ISSN: 1231-4005
e-ISSN: 23540133
DOI: 10.5604/01.3001.0010.3078

DIAGNOSTICS OF A COMMON RAIL SYSTEM USING A SIGNAL ANALYSER

Sławomir Wierzbicki, Mateusz Stolarski

University of Warmia and Mazury in Olsztyn
Faculty of Technical Sciences
Oczapowskiego Street 11, 10-710 Olsztyn, Poland
e-mail: slawekw@uwm.edu.pl
mateuszstolarski@o2.pl

Abstract

Self-ignition engines are currently used to drive lorries, agricultural and road construction machines, as well as passenger cars. Common Rail supply systems are widely used in such engines. Arguments for using these systems include the simple construction of a system as well as practically unlimited control of fuel feeding (division of a fuel dose into several portions), which allows for controlling the fuel combustion process. This facilitates optimisation of the combustion process in limiting toxic emissions, which is the main evaluation criterion for modern combustion engines. Operation of an engine with a Common Rail system is controlled by an Electronic Diesel Control (EDC), which is responsible not only for controlling the supply system, but also for the diagnostics of the whole engine. The diagnostic monitors embedded in the controller supervise the operation of the supply system, but also of the whole engine, including the systems responsible for reducing toxic emissions released to the atmosphere, in accordance with the European On Board Diagnostic (EOBD) standard. Unfortunately, despite sophisticated diagnostic functions, defects sometimes occur in vehicles with engines with a CR system, which are not signalled by EOBD systems. In such cases, an additional tool is needed to help a diagnostician to identify the cause of improper operation of an engine. This article presents several examples to describe the diagnostics of a Common Rail system using an analyser of diagnostic electric signals to detect the cause of such defects.

Keywords: *Common Rail, EOBD, signals, electric, signal analyser, on-board diagnostics*

1. Introduction

The Common Rail system is currently the most commonly used system to feed self-ignition engines. Compared to earlier constructions, owing to a relatively simple structure and electronic control, these systems allow for achieving good parameters of engine operation, particularly low levels of toxic emissions. The structure of a Common Rail feed system for a self-ignition engine is shown in Fig. 1 [1, 10].

A Common Rail system supplies a specific fuel dose to a combustion chamber at specified time intervals (crankshaft positions). The mutual relation of these two quantities has a great effect on the mechanical parameters of the engine operation and side effects mentioned above: toxic emissions [4, 6].

A formal description of the mechanisms and phenomena during the process of introducing fuel to the workspace is complex and has been extensively described in the literature. The optimum fuel injection depends on a range of factors, including mainly: mechanical structure, engine load, fuel quality and weather conditions [8, 9].

Operation of an engine with the Common Rail system is supervised by an electronic control system, with a controller called an Electronic Diesel Control (EDC) as its main part. Apart from controlling the supply system and the other engine operation aiding systems, it monitors their operation and signals a defect if any abnormalities are detected in the operation of any subsystem. Moreover, information about the defect is saved in the controller's memory, which enables an external diagnostic device to read it.

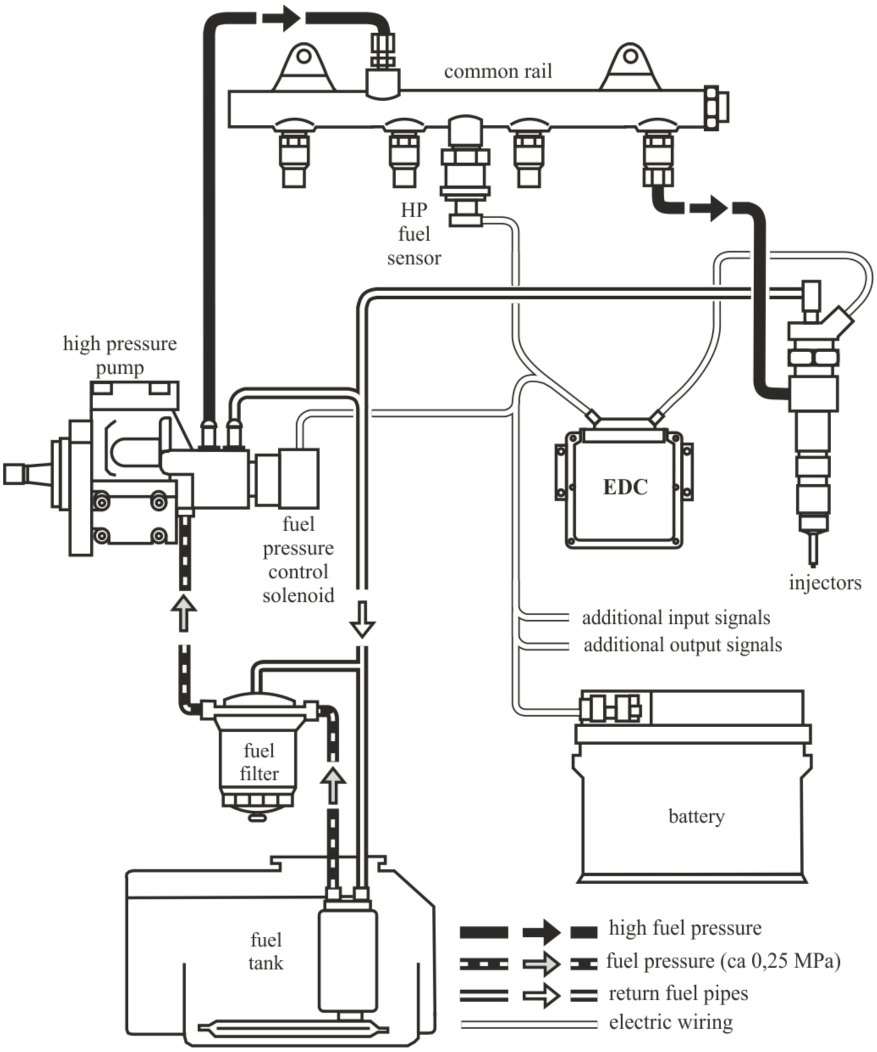

Fig. 1. Common Rail fuel supply system

Despite advanced diagnostic monitors embedded in an engine control system, some faults occur which result in improper operation of an engine, and the on-board diagnostic system does not signal a defect. In such cases, additional diagnostic tools must be used in order to identify the defect [4, 7, 8].

This article describes the application of an electric signal analyser of an injection system, which registers and analyses actual signals controlling the operation of an injector as well as a pressure sensor in the fuel tank.

2. Description of the EDIA-PRO signal analyser

An injection system signal analyser EDIA-PRO (Fig. 2) was used in the study. It is a device used in diagnostics of a Common Rail injection system. Connected to a computer via a USB port, the analyser can be used to register the current variations on each injector and a fuel tank pressure gauge signal [2, 3].

The registered signal trajectories are analysed and the results are used to determine the condition of each part of the injection system under examination. The measurement results can help to detect the malfunction of such parts as fuel injectors, a high-pressure sensor, a high-pressure pump and other subassemblies of the injection system.

The injector control signal trajectories can be measured with current probes; injectors do not have to be dismantled and the insulation of the injector feed lines does not have to be damaged.

An EDIA-PRO is a signal-registering device with five separate measuring channels. It transforms measured signals into digital signals, which later, after being processed in a signal processor, are sent to the program with an USB controller. EDIA-PRO communicates with the device, filters, analyses the signals, and enables a user to operate the device in various operation modes [2, 3, 5].

Fig. 2. An EDIA-PRO injector system signal analyser [2].

It precisely determines the times of registered injection signals simultaneously for all injectors. At the same time, changes in the fuel tank pressure are measured; such changes being caused by operation of the injectors, fuel pump and other system parts. When juxtaposed, these parameters can be used to diagnose the injector system and to detect difficult defects, which, though present, do not cause faults in the electronic engine control unit.

