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Comparative analysis of the characteristics of a low-pressure gas-phase injector

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ABSTRACT

The paper presents the results of comparative research of selected most popular vapor phase LPG pulse injectors. A group of brand new injectors was compared with the ones already in service. The investigations aimed at determining of the parameters of the electromagnetic circuit, involved flow tests and the response time to the pulse. The coil parameters were determined using an RLC bridge for different feed frequencies. For the flow tests, where, for safety reasons, air was applied instead of vapor phase LPG, an original test stand was applied. The same test stand was used for the assessment of the response time. In the flow tests, volumetric flow rate reduced to normal conditions was analyzed at different feed frequencies. The maximum variant of the volumetric flow was also analyzed. The determined response times for the pulse have shown differences depending on the design of the actuator, coil parameters or rigidity of the springs. As a result, only some of the injectors realized their tasks in the pulse-response relation. The presented results may be useful in simulation research as a source of data for the initiation of calculations as well as in the global aspect when estimating the fuel flow rate.

1. Introduction

LPG injectors are the final components in alternative fuel systems. Their functional characteristics have great impact on the process of fuel feed, which translates into the value of the external parameters or the exhaust emissions.

Fuel systems that use LPG as a replacement for conventional fuels are widely applied in traction spark ignition engines, motor vehicles in particular [1]. They are gaining popularity across Europe and worldwide. The main reason for the application of this fuel is its price, which renders all other advantages and disadvantages less important. Currently, the process of downsizing initiated in the beginning of the XXI century [2] and the increasingly stringent exhaust emission limits force the application of the LPG liquid phase injection systems [3,4]. In modern solutions, original gasoline injectors are used to inject the liquid phase LPG. This type of LPG systems is still rare in the market and the adaptation of the engine requires a system dedicated to individual engine types and models.

Bearing the transport applications in mind, one should mention that the most frequently applied in Europe (also worldwide) LPG systems are sequential LPG injection systems (vapor phase – IV generation utilizing pulse injectors). The systems of this type are designed as universal and can be applied in a wide variety of engine models [5], yet, not always successfully [6]. The external indexes for LPG may significantly diverge from conventional fueling [7]. Results of investigations confirm that some IV generation LPG systems may increase the engine power, reduce fuel consumption and exhaust emissions [2,8].

Additionally, attempts are made to fuel diesel engines with LPG (dual fuel - diesel fuel + LPG). Simulation research [9–12] as well as experimental research [13–15] confirm such a possibility. However, an increasing number of papers indicates that LPG in diesel engines is not beneficial [16]. The main obstacle is the combustion process itself, which is entirely different for diesel fuel and LPG. Fuel cracking and elevated emission of nitrogen oxides are still a problem when fueling diesel engines with the addition of LPG.

An adaptation of a gasoline engine to LPG fueling in the case of IV generation LPG systems in brand new vehicles consists in fitting an additional fuel system. It is composed of: a tank (*1* in Fig. 1) with a multi valve *2*, a reducer, an evaporator *3* and vapor phase pulse injectors *4*. The system must be additionally fitted with hydraulic and electrical lines and sensors responsible for the feed of LPG and control of the entire system. The control of the LPG injectors is realized through an additional electronic module *5* and procedures contained in the control software [5]. Based on the opening pulses of the gasoline injectors *6* (gasoline EMU *7*), the LPG controller can adjust the opening times of the LPG injectors. Very often, the values of the opening time correction coefficients (against gasoline) are misinterpreted, which results from the differences in the calorific values of these fuels or their octane number. The values of the correction coefficients are a direct

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Nomenclature

AMFA	Alternative Motor Fuels Act
CAFÉ	Corporate Average Fuel Economy
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
ECE 83	it consists of four repeated ECE-15 urban driving cycles (UDC) and one Extra-Urban driving cycle (EUDC)
EOBD	European On-Board Diagnostics
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
OBDII	On-Board Diagnostic level 2
PWM	Pulse-Width Modulation

