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Diagnostics and measurement of the gasoline engines injection system

***Streszczenie**. W pracy przedstawiono wyniki badań elektronicznego system wtrysku paliwa, które mogą być stosowane w kwestiach diagnostycznych. Opisano konstrukcję i pracę typowego systemu wtrysku paliwa, a także przeanalizowano jego elektroniczną część. Zaproponowano również metodę wykrywania wadliwego wtryskiwacza, bazującą na analizie charakterystyk prądu różnicowego. Wykazano różnice w parametrach elektrycznych poszczególnych wtryskiwaczy paliwa, które mogą być poprawione np. dzięki odpowiednim algorytmom samokształcenia. (**Diagnostyka i pomiar układu wtryskowego silników benzynowych**)*

***Abstract**. The paper presents the electronic fuel injection system research results, which can be used in diagnostic issues. Have been described the construction and operation of a typical fuel injection system and analysed its electronic part. It has also been proposed method for the detection of the injector malfunction, based on the analysis of differential current characteristic. Have been shown differences in the electrical parameters of the individual fuel injectors, which can be corrected e.g. by suitable self-learning algorithms.*

Słowa kluczowe: elektroniczny wtryskiwacz paliwa, diagnostyka, pomiar, charakterystyka prądu różnicowego.
Keywords: electronic fuel injector, diagnostics, measurement, current characteristic analysis.

Introduction

Electronic fuel injector is an important part of the engine gasoline fuel system. The fuel injector is a solenoid valve. Forces which act on the active injector core are caused by friction, spring tension and fuel pressure. Rising current curve is partially different from the curve of an ideal inductor current. The effect which causes a change of permeability is caused by the movement of the needle valve. Injector opening time is visible on the current characteristics and the closing time – on the voltage characteristics. Stopping the movable element of the injector is seen as disturbance on the measured characteristics.

Principle of the Electronic Fuel Injector Operation

Electronic fuel injector is an electromagnetic valve. Its internal structure is shown in the Fig.1.

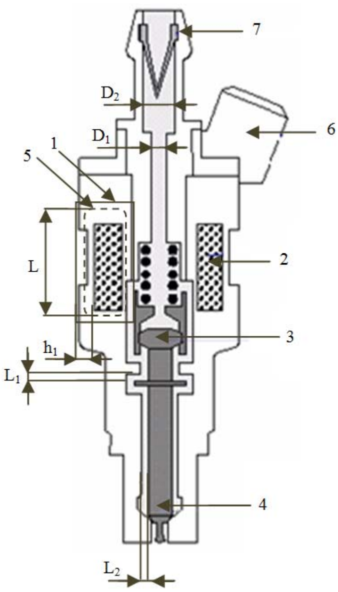

Fig.1. Construction of an electronic fuel injector [4]: 1 – Iron core, 2 – electromagnetic coil, 3 – armature, 4 – needle valve, 5 – yoke of magnet, 6 – electrical connection, 7 – filter

The basic part of the valve is armature, needle valve, iron core, electromagnetic coil and returning spring. Before injection, the needle valve is compressed tightly on the fuel needle valve pedestal by spring and fuel. Electromagnetic force provided by injection coil is greater than spring force fuel pressure and friction force. When the current flows through coil, then needle valve opens upward, electronic fuel injector sprays once. When in injector coil power is turned off, under spring force effect, needle valve electromagnetic force decreases rapidly. Needle valve starts closing, then an injection process will be finished [1, 2].

Measuring System for Determining the Current and Voltage Characteristics of the Fuel Injectors

Fig.2 shows block diagram of the measuring system for gasoline injectors. The main component of the electronic control device is a programmable controller, which is designed to open and close the transistors. Injectors are connected to the collectors of these transistors. Five buttons keypad allows setting the transistors opening time. LCD display shows the current mode.

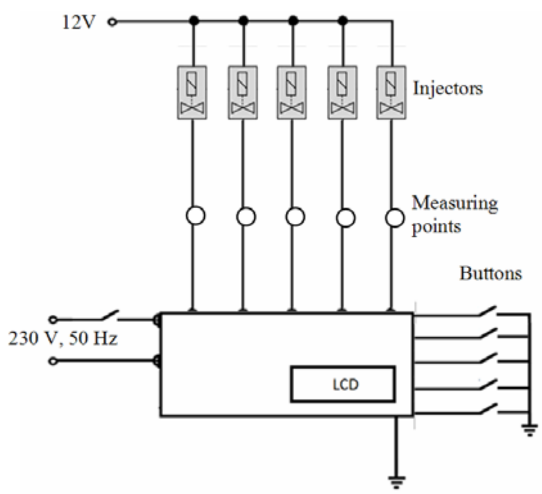

Fig.2. Block diagram of the measuring system

Measured current and voltage characteristics show the deviations from the ideal state. Movement of the core, which causes the inductance change, affects on the current and voltage characteristics.

