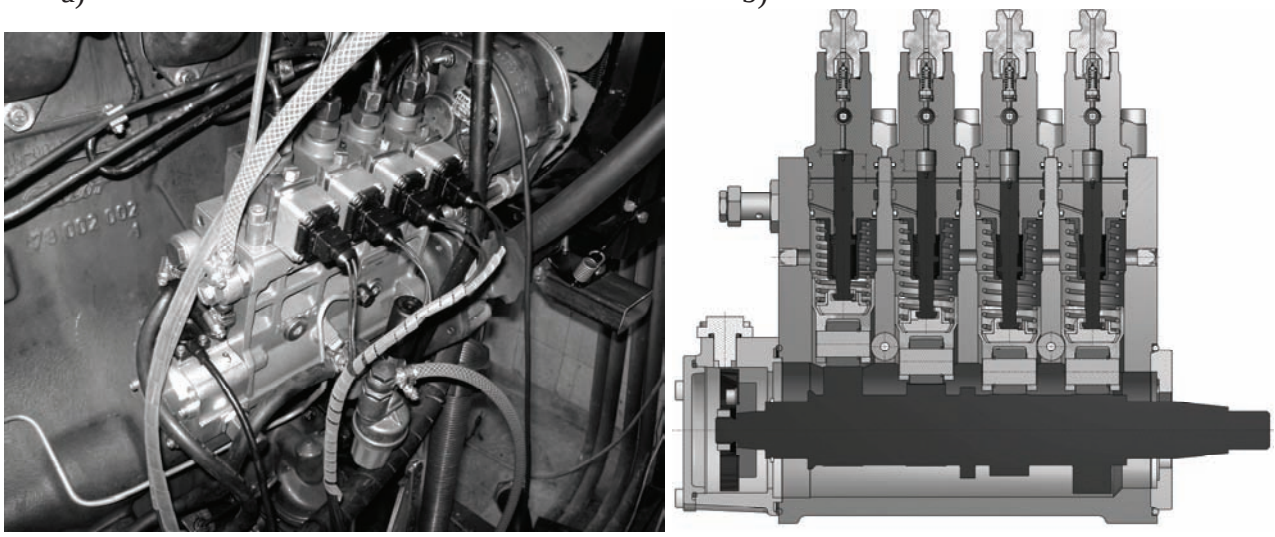

Fig. 1. Modified in-line injection pump EPP4M: a) view of a system fixed to the research engine, b) cross section of a pump EPP4M made in CAD

Important impact on the injection process and performed fuel pressure has proper geometrical shape of pressure section, whose active working range is up to 120° of pump camshaft's angle of rotation [3]. Presented in our study [2, 3] researches of such a pressure section provides the opportunity to modify the process of fuel injection to the rotational speed of 1600 RPM. It is caused by a reaction of solenoid valves to the control signal from ECU as well as to the hydraulic occurrences that are happening in the high pressure ducts. Technical parameters of EPP4M pump were included in Tab. 1.

In order to check how the modification of injection system influences the parameters of diesel engine operation, the above-described injection pump was fixed to the research diesel engine Z 1505 that was taken out of agricultural vehicles. The engine was fixed in the engine test house in the Opole University of Technology Department of Road and Agricultural Vehicles (Fig. 2).

Tab. 1. Technical parameters of modified in-line injection pump EPP4M

BASIC PARAMETERS OF IN-LINE INJECTION PUMP EPP4M	
Maximum power of engine cylinder	35 kW
Number of pressure sections	4
Diameter of piston	10 mm
Section piston travel	15 mm
Max working pressure of a pump	180 MPa
Gauge of pressure sections	45 mm
External diameter of pressure section	35 mm
Fuel dose	180 mm^3· stroke
Maximum speed of pump rotation	1500 RPM

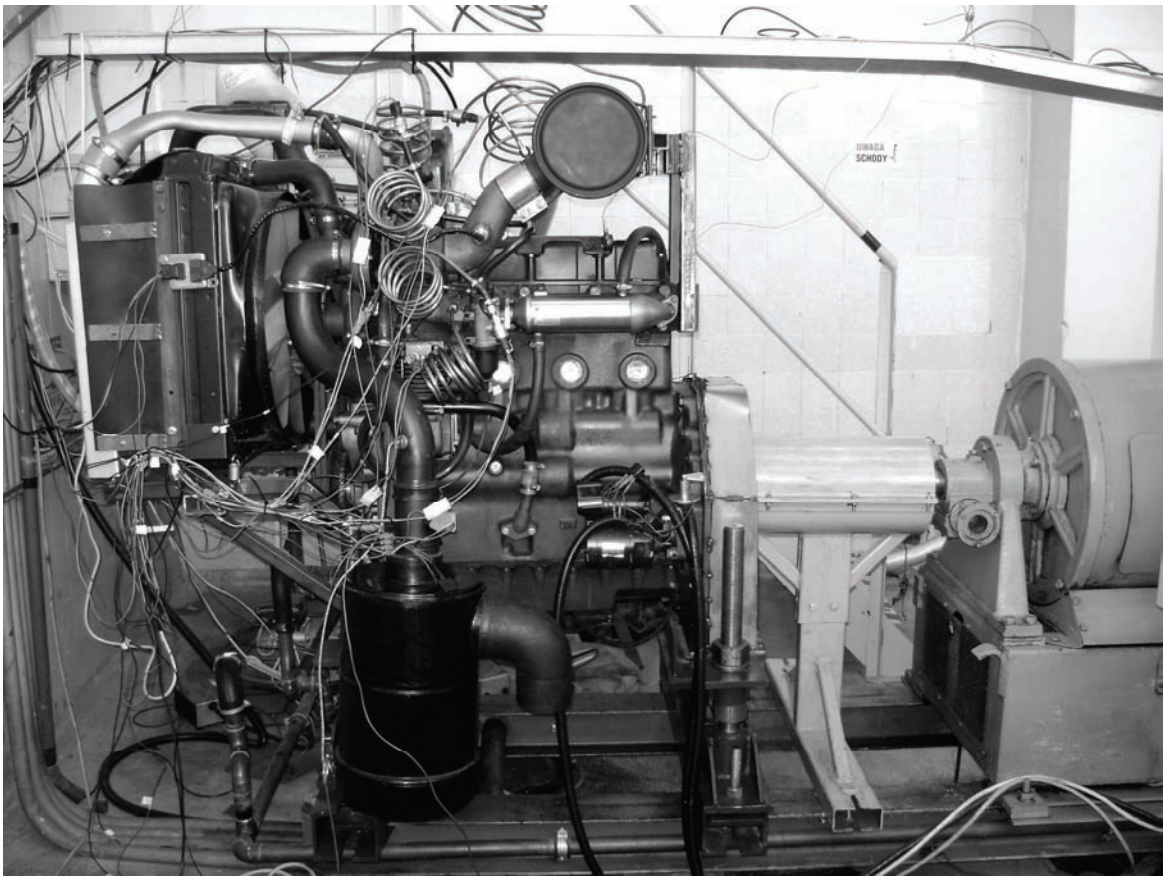

Fig. 2. Research station in the engine test house with the diesel engine Z 1505 fixed including implemented additional sensors and modified injection system

Dominant role in the process of controlling and supervising engine operations parameters is played by the ECU. Therefore, the research engine has been equipped with additional elements:
- electronic accelerator pedal,
- EGR valve,
- crankshaft sensor,
- air pressure and temperature in suction manifold sensor,
- fuel temperature sensor,
- oil temperature sensor,
- camshaft injection pump sensor.

Thanks to the signals sent to ECU, it is possible, using proper algorithm, to obtain diagnostics information concerning engine technical condition. Complete scheme of control system applied in Zetor Z 1505 engine has been presented in Fig. 3.

