ANALYSIS OF GASOLINE INJECTION SYSTEM

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Abstract: *To determine the state of the injection system could be used voltage and current check during injection system operation. This contains measure of quantity information which could be applied in On Board Diagnostics. That means advantage in the measuring process, but there is problem with model creation. Problem is associated with differences in injector's manufacture, which are shown in the measured characteristics. One way to solve this problem is applying the tutoring algorithms which remove this issue.*

Key words: *gasoline fuel injector; diagnostics; coil; tested device.*

1. Introduction

Electronic fuel injector is the important part of the gasoline fuel system of engine. Fuel injector is a solenoid valve. Forces, which getting along active injector core are involved by frictions, spring tension and fuel pressure. Rising current curve is in the part of the regions different from curve of ideal inductor current. Effect which cause the changing of permeability by movement of needle valve is concerned. Open time of injector is visible on current characteristics and closing time on potential characteristics. By the stopping motion of seed of injector is an expression disturbance visible on measured characteristics.

2. Principle of electronic fuel injector

Electronic fuel injector is an electromagnetic valve. Its internal structure is shown in the Fig. 1. The basic part of 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 failure status, under spring force effect, needle valve electromagnetic force decreases rapidly. Needle valve starts closing, then an injection process will be finished. [1][2]

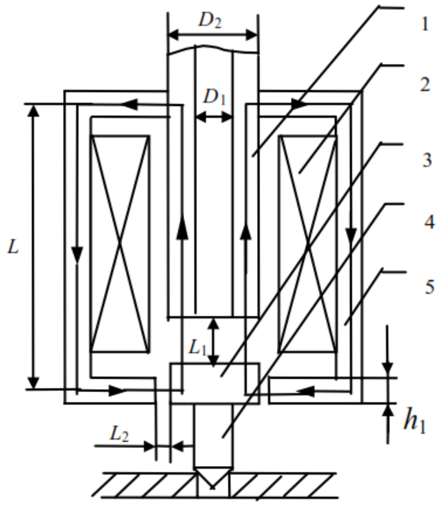


Fig. 1. Electronic fuel injector structure: 1-iron core, 2-electromagnetic coil, 3-armature, 4-needle valve, 5-yoke of magnet, 6- electrical connection, 7-filter [4]

3. Magnetic circuit analysis of an electronic fuel injector

Equivalent magnetic circuit of the electronic fuel injector is shown in Fig. 2, where iN is magnet moving force (N is coil turns); Φ_b is magnetic flux; R_M is magnetic circuit total magnetic reluctance. According to Maxwell formula, working air gap is electromagnetic attraction of L_1:

$$F = \frac{\phi_b^2}{2\mu_0 S} \qquad (1)$$

where: μ_0-vacuum magnetic permeability, S cross-sectional area of air gap.

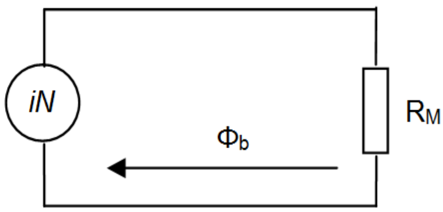


Fig. 2. Equivalent magnetic circuit of injector

In suppose of core diameters of outside and inside are D_2 and D_1, then:

$$S = \frac{\pi(D_2{}^2 - D_1{}^2)}{4} \quad (2)$$

By the ignoring the spread magnetic flux, working air gap L_1 and slipping air gap L_2 magnetic reluctance are:

$$R_{ml_1} = \frac{L_1}{\mu_0 S} \quad (3)$$

$$R_{ml_1} = \frac{1}{2\pi\mu_0 h_1} ln \frac{D_2 + 2L_2}{D_2} \quad (4)$$

The iron core cross-sectional area of air gap is small in compare with other parts. We only consider iron core magnet pressure closing to simplify the model in magnetic circuit calculation. In suppose of iron core length L_0, the iron core magnetic reluctance is:

$$R_{ml_0} = \frac{L_0}{\mu S} \quad (5)$$

Where μ is magnetic permeability, H is magnetic field intensity, B is magnetic strength. According to magnetic strength B, for H, magnetization curve is shown in this calculation of magnetization curve fitting which is described as:

$$H = a + \frac{b}{B + c} \quad (6)$$

Ignoring the magnetic flux leakage, according to Ampere circuit law:

$$\emptyset_b \cdot R_M = i.N \quad (7)$$

Where $R_M = R_{ml1} + R_{ml2} + R_{ml0}$. [4]

4. Electronic fuel injector's circuit analysis

Electronic fuel injector driving circuit is shown in Fig. 3. When we ignore closing power triode saturation voltage, electronic fuel injector coil electrical equivalent circuit is shown in Fig. 4, R and L are equivalent electromagnetic coil resistance and inductance of injector. So circuit voltage equilibrium equation is:

$$U_0 = R \cdot i + N \frac{d\emptyset_b}{dt} \quad (8)$$

Coil power failure equivalent circuit is shown in Fig.5. Circuit voltage equilibrium equation is:

$$0 = i(R + R_0) + N \frac{d\emptyset_b}{dt} \quad (9)$$

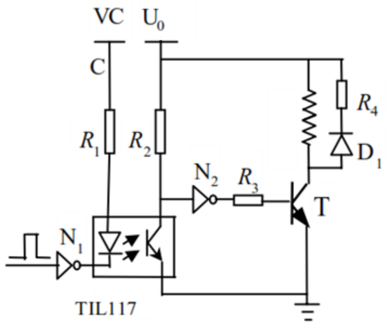


Fig. 3. Injector driving circuit. [3]

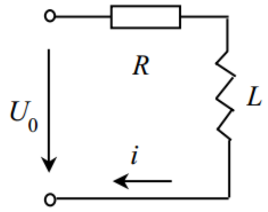


Fig. 4. Equivalent coil electric circuit

5. Experimental measurements

Fig. 5 shows block diagram of the test device for gasoline injectors. Control electronic consists from a programmable controller which is designed to open and close the transistors. Injectors are connected to the collector of the transistors. By using the four buttons we could set opening times for transistors. LCD display shows the current mode.

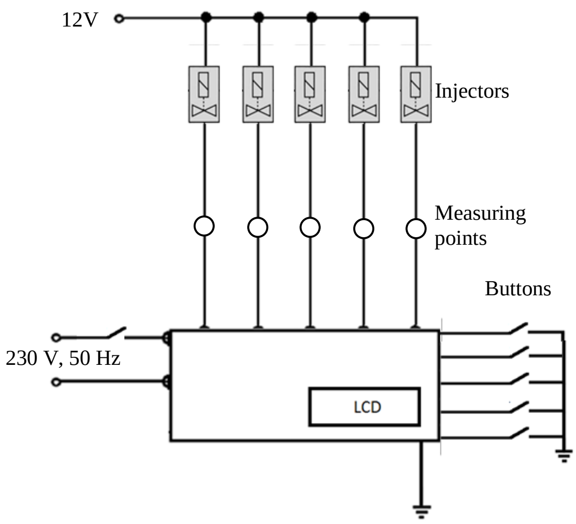


Fig. 5. Block diagram of the testing device.

Current and voltage characteristics shows the deviations from the ideal state. Characteristics of current and voltage affects the movement of the core, which in results change an inductance.