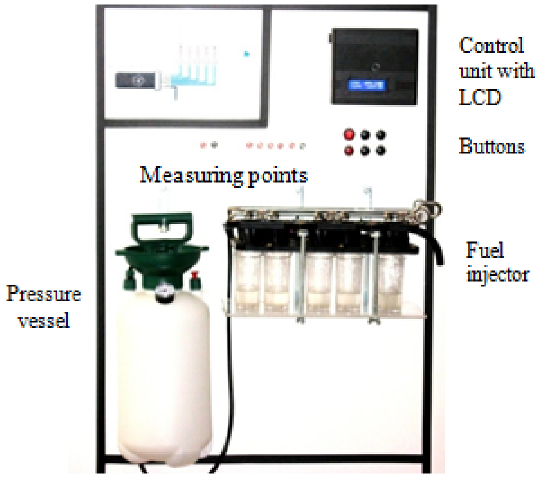

Fig.3. Testing device

Measurement results shown in Fig.4 were divided into a few intervals. The interval A is injector inaction, B refers to moving the injector core, C is the injection action with the current increasing, D is injector in operation, E refers to overvoltage caused by the inductance of the injector (moving core injector to initial position), F is fading overvoltage and G is injector inaction [3, 4].

The time required to open the 12 – 16 Ω injector is about 1.5 ms. This time is depending on the fuel pressure, injector spring force, inertial core properties, electromagnetic coil, core and injector material. The time required to close the injector is only half of the opening time. Closing of injector is executed by spring and fuel pressure only [5].

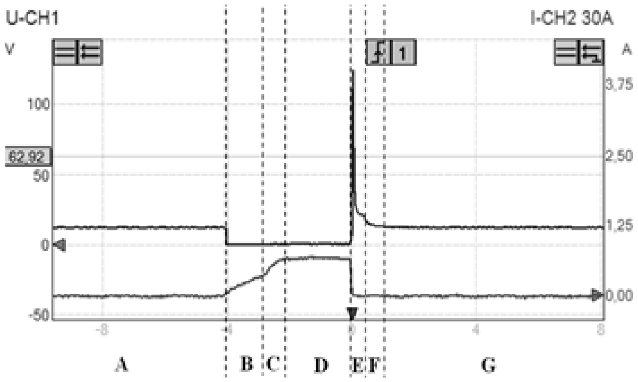

Fig.4. Fuel injector voltage and current characteristics

Current Characteristic Analysis

In Fig.5a are shown the measured characteristics of the reference current and failure current. Reference current time behaviour is composed from five measurements with the fluid under pressure at 2.5 bar.

Sampling value on oscilloscope has been set to 100 kS/s (time between sample is 10 μs). Injection time has been set to 5 ms. Characteristic of the failure current was obtained by stopping the needle valve in the opening position.

The difference between the reference and fault currents is shown in Fig.5b. On this characteristic can be seen two extremes. One is in 650 μs (for current: 64 mA) and a second is in the 1460 μs (for current: -180 mA).

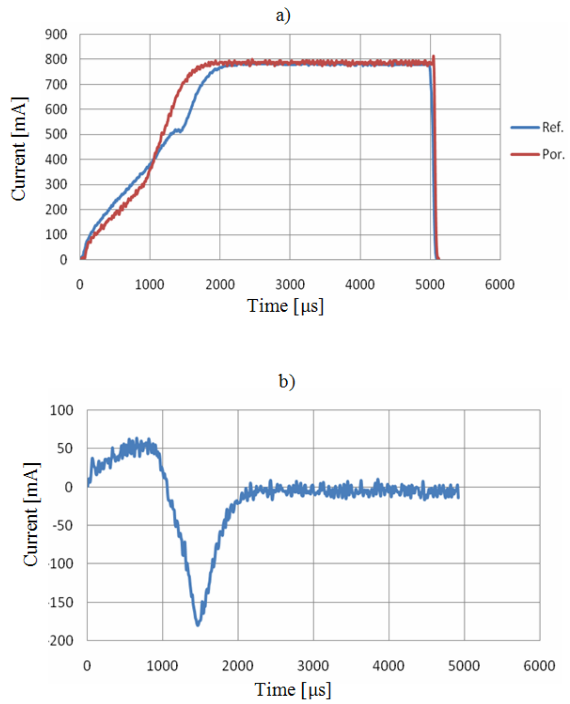

Fig.5. Reference injector current and the current at standstill needle valve in the open position: *a*) referent and failure currents, *b*) their difference

Fig.6 shows the current characteristics for another, often occurring movement problem of injector valve needle. In this case the needle valve solely moves in the top portions of its moveable sector. The difference between the reference and failure currents again shows the extremes. The first one is marginal for diagnostics of fuel injector. Two others are in 1250 μs (for current: 100 mA) and in 1490 μs (-43 mA).