Work with an EDIA-PRO signal analyser mainly involves the operating of the measurement program. An appropriate operation mode should be selected as needed. The program has five different operation modes [2]:

- temporal analysis – simultaneous registration of injection signals in the injectors and pressure changes in the fuel tank,
- shape analysis – high frequency registration of consecutive injector signal trajectories, displaying them on one graph, superimposing one upon another for comparison,
- pressure analysis – a program operation mode which involves registration of fuel tank pressure, ability to carry out continuous registration for up to 10 minutes, intended mainly for diagnostics of a high pressure pump and the pressure control system,
- analysis of compression pressure – a function which enables assessment of the compression pressure in individual cylinders, a measurement is carried out indirectly by analysing the battery voltage changes during the engine start,
- analysis of a battery and an alternator – a program mode in which the electric system voltage on engine start and during its operation is registered; it determines a voltage drop on start-up, the alternator recharge voltage and voltage ripples after an engine start-up.

Figure 3 shows examples of injector control signal trajectories and tank pressure changes during an engine start-up, as registered with an EDIA-PRO signal analyser [5].

3. Temporal analysis of injection signals and tank pressure changes trajectory for diagnostics of malfunction of a Common Rail system

3.1. Diagnostics of uneven engine operation

The following is a description of an example of diagnostics of an engine with a CR system with uneven engine operation, although the engine control unit did not signal any defect.

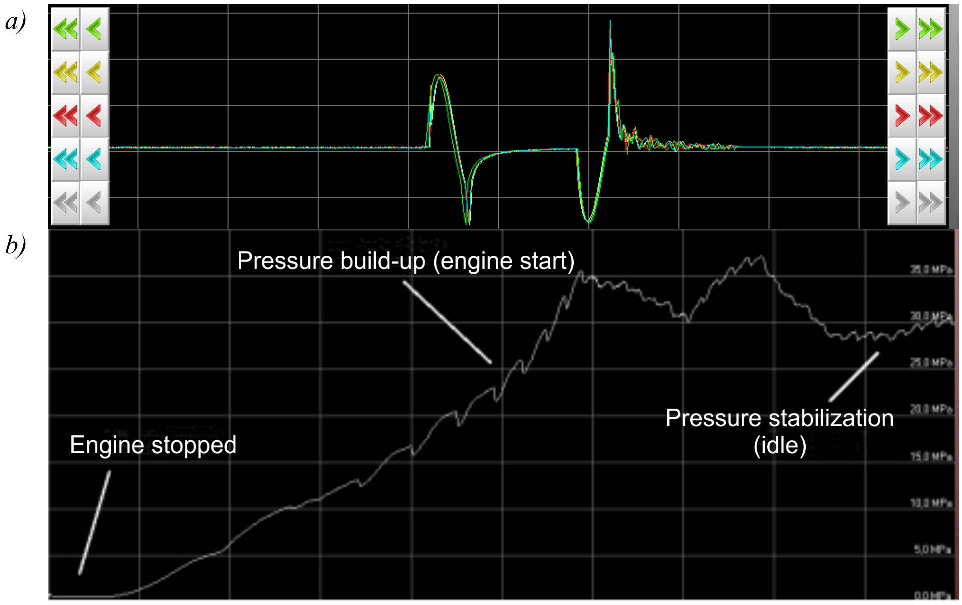

Fig. 3. Example of trajectories: a) injector control signals, b) fuel pressure in the tank during the starting of an engine

A temporal analysis mode was selected for precise analysis of fuel injector control signals and fuel tank pressure changes. The measurement yielded the trajectory shown in Fig. 4 [5].

An analysis of the signal trajectory shown in Fig. 4 reveals large fuel tank pressure fluctuations. These changes are not caused by fuel injections because they also occur between them. During the measurements, since the engine was working on idle gear with relatively constant load, the fuel tank pressure should not change so rapidly (by over 5 MPa). Rapid pressure changes between individual fuel injections with similar injector settings result in considerable differences in the fuel doses supplied to cylinders. This causes uneven angular acceleration between cylinders, waving rotation and hard engine work [3, 5].

Fig. 4. Analysis of signal trajectory in the temporal analysis mode for uneven engine operation

To diagnose this defect precisely, a diagnostic tester was connected, which enabled monitoring the setting of the high-pressure control valve by an electronic engine control unit. A simultaneous analysis of the pressure changes with EDIA-PRO and of the setting of the high-pressure control valve on a diagnoscope revealed a malfunction of the high-pressure valve.

After the high-pressure valve was replaced, the engine started working normally. Measurements with EDIA-PRO were carried out again to observe the changes.

Replacement of a high-pressure valve resulted in proper operation of the engine and the pressure regulation system. An analysis of the trajectories shown in Fig. 5 reveals that pressure changes are caused by injector opening and that pressure fluctuations are periodical [5]. Uneven engine work in this case was caused by a faulty valve, which seized, which resulted in jumpy pressure changes. Because of rapid changes of pressure in the fuel tank, diagnostics of this defect with a diagnostic tester alone proved very difficult. On the other hand, a diagnoscope combined with an EDIA-PRO injector system signal analyser provided a precise picture of the injector system operation. Its analysis enabled rapid and precise diagnosis of the defect without having to dismantle the system.

Fig 5. Analysis of a signal trajectory in the temporal analysis mode for even engine operation

3.2. Diagnostics of the cause of an engine being difficult to start

Another case, which shows the application of a signal analyser, involves an engine, which was difficult to start. The main parameters affecting the starting of an engine were checked before the EDIA-PRO device was connected [3, 5]:

- engine speed upon starting,
- fuel pressure in the tank upon starting,
- error memory in installed controllers,
- compression pressure in cylinders,
- performance of heater plugs.

After all of these possible causes of the engine malfunction were excluded, fuel injectors and their setting by an electronic engine controller were checked.

A test with a device for injector check is the most precise method of determination of the injector condition. During the checking procedure, the device supplies fuel to the injectors under the required pressure and the injectors are then controlled with various opening times in order to simulate work under various engine load levels. Various injection doses and injector leaks are measured during the test. The results are compared with control values in the injector tester database; subsequently, they are used to determine the condition of fuel injectors. Injectors can be checked with a tester only after they have been dismounted. Moreover, injector testing generates additional diagnostic costs.

An overall assessment of injector condition without having to dismount them can be made only by analysing the measurement results with an EDIA-PRO device. To this end, a signal analyser must be connected to the vehicle and the temporal analysis mode must be started.

Figure 6 shows examples of injector control signal trajectories and tank pressure changes during an engine start-up [5].

