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TEST STAND FOR RECORDING AN EFFECT OF OPERATION CONDITIONS ON INJECTOR OPENING TIME

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Summary. The paper presents a design concept for a stand to record electromagnetic and mechanical opening/closing time of injectors used in fueling systems of I.C. engines. The device makes it possible to precisely determine the injector needle opening and closing time due to the application of an oscilloscope of the 100 MHz sampling rate and an IR sensor to record the real-time needle position. Results of testing gas injector opening lag for various values of supply voltage and injected gas pressure have been presented.

Key words: gas injector, test stand, control pulse, needle opening lag, position sensor

INTRODUCTION

Current standards and requirements concerning exhaust gas emission by automotive vehicles induce on vehicle producers, apart from the installation of electronic control systems, also the application of very fast fuel-dose feeders i.e. injectors, which contributes to a decrease of fuel consumption, optimization of engine efficiency and most of all to the reduction of noxious-compound emission to the environment. All modern vehicles meet the strictest standards for exhaust gas emission EU4, also due to the application of piezoelectric injectors, which are characterized by 10-times greater operation speed compared to conventional injectors and make it possible to obtain up to five fuel doses per one cycle. Additionally, due to the application of piezoelectric sensors it is possible to optimize pilot injection time, which leads to considerable reduction of combustion-accompanying noise. However, their expensive design makes them applicable only to the highest-class vehicles.

Opening/closing time of an ideal injector should be of the order of control signal edge length. In practice, identity of both the time values gives a satisfactory result. If injector opening lasts as long as its closing each fuel dose transferred by the injector will correspond to the control signal length. Knowing the injector output vs. injection time characteristics, it is possible to very precisely estimate the fuel mass injected to the cylinder. Additional application of a microprocessor controller makes it possible to compensate such conditions as: inaccuracies of the injector make, the effect of pressure difference between the fuel inlet and outlet, of needle friction against the walls or of supply voltage. Influence of all the mentioned conditions on mechanical time of injector opening can make the compensation impossible and then a change of the injector design is necessary.

The project objective was to check usefulness of the designed stand at producing traditional directly controlled gasoline or LPG injectors. The stand makes it possible to precisely determine the effect of practically all the factors that influence the needle lifting/dropping rate and mechanical opening time. It is also possible to estimate the control signal shape effect on the injector.

THE TEST STAND MODEL

Within the test stand design (Fig. 1) a control circuit composed of a microprocessor controller with MOSFET switches was applied. The controller enables to smoothly preset the opening time values for the injector. It is possible to define time interval beteeen successive pulses and injection pulse duration. Due to the lab feeder supply voltage, the system can be smoothly changed, which makes it possible to observe its effect on the injection lag.

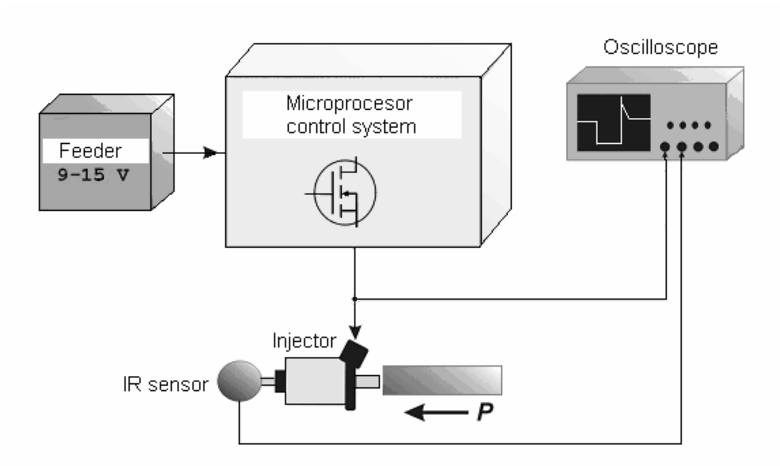

Fig. 1. Block diagram of the lab stand. P – pressure preset option

An infrared transmitter-receiver system was applied to record the injector needle position. The receiver records an accurate position of the injector needle within the minimal-maximal opening range. A two-channel oscilloscope of the 100 MHz sampling rate makes it possible to observe control pulses and the needle position. Fig. 2 presents a view of the test stand.