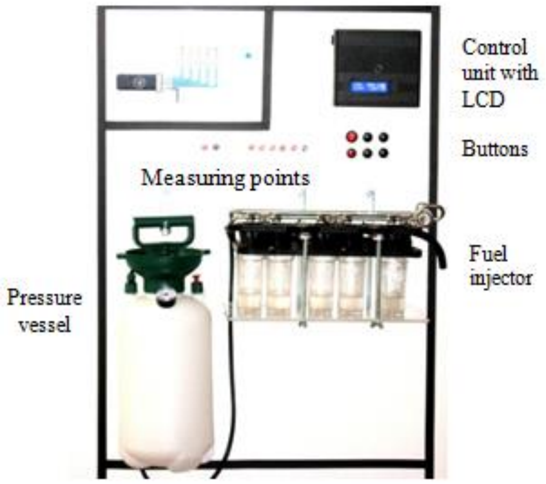


Fig. 6. Testing device.

Measurement in Fig. 7 is divided into few intervals. The interval A is injector inaction, B is moving the core of the injector, C is injection action with the increasing of the current, D is injector in operation, E is overvoltage caused by the inductance of the injector (moving core injector to initial position), F is fading overvoltage and G is injector inaction.

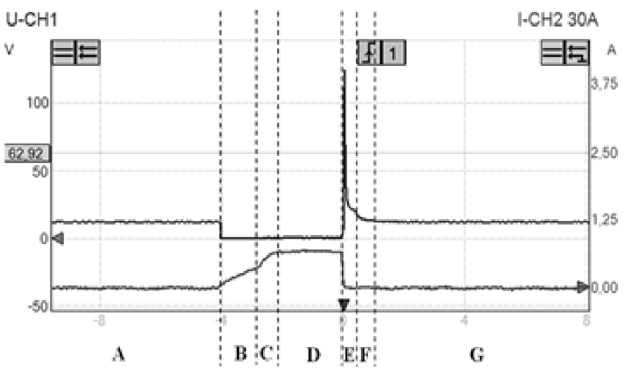


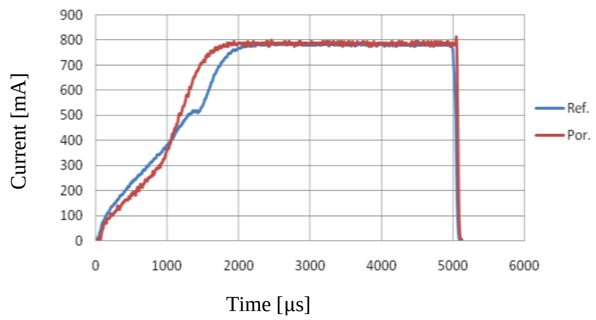
Fig. 7. Characteristics of voltage and current fuel injector.

The time required to open 12-16 ohm 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. Time to close the injector is only half of opening time. Closing of injector is execute by spring and fuel pressure only.

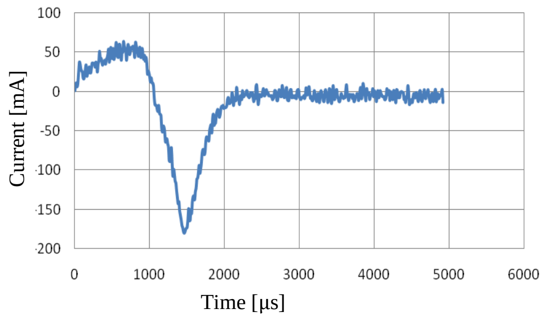
6. Current analysis

Characteristics on Fig. 8a illustrate measured reference and failure current. Reference time behaviour is composed from five measurements with the fluid under pressure at 2.5bar. Sampling value on oscilloscope has been set to 100kS/s (time between sample is 10µs). Injection time has been set to 5ms.

On next characteristics is failure current which was made by stopping the valve needle in opening position. Different reference and failure flow is on fig. 8b. We could observe two extremes on characteristics. One is in 650µs (64mA) and a second is in the 1460µs (-180mA).



a)



b)

Fig. 8. Reference injector current and the current at standstill needle valve in the open position: a) reference and fault current, b) difference

In Fig. 9 is second concept of movement problem of injector valve needle. In this case the needle valve solely moves in the top partions of its moveable sector. It again shows an extremes. The first one is marginal for diagnostics of fuel injector. Two others are in 1250µs (100mA) and in 1490µs (-43mA).