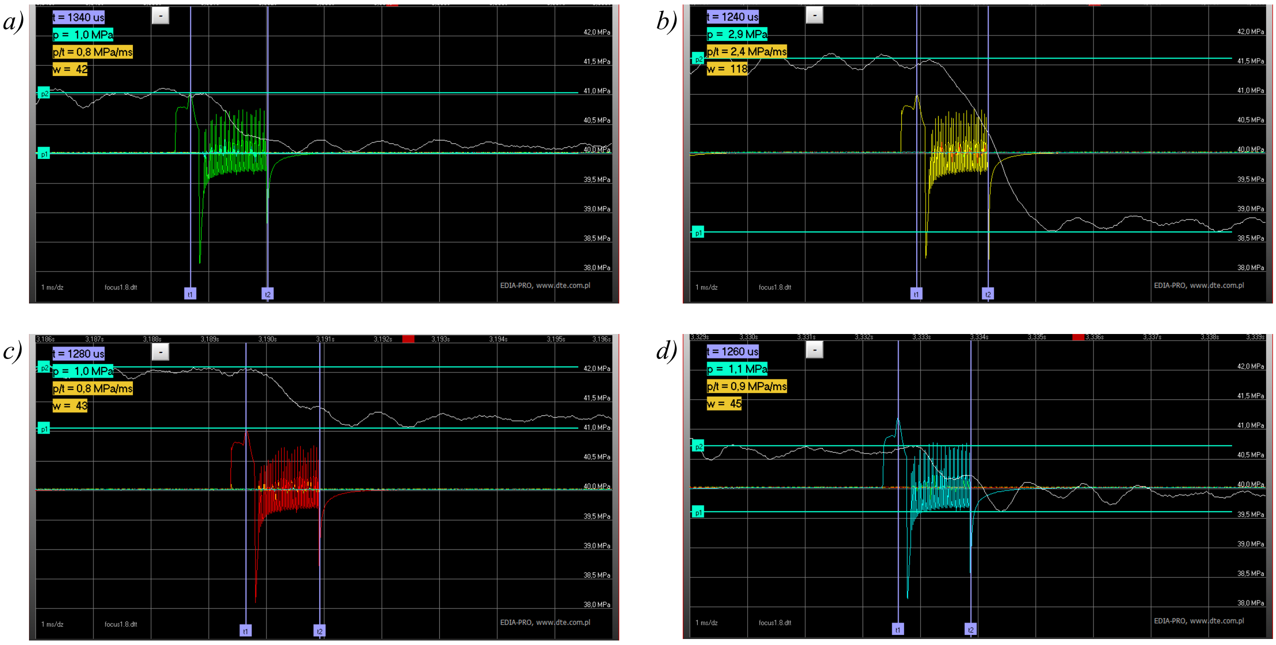

Fig. 6. Temporal analysis of injector signals: a) injector no. 1, b) injector no. 2, c) injector no. 3, d) injector no. 4

These measurements show that injection times are similar in all the four injectors and they range from 1240 us to 1340 us. Upon opening, injectors 1, 3 and 4 induced a pressure drop in the fuel tank by ca. 1 MPa. The pressure drop rate for the tank p/t = 0.8 MPa/ms for injectors no. 1 and 3 and p/t = 0.9 MPa/ms for injector no. 4. Injector no. 2 brought about a pressure drop of 2.9 MPa in the tank; pressure drop rate: p/t = 2.4 MPa/ms. With such discrepancies in the operation parameters, injectors should be dismounted and checked with an injector tester [5].

An analysis of the results of these measurements revealed defects in injectors no. 1, 3 and 4 because a low pressure drop rate for a fuel tank p/t is a sign of too low fuel flow rate. This means that starting the engine was prevented by insufficient amounts of fuel dispensed by defective injectors 1, 3 and 4.

The injectors were dismounted and checked with an injector tester. The test result confirmed the findings of the diagnosis with EDIA-PRO. Injectors no. 1, 3 and 4 were defective, they supplied insufficient doses of fuel to the engine, which is a sign of their seizure or blockage [5].

3.3. Diagnosing the cause of an engine jerking and excessive vibrations

The third example of diagnostics with an injector system signal analyser involves an engine whose malfunction manifested itself with vibrations, jerking and uneven work on idle gear. Moreover, the issue does not appear regularly and the interval between engine jerks can be as long as several minutes.

Diagnosis of the engine was started by connecting a diagnostic tester to the engine controller. Due to the sporadic occurrence of the issue and momentary disruptions of its work, the engine controller did not register any faults associated with the malfunction. Due to the nature of the defect, a mechanical defect of the engine was ruled out preliminarily and a subsequent diagnosis of the function of the Common Rail fuel injection system was started. Due to the frequency of occurrence of the symptoms, the issue could not be grasped until after several consecutive measurements. Fig. 7 shows fragments of signal trajectories during the faulty engine operation [5].

An analysis of these signal trajectories shows that injector no. 2 jammed in the open position, which resulted in a momentary pressure drop in the fuel tank, further resulting in uneven engine operation. Injector no. 2 started working normally after two consecutive injection signals, and the fuel pressure regulation system was able to bring it to the pre-defect level.

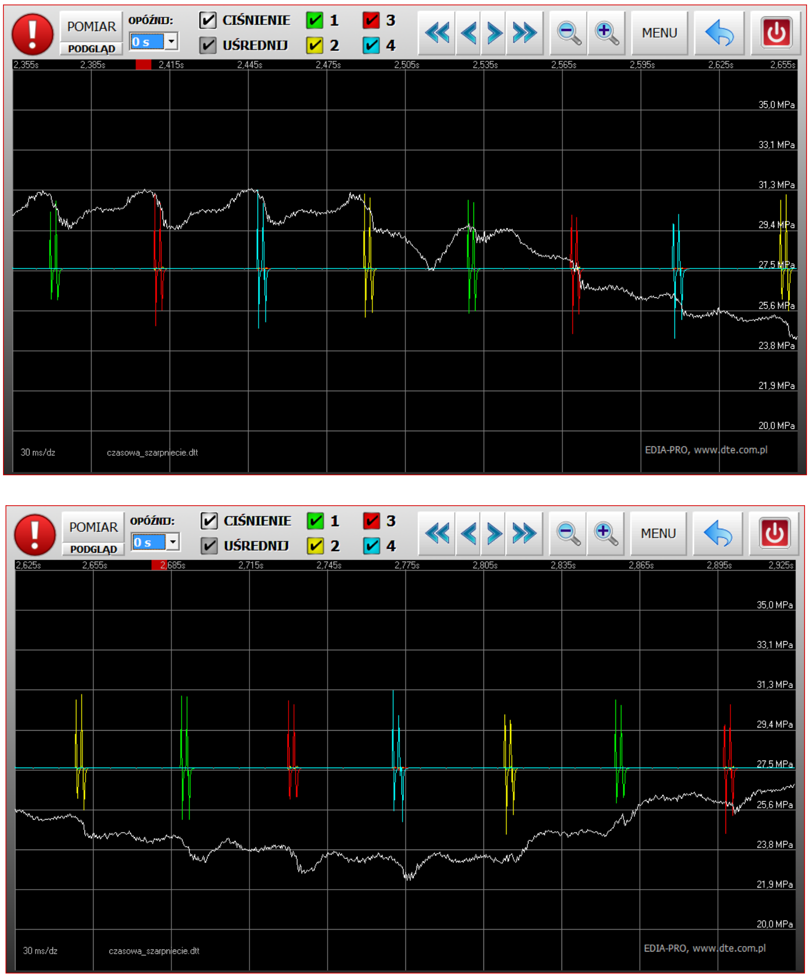

Fig. 7. A temporal analysis of injector control signals and pressure changes in the fuel tank during engine jerking

4. Summary

Common Rail injection systems enable precise dispensing of fuel and a proper injection process, regardless of the current engine operation, thereby ensuring low fuel consumption, highly dynamic and smooth engine work.

However, they are also susceptible to defects and abnormalities of operation. Proper diagnostics and assessment of operation of Common Rail systems is very important because of expensive spare parts and time-consuming replacement procedures. A diagnostic tester is the main tool used to diagnose defects in the injection systems discussed here. It often happens that an electronic engine controller does not register faults despite abnormal operation of the system. One of the possible causes is that not all parameters and behaviours of an injector system can be measured and analysed properly by the engine controller. Another reason why faults are not registered is that engine controller software is updated increasingly often in order to hide various defects or to remove by software modifications such elements as a particulate filter or an exhaust gas recirculation valve. If an engine controller is damaged or its repair has not been done properly, an engine may not work properly and the engine controller will not register any defects.

Defect diagnostics in such cases is very difficult and often time-consuming. The application of an injection system signal analyser to register and analyse signal trajectories enables diagnostics “from the outside”, regardless of the engine controller software, its damage or possible modifications. Owing to the simplicity of the device connection and its capabilities, it is justified to use it for rapid diagnostics of Common Rail injection systems and to determine the system operation.

An injector system signal analyser combined with a diagnostic tester enables rapid and comprehensive assessment of the condition of a Common Rail injection system. The devices are complementary and enable the proper diagnosis of defects whose detection could be time-consuming or even impossible.

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