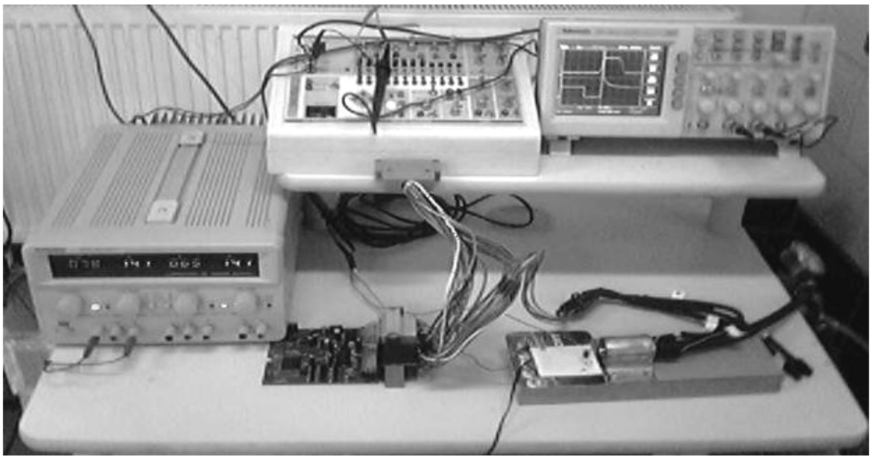

Fig. 2. A stand to test LPG injectors

TESTING OF THE INJECTORS

Low-ohm LPG injectors of 1.5 Ω and 2 Ω resistance were tested. Fig. 3 presents design of such an injector.

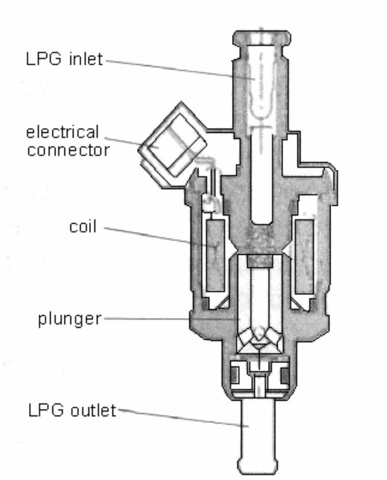

Fig. 3. LPG injector of 1,5 Ω made by the KEIHIN company [Majerczyk and Taubert 2004]

Both injectors are of identical design and the only difference between them consists in the application of coils of different resistance. They are directly controlled, which means that electromagnetic field produced by the coil current directly influences the gas-flow control element. Because of high values of coil currents and insufficient cooling conditions (no gas flowing through the injector) the maximal control pulse was limited to 4 milliseconds.

Testing of the injectors was performed in order to find the effect of supply voltage and of pressure difference between nozzles on the injector opening lag counted from the moment of the control pulse occurrence up to the full opening of an injector.

Table 1 contains example results of testing LPG injectors of 1.5 Ω resistance. Oscillograms of control pulse waveforms and injector opening times are shown in Fig. 4 for LPG pressure of 1.1 bars and supply voltage of 13 V and in Fig. 5 – for 1.8 bars and 14 V, respectively.

Table 1. Testing results for an injector of 1.5 Ω

t_w	t_{wa}	*PWM*	*U*	*P*	t_{op}	*P*	t_{op}
ms	Ms	%	V	bar	ms	bar	Ms
3	2500	35	13	1.1	2.2	1.8	2.4
3	2500	35	14	1.1	2	1.8	2.3

Symbols used in the table: t_w – injection pulse width, t_{wa} – injection pulse width without PWM, *PWM* – pulse width modulation, *U* – supply voltage to the injector, *P* – pressure difference between injector nozzles, t_{op} – maximal opening lag.

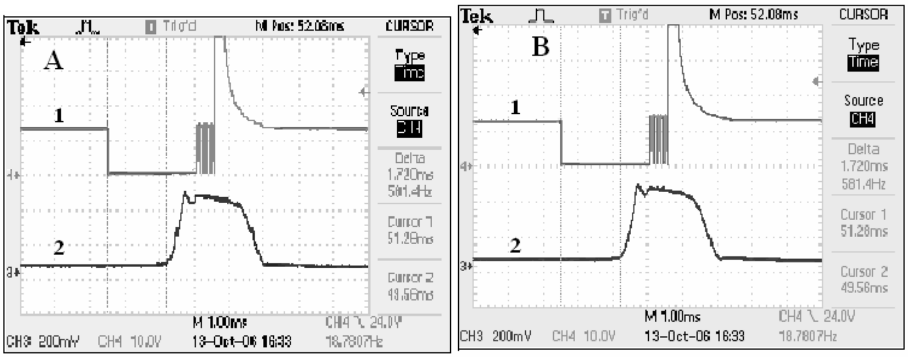

Fig. 4. Testing results for an injector of 1.5 Ω: 1 – control pulse, 2 – needle position;
A – U = 13 V, P = 1.1 bars; B – U = 13 V, P = 1.8 bars

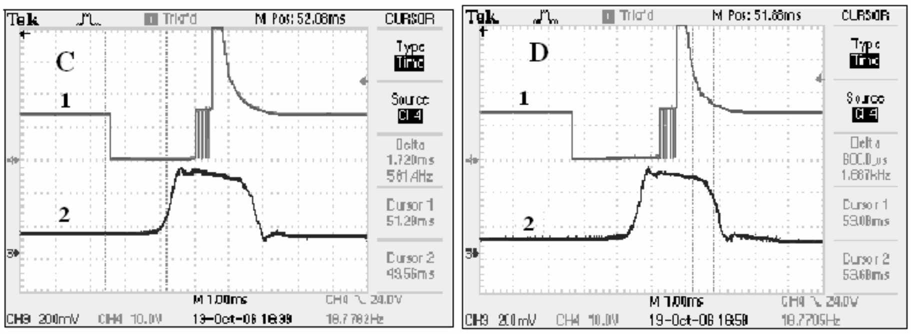

Fig. 5. Testing results for an injector of 1..5 Ω: 1 – control pulse, 2 – needle position;
C – U = 14 V, P = 1.1 bars; D – U = 14 V, P = 1.8 bars

Table 2 presents example results of testing LPG injectors of 2 Ω resistance. Oscillograms of control pulse waveforms and injector opening times are shown in Fig. 6 for LPG pressure of 1.1 bars and supply voltage of 13 V and in Fig. 7 – for 1.8 bars and 14 V, respectively.

Table 2. Testing results for an injector of 2 Ω

t_w	t_{wa}	PWM	U	P	t_{op}	P	t_{op}
ms	ms	%	V	bar	ms	bar	ms
3	2500	35	13	1.1	2.8	1.8	3.4
3	2500	35	14	1.1	2.6	1.8	3.0

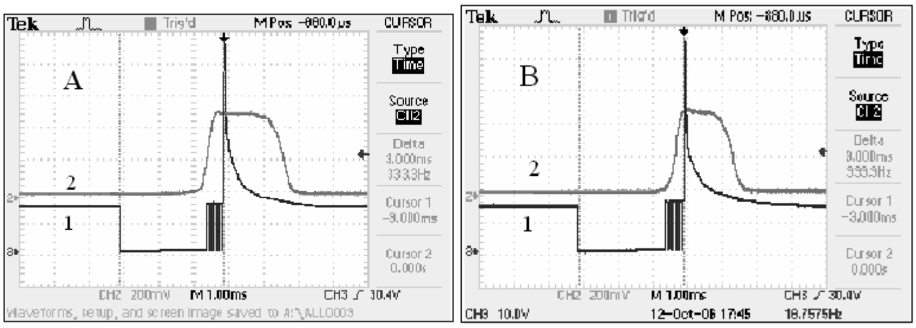

Fig. 6. Testing results for an injector of 2 Ω: 1 – control pulse, 2 – needle position;
A – U = 13 V, P = 1.1 bars; B – U =13 V, P = 1.8 bars

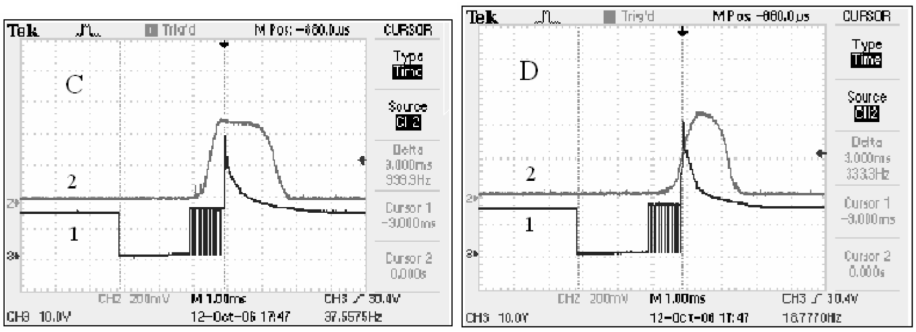

Fig. 7. Testing results for an injector of 2 Ω: 1 – control pulse, 2 – needle position,
C – U = 14 V, P = 1.1 bars, D – U = 14 V, P = 1.8 bars

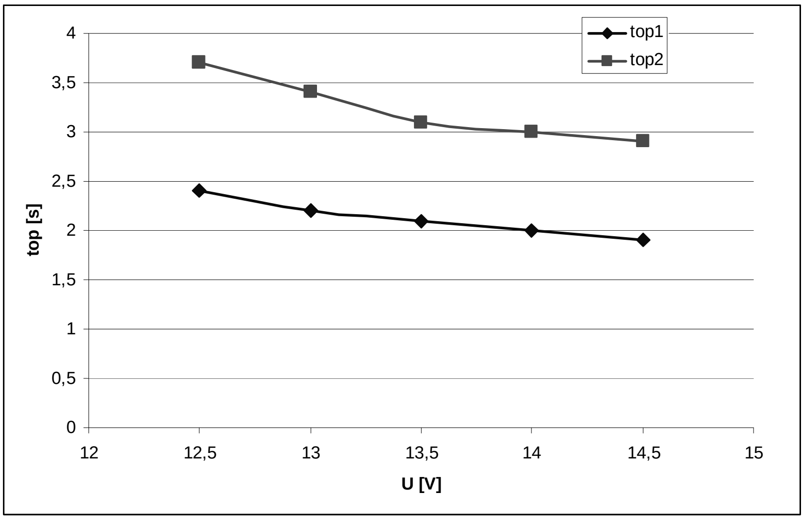

Fig. 8. Injection lag vs. supply voltage: t_{op1} – injector of 1.5 Ω, gas pressure of 1.1 bars; t_{op2} – injector of 2 Ω, gas pressure of 1.8 bars

The testing was performed for supply voltage ranging from 12.5 V to 14.5 V and gas pressure values from 1.1 bars to 1.8 bars. Testing results confirm the influence of pressure and supply voltage on the injector opening time (Fig. 8). An injector of 1.5 Ω, despite identical conditions (supply voltage and pressure) opens by 0.5–0.7 ms faster than an injector of 2 Ω. It is possible to more accurately estimate the pressure and voltage effect on the injector opening time by introducing adequate characteristics to the microprocessor controller. Then compensation of supply voltage drop and pressure increase can be obtained by changing the control pulse length.

An injector can be modeled in a simplified way by a cored coil with the application of a formula for electromagnet lifting force:

$$F = \frac{B^2}{2\mu} S \tag{1}$$

where:

B – magnetic induction,
F – electromagnet lifting force,
μ – magnetic permeability of the core,
S – cross-sectional area of the core.

$$B = \frac{IN}{l} \quad F = \mu \frac{I^2 N^2}{2l^2} S \tag{2}$$

where:

I – current passing through the coil,
N – number of winding turns,
l – magnetic flux path length.

Based on the formula (2) it can be preliminarily stated that the injector of 1.5 Ω draws higher current as compared to the 2 Ω, injector and consequently generates higher counter-force to the pressure of gas pushing onto the plunger and to the spring force (dependence $F \approx k_1 B^2 \approx k_2 I^2$). It follows from the above that an injector of lower resistance is less sensitive to the pressure difference between gas inlet and outlet. and consequently its opening time should get shorter.

CONCLUSIONS

The discussed test stand makes it possible to investigate an effect of environment and supply conditions on injector operation parameters, which offers a possibility of fast detection of production defects in individual serial products. It can also be useful at the construction stages. It is possible to determine an influence of such parameters as a number of winding turns, wire thickness, needle shape change or spring pressure force on the injection lag. The application of a microprocessor controller that enables to preset control pulses of various lengths gives the possibility of introducing compensation characteristics for such harmful actions as the effect of supply voltage drop on lengthening of the injector opening time. It is possible to quickly elaborate such characteristics at an off-engine stand, quickly write them into the microprocessor memory and perform successive tests with their use.

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