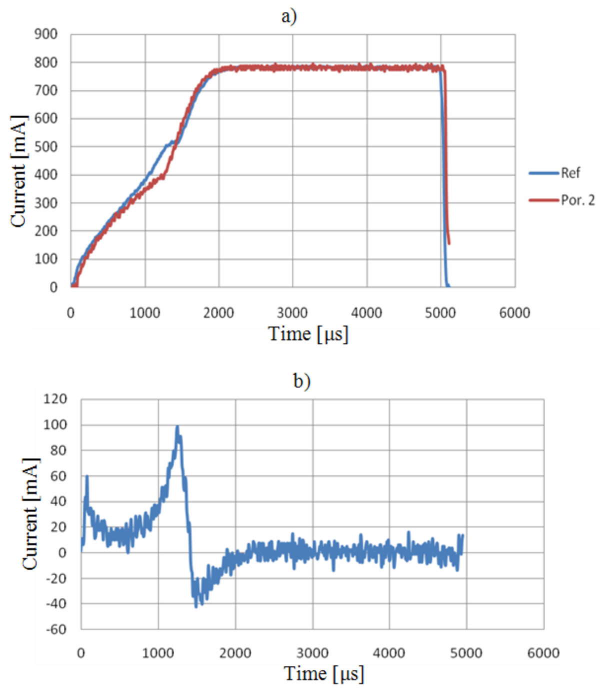

Fig.6. Reference injector current and the partial movement current of the needle valve: *a*) referent and failure currents, *b*) their difference

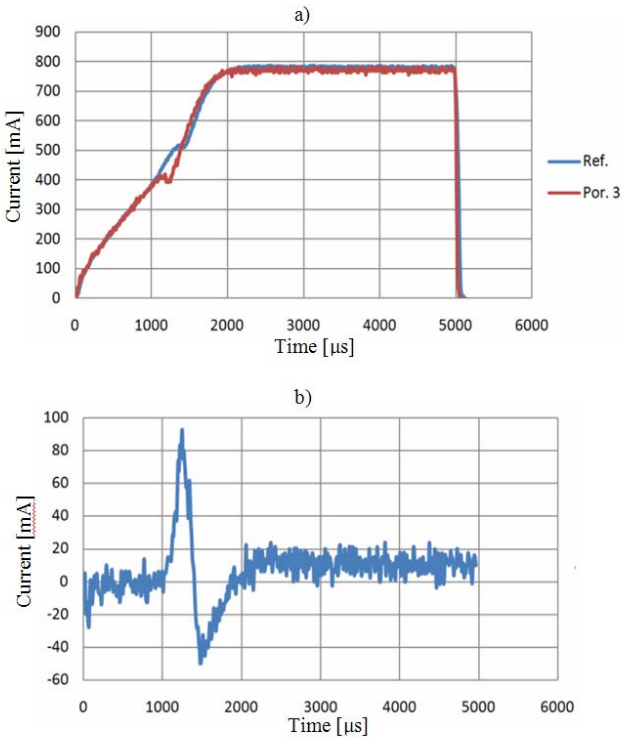

Fig.7. Reference injector current and current at a fuel zero pressure: *a*) referent and failure currents, *b*) their difference

Reduction of fluid pressure shortens the time necessary to open the fuel injector. This is illustrated by the measurement results shown in Fig.7. On the differential characteristic, again could be seen two extremes, in 1250 µs (for current: 92.5 mA) and in 1480µs (-50 mA).

Fig.8. Differences in the injection for different types of injectors

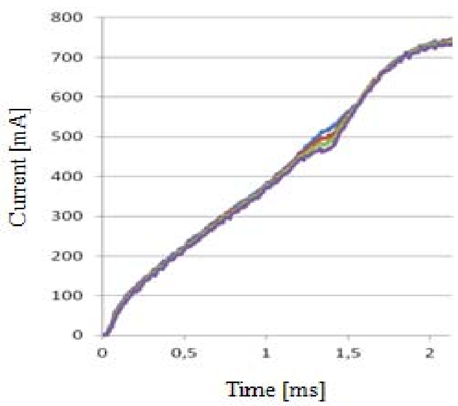

Fig.9. Differences in current characteristics for the same type of the injectors

There are many types of fuel injectors. The difference is mostly in arrays of injection quantity and in a way of injection (e.g. Fig.8). There are differences by the fuel injector of the same type too. We obtain differences in the characteristics of four fuel injectors from the same car. Measurement results are visible in Fig.9.