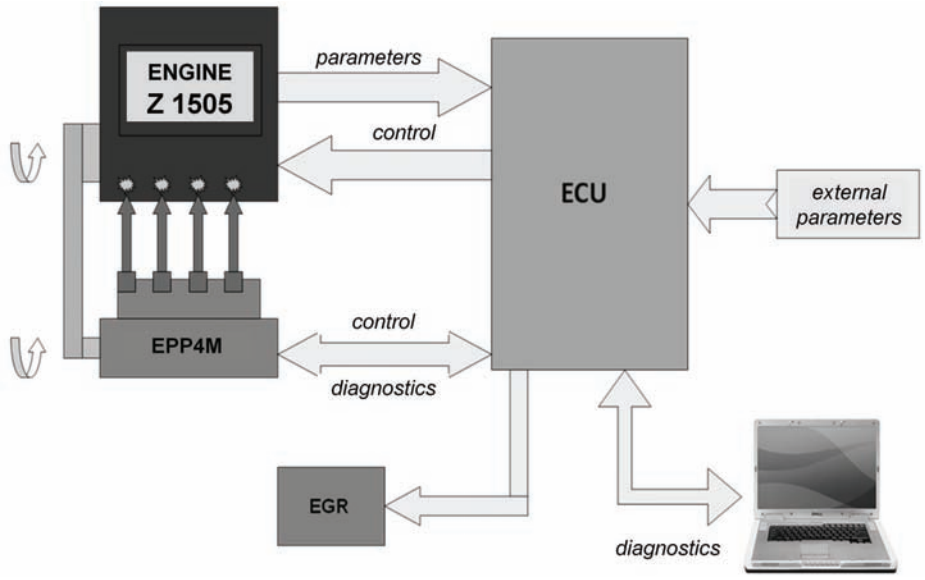

Fig. 3. Scheme of control system integrated with EPP4M pump

4. Research results

Research was performed on the unloaded engine at different speed of rotation. In the study we present results obtained basing on chosen trials. Parameters of injection such as time and angle of injection advance, number of injection phases, distance between individual phases have been modified. During the measurements, signals from the speed of crankshaft rotation have been registered.

Tab. 2. Test performance conditions

Test no.	Speed of engine rotation RPM	Engine cylinder operation	Injection phases
1	915	All cylinders	1 phase
2	915	All cylinders	2 phases
3	915	Cylinder no. 1 switched off	1 phase

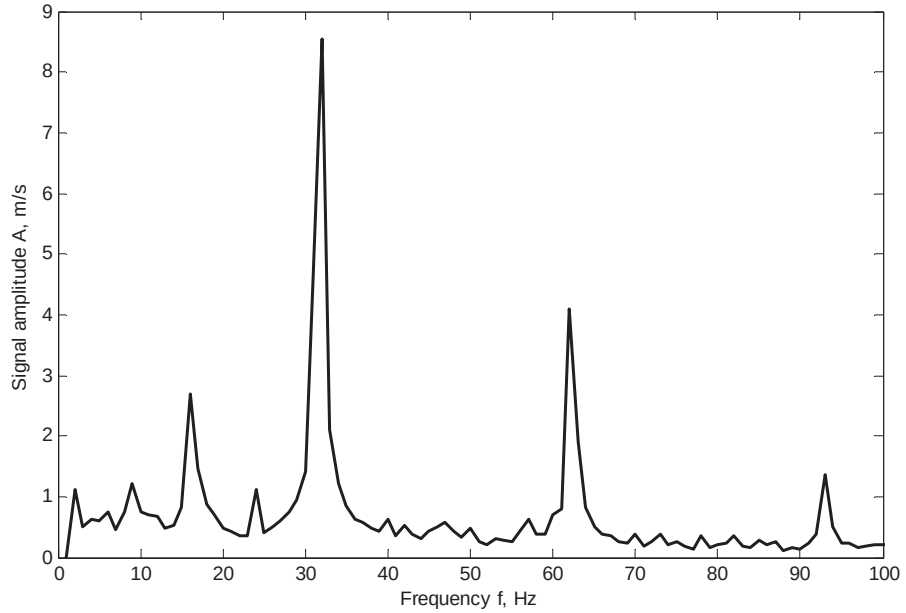

Fig. 4. Amplitude spectrum of signal of crankshaft rotation speed with one-phase injection

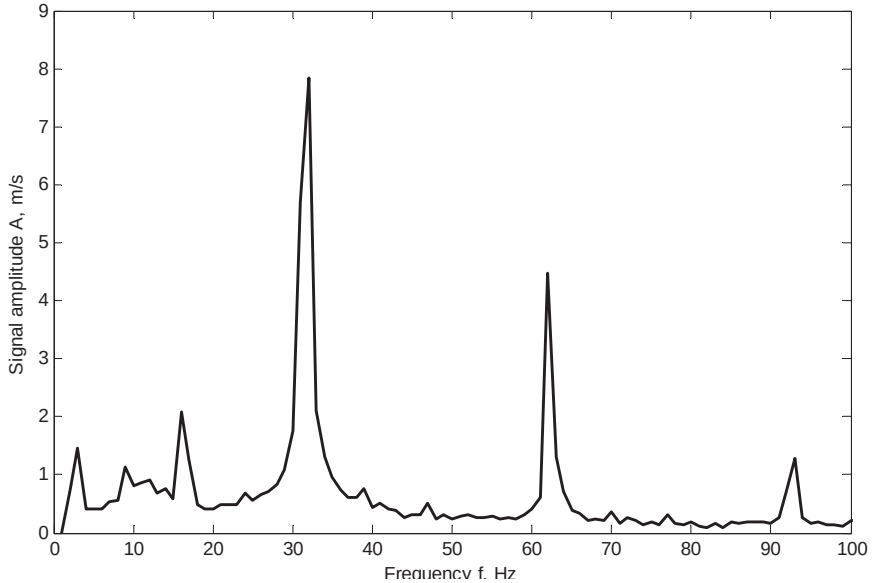

Fig. 5. Amplitude spectrum of signal of crankshaft rotation speed with two-phase injection

As the graphs show, switching off any cylinder results in great irregularity of engine operation that manifests in extended amplitude of frequency bandwidth connected with periodicity of engine operation proportional to its rotational speed.

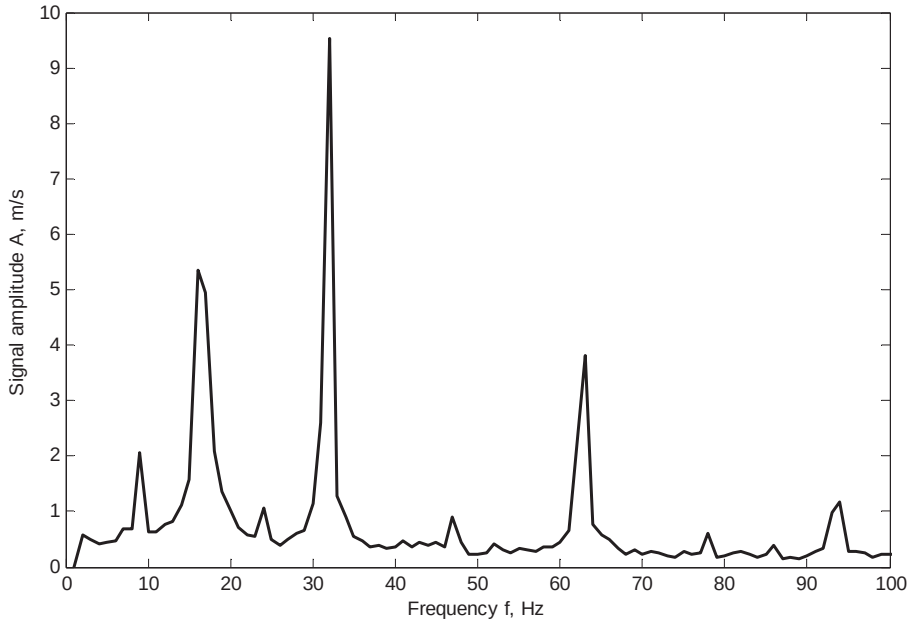

Fig. 6. Amplitude spectrum of signal of crankshaft rotation speed with first cylinder switched off

As the amplitude spectrum of the signal of crankshaft rotational speed analysis shows, the highest amplitude takes place at 32 Hz frequency, during tests with injection to the first cylinder switched on and off. Switching off the injection results in dominating harmonic amplitude increase by 1/5. Additionally, in both cases it was observed that with the frequency equal to ½ of dominating harmonic frequency peak takes place. It is worth noticing, that after the injection in the first cylinder was switched off, peak amplitude increase was doubled (Fig. 6). Dominating harmonic amplitude takes place with the frequency equal to half of the crankshaft rotation, hence, the frequency of combustion cycles, where half of this frequency is equal to circular frequency of the crankshaft.

4. Summary

Modifications in the in-line injection pump offer new opportunities for its use, mainly due to the occasion to shape the fuel injection process. Developing electronic control system that also allows for controlling the so called no combustion in the cylinders that manifests as irregularity of engine operation is an important element that enables to limit dumping and pollutants emission by the diesel engine. Research results indicate the opportunity to use alternative method in order to detect irregularity of engine operation and to shape fuel injection process, while properly adjusting load and engine operations to the conditions. The research also confirms that multi-phase injection process decreases irregularity of engine operation, which results in reduced vibrations and emission of harmful substances.

Acknowledgements

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