TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2015, Vol. 15, No. 1, 61–64

Diagnosing Common Rail Fuel Injectors Using Fuel Micro-Doses

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Received February 09.2015; accepted February 19.2015

Summary. This paper presents the methods for diagnosing modern fuel injectors. One of the methods for analysing fuel injector operation is its diagnostics using fuel micro-doses. Small fuel doses are produced at low fuel injection pressure and short fuel injection times. When fuel injector components have been damaged or seized, then a fuel injector loses its power. The first signs of its malfunction are the losses of fuel micro-doses.
Key words: compression-ignition engine, fuel injector, fuel for CI engine, fuel spray nozzle, fuel injector valve, fuel injection time, fuel injection pressure.

INTRODUCTION

The development of automotive industry is directed towards the reduction of toxic substance emissions into the atmosphere and the reduction of fuel consumption by internal combustion engines [1]. In recent years, a particular attention has been paid to compression-ignition (CI) engines through their dynamic development. In 1997, a Common Rail (CR) fuel injection system was implemented due to the standards referring to exhaust gas toxicity, which has been continuously evolving year by year. The major advantage of the CR system is multi-stage division of injected fuel dose by the electronic control of fuel injector operation and high fuel injection pressure, reaching at present up to 250 MPa. The purpose of modern engine fuel supply system development is to meet rigorous standards through such an organisation of the process of air-fuel mixture combustion that as little toxic substances are emitted into the atmosphere by the engine as possible at the lowest possible fuel consumption, maintaining its basic operating parameters, such as power and torque [3, 4, 5, 6, 15, 16, 17].

CHARACTERISTICS OF FUEL INJECTORS USED IN COMMON RAIL SYSTEM

Major manufacturers of Common Rail fuel injection systems are Bosch, Delphi, Siemens Continental VDO and Denso.

Different fuel injector divisions are known but for practical reasons they are divided in the process of diagnosing into reparable and non-reparable ones.

Reparable Common Rail fuel injectors include Bosch solenoid-controlled fuel injectors (1.0, 2.0, 2.1 and 2.2 generation) and all Delphi solenoid-controlled fuel injectors. Non-reparable fuel injectors include: Bosch piezoelectric fuel injectors solenoid-controlled fuel injectors (2.5 generation), Siemens piezoelectric fuel injectors, Denso solenoid-controlled and piezoelectric fuel injectors, and Delphi piezoelectric fuel injectors.

The above-mentioned fuel injectors are non-reparable due to the lack of spare parts and repair technology (lack of mounting parameters and specialist original tools) [18, 19, 20, 21].

During fuel injector tests, four primary fuel injection doses and two fuel return doses are tested. The tested fuel injection doses are the following: a dose at full engine load (being characterised by the highest fuel injection pressure and a relatively long time of fuel injection, more than 800 μs), an emission dose (or a dose of part engine load at a fuel injection pressure of about 80 MPa and fuel injection time of about 400-600 μs), an idle dose (fuel injection pressure of 25 MPa and fuel injection time of 400 μs), and an initial dose (fuel injection pressure of about 50 MPa and fuel injection time of 800 μs). Internal combustion engine operates under variable conditions. The engine load during its operation changes all the time. Before each primary fuel injection, a fuel injector delivers an initial dose of fuel to the combustion chamber. Its volume depends on the engine operation status [2]. When the engine is idling, the volume of an initial doses is 250 μs at a fuel injection pressure of 25 MPa. The volume of fuel dose being injected amounts then to 1 mm³/H. They are very small values. The first fuel injector malfunction is characterised by their loss, which adversely affects the operation of CI engine.

STUDY OBJECTIVE

The aim of this study was to analyse the technical condition of Siemens Common Rail piezoelectric fuel injectors. The tested fuel injectors belong to the group of non-reparable injectors. As has been mentioned above, all the fuel injectors belonging to this group are non-reparable ones and therefore it is not possible to perform a microscopic examination of their components. The proposed diagnostic method is designed to examine them using fuel micro-doses. Micro-doses, called pilot doses, occur at short fuel injection time amounting to 250-300 μs, prior to a proper fuel injection [7, 8, 9]. They are intended to prepare the combustion process in a CI engine. A micro-dose can be also used as a tool for diagnosing fuel injectors. At low fuel injection pressure and times, it is possible to diagnose the malfunction of an injector's plunger and barrel assembly components. When a fuel injector starts to fail, the first fuel dose which starts changing its parameters is the initial dose because it has a low value and every seizure of plunger and barrel assembly component, leaking or fouling affects it, reducing its volume [10, 11, 12, 13, 14].

PRESENTATION OF TEST OBJECT AND TEST BED

The test object was the Siemens piezoelectric fuel injector, with the catalogue number 9674973080. It is a non-reparable and sealed [not dismountable] injector due to the lack of spare parts, sealing and mounting information. Figure 1 presents the tested object.

Fig. 1. The tested Siemens piezoelectric fuel injector

Laboratory tests were conducted using specialist test bench STPiW-3 (Fuel Injection Pump and Fuel Injector Test Bench) used to diagnose Common Rail fuel injectors and fuel injection pumps. The tests consisted in the examination of fuel injection doses and return fuel doses of fuel injectors. The first stage of tests was to perform a general test. The full engine load dose, emission dose, idle dose and initial dose were examined. In the second stage of tests, the focus was put only on the examination of micro-doses at different fuel injection pressure. The adopted time of fuel injection for a micro-dose was 250 μs. Figure 2 presents the test bench STPiW-3.

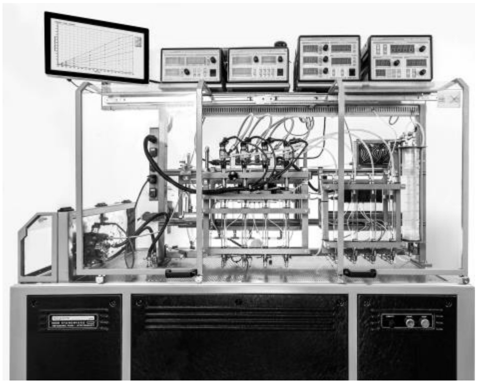

Fig. 2. The STPiW-3 test bench for fuel injector testing

LABORATORY TESTS

The first stage of laboratory tests was to perform a general test of fuel injector. Table 1 presents the test findings.

Table 1. General test of the examined fuel injector

	Fuel injection dose	
	Set value	Actual value
160 MPa, 1020 μs	41.12-53.12	51.24
125 Mpa, 290 μs	12.47-17.47	15.43
85 Mpa, 440 μs	17.19-12.31	14.67
24 Mpa, 510 μs	7.31-12.31	9.65

In the second stage, the fuel injector was tested for the volume of micro-doses. The time of fuel injection was set to 250 μs, while the range of fuel injection pressure to 25-150 MPa. Table 2 presents the volumes of fuel injection doses for the tested and the model fuel injector.

Tab. 2. Volumes of fuel injection doses for the tested and the model fuel injector

Fuel injection pressure [Mpa]	Model dose [mm³/H]	Tested dose [mm³/H]
25	1.5	0.43
50	4.4	3.1
75	6.6	4.5
100	8.9	5.5
125	10.9	7.2
150	12.3	8.4

Figure 3 presents the operating characteristics of a fuel injector operating on micro-doses.

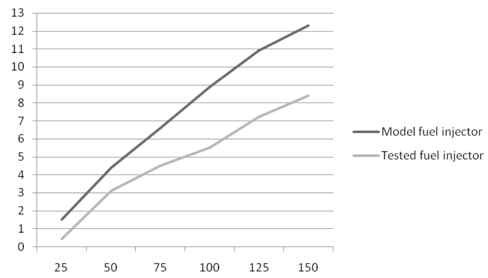

Fig. 3. The operating characteristics of a fuel injector operating on micro-doses

Table 3 presents the volumes of return fuel doses for the tested and the model fuel injector.

Table 3. Volumes of return fuel doses for the tested and the model fuel injector

Fuel injection pressure [MPa]	Model overflow [mm³/H]	Tested overflow [mm³/H]
25	0.4	3.5
50	3.8	8.7
75	6.2	12.5
100	8.2	24.8
125	11.4	36.2
150	19.5	55.3

Figure 4 presents the operating characteristics of a fuel injector allowing for the volumes of return fuel doses. This characteristic curve was prepared also owing to the application of the test bench for testing fuel injection pumps and fuel injectors (STPiW-3).

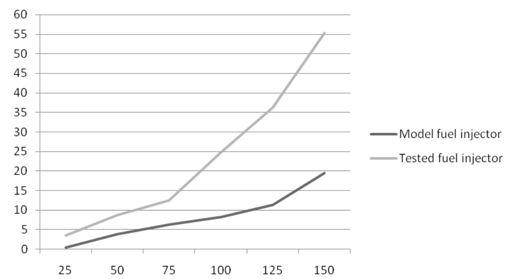

Fig. 4. A roller found in the body at faulty position

One of the most frequent causes of micro – dose loss is a seizure in the fuel injector's plunger and barrel assembly. Figure 5 presents a sample fuel injector tip which was damaged and slightly seized. This wear induced a reduction in the value of initial dose.

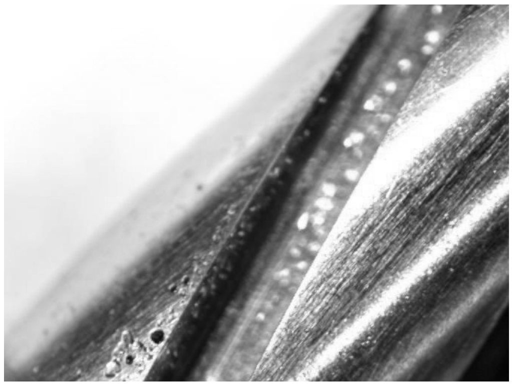

Fig. 5. A seized component of the plunger and barrel assembly of a fuel injector's needle

CONCLUSIONS

The conducted laboratory tests showed that the actual values of fuel injection doses during a general test were within the set ranges. This means that the tested fuel injector is in working order. Additional tests on the values of fuel injection micro-doses showed a starting malfunction of the tested fuel injector. All the volumes of initial fuel injection doses were reduced in relation to the model fuel injector, whereas the volumes of return fuel doses, called the overflow volume, were increased. This is due to the wear of components in the plunger and barrel assembly of the tested fuel injector. Conducting tests on fuel micro-doses is helpful for non-reparable fuel injectors. Reparable fuel injectors can be disassembled, examined under a microscope and the technical condition of their plunger and barrel assemblies can be evaluated, whereas non-reparable fuel injectors can only be diagnosed by testing. If during the testing a loss of initial doses occurs, it can be concluded that the tested fuel injector is getting worn.

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DIAGNOZOWANIE WTRYSKIWACZY UKŁADU COMMON RAIL ZA POMOCĄ MIKRODAWEK

Streszczenie. Artykuł opisuje sposoby diagnozowania współczesnych wtryskiwaczy paliwa. Jednym ze sposobów analizy pracy wtryskiwacza paliwa jest jego diagnoza za pomocą mikrodawek wtrysku. Małe dawki wytwarzane są przy niskich ciśnieniach i krótkich czasach wtrysku. Jeżeli elementy wtryskiwacza paliwa uległy uszkodzeniu, zatarciu wtedy wtryskiwacz traci moc. Pierwszymi objawami jego niedomagania są zaniki mikrodawek.
Słowa kluczowe: silnik o zapłonie samoczynnym, wtryskiwacz paliwa, paliwo do silnika ZS, rozpylacz paliwa, zawór wtryskiwacza, czas wtrysku, ciśnienie wtrysku.