Discussion

In the Fig.10a is visible influence of fuel pressure changes on current characteristics. The pressure was increased from 0 to 2.6 bar (260 kPa).

Subtracting the reference signal from the chart shown in Fig.10b allows obtaining a differential signal, which may be treated as a fault signal or a fault decomposition.

Exemplary fault decomposition is illustrated in Fig.11. As the cause of failure is assumed the fuel pressure drop caused by, for example, inactivity hot pump, choked fuel filters, damaged tubes eventually corrupted regulator pressure. The time to open the fuel injector is approximately 1.5 ms.

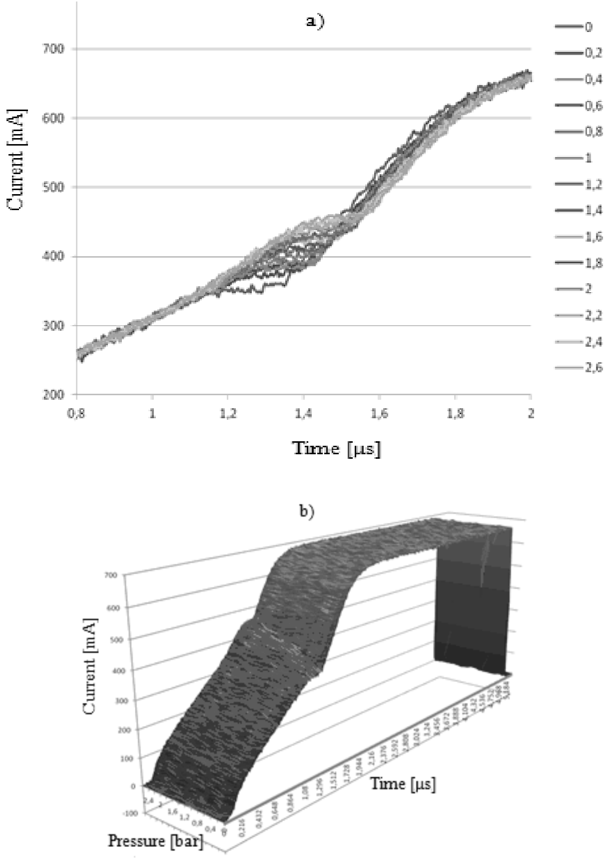

Fig.10. Effect of fuel pressure changes on the current characteristics: *a*) 2d chart, *b*) 3d chart

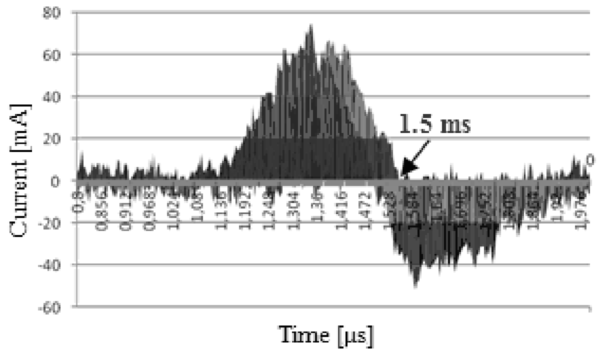

Fig.11. Current waveform during the fuel pressure drop

Conclusion

Fig. 12 shows the idealized timing chart of current during fuel injector operation. Have been marked on it some characteristic moments of time and the corresponding current values, which can be useful for determining the state of the injection system. It is possible to determine the opening time of fuel injector by monitoring the t_x time. This time had influence to pressure ratios of fuel jet and assembly solution of injector.

It is possible to determine fault fuel pressure by evaluating of these times or determine the damage of reversible springs of fuel injector. Implementing measurement in the times t_{m1} and t_{m2}, allows to obtain the maximum current [6, 7].

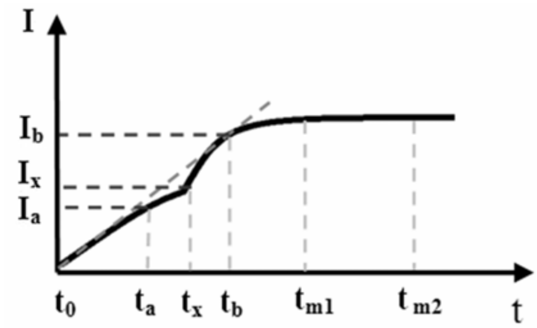

Fig.12. Current characteristic with marked moments of time in which the current measurement allows to determine the state of the injector system

The fuel injectors have many differences resulting from the production technology. It causes difference in the injectors voltage and current characteristic. In order to detect the fault state, it is needed to use self-learning process, by the use of an appropriate self-learning algorithm. Such issues will be described in the next paper.

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