Reducing the pressure of fluid case shortening time necessary to opening the fuel injector. That shows measuring on Fig. 10a. On difference between two measuring we obtain two extremes in time 1250µs (92,5mA) and in 1480µs (-50mA).

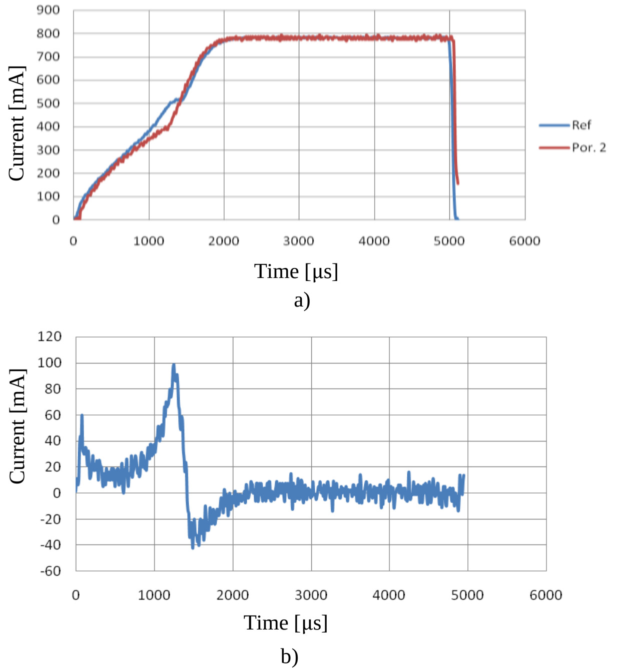


Fig. 9. Reference injector current and the partial movement current of the needle valve: a) reference and fault current, b) difference

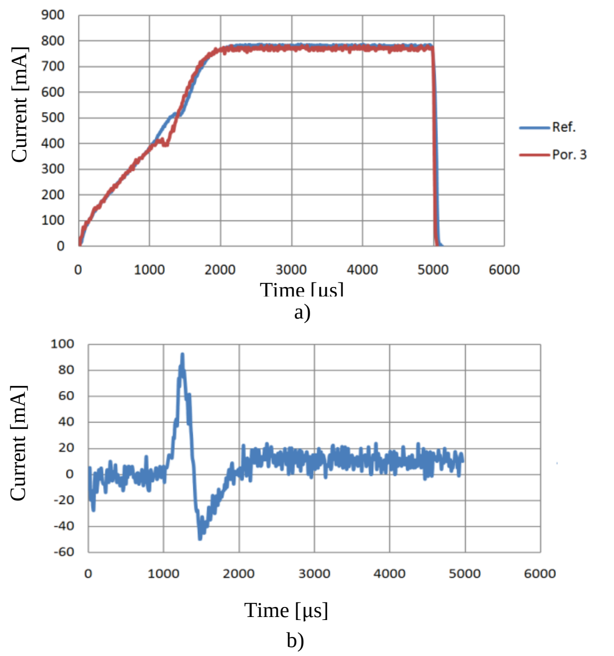


Fig. 10. Deviation from the reference flow at zero pressure liquid: a) reference and fault current, b) difference

7. Discussion

On Fig. 11a is visible influence of fuel pressure changes on current characteristics. The pressure was increased in measuring range from 0 to 2.6bar (260kPa).

When we subtract reference signal from chart Fig.11b we obtain 3D fault decomposition. This fault decomposition is on Fig. 12. By fault distribution we determine pressure fuel drops caused for example inactivity hot pump, choked fuel filters, damaged tubes eventually regulator pressure too. The time to open the fuel injector is approximately 1.5ms.

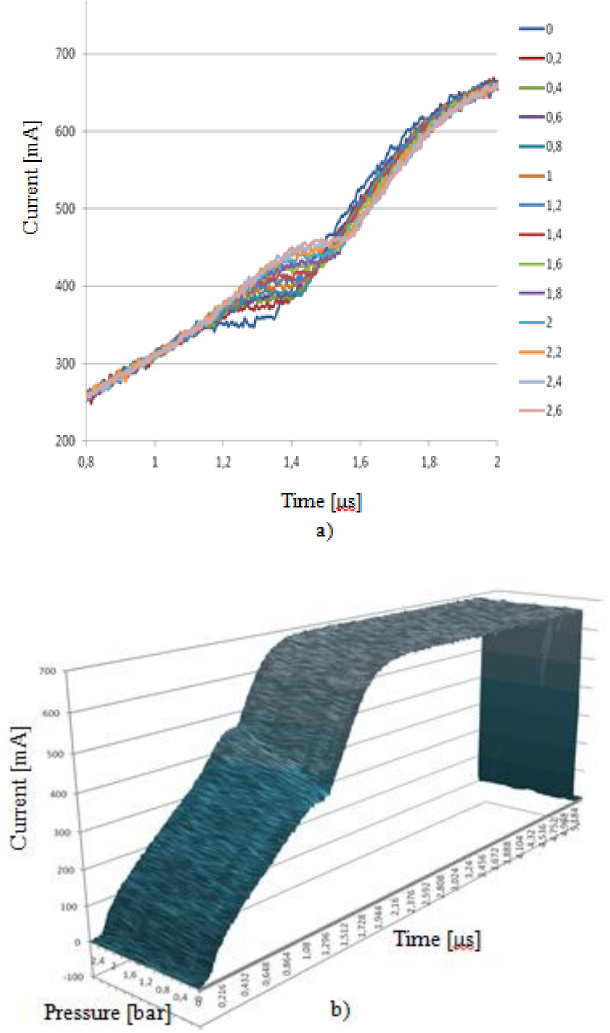


Fig. 11. Effect of pressure changes on the current characteristics. a) 2d chart, b) 3d chart

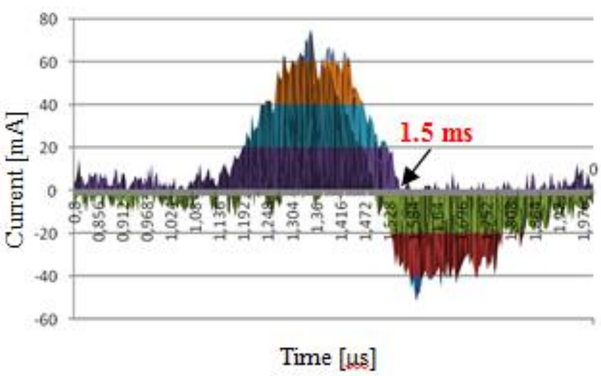


Fig. 12. Fault current at a pressure drop

8. Conclusion

Fig. 13 shows idealized current time interval during fuel injector operation with the visible sample interval, which could be a part of the evaluation state of injection system. We could obtain the length of the opening time of fuel injector by monitoring the time t_x. This time had influence to pressure ratios of fuel jet and assembly solution of injector. We know how to determine fault fuel pressure by evaluating of these times or determine the damage of reversible springs of fuel injector. If we implement measuring in the times t_{m1} and t_{m2}, we will obtain maximum current.

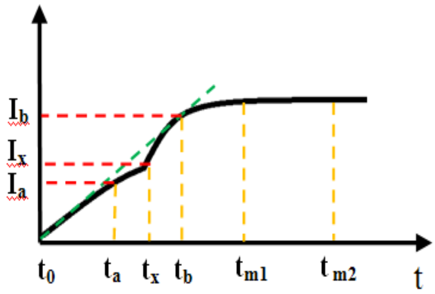


Fig. 13. The principle of sampling signals

Fuel injectors had many differences in manufacturing. It causes difference in voltage characteristic for the injectors, so there are needs for self-learning process. This process could lead to self-learning algorithm.

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