Glossary and units

a	acceleration, g
C	capacitance, μF
f	frequency, 1/min
I	current, A
L	inductance, mH
n	rotational speed, rpm
Nl/min	The word "Normal" means the volume has been adjusted from volume at actual temperature and pressure conditions to the volume the substance would occupy at 0 °C, 101.325 kPa (1 standard atmosphere).
p	pressure, Pa
t_{c1} and t_{c2}	closing times, s
t_{cr1} and t_{cr2}	closing response times, s
t_{fc}	full closing times, s
t_{fca}	full closing times for acceleration sensor, s
t_{fcp}	full closing times for pressure sensor, s
t_{fo}	full opening times, s
t_{foa}	full opening times for acceleration sensor, s
t_{fop}	full opening times for pressure sensor, s
t_{imp}	induction pulse time, s
t_{inj}	injection time, ms
t_{inj}	injection time, s
t_o	opening time, s
t_{or}	opening response time, s
U	voltage, V
Z	impedance, Ω

evaluation of the correctness of the engine adaptation for alternative fueling in a global approach – the entire fuel system. After all, this is an entirely new fuel system built independently from the gasoline system that is dealt with. The only common things for these systems are the control pulses.

The injector, as the final element of the vapor LPG fuel system, is responsible for precise fuel dosage. There are many injector design solutions differing mainly by the valve elements (Fig. 2). The opening movement of the valve element is realized through an electromagnetic force from the electromagnetic circuit. The closing of the injector is realized by a spring. The following types of valve elements are distinguished: plunger (Fig. 2a), plate (Fig. 2b), flap (Fig. 2c) and membrane (Fig. 2d). There are differences in the completion of the fuel inlet process (transverse or longitudinal against the valve element) or the design of the electromagnetic circuits.

The most popular type of injector in the market is the ‘plunger’ type. It is composed of a body (*1* in Fig. 3), in which a pilot *2* is fitted. Pilot is a guide of the plunger *3*. The pressing of the valve against the seat is done by a spring *4*. The limiter *5* limits the movement of the plunger and the coil *6* realizes its lift. The fuel is fed through the inlet *7* common for all sections, if the injector is a multi-section one. When the plunger is lifted, the fuel flows to the outlet hole *8,* at the end of which injection nozzles are fitted. The fuel passes to the intake manifold through the fuel ducts. The principle of operation is based on inducing an electromagnetic force in the electromagnetic circuit *6* that must overcome the force of the spring *4*, the inertia of the plunger *3*, the friction and the inlet – outlet pressure differences. As a result, the plunger is lifted to the height limited by the limiter *5* (usually it is (0.35…0.6) mm). The return of the piston to the initial position is realized by the spring *4*. Aside from the mechanical factors, the parameters of the electromagnetic

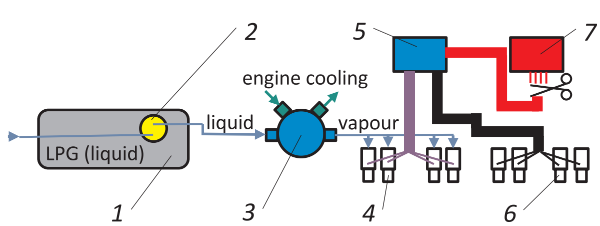

Fig. 1. Design of the LPG fueling system (vapor phase – IV generation utilizing pulse injectors): *1* – tank, *2* – multi valve, *3* - reducer, an evaporator, *4* – LPG injectors, *5* – LPG EMU, *6* – gasoline injection, *7* – gasoline EMU.

circuit responsible for proper injector operation are also significant.

From the practical point of view, the parameters of the coil are the load of the electrical circuit and additional heat generated during its operation. Analyzing the injector in terms of mathematical modeling, one has to know the coil parameters as the input data necessary for the mathematical modeling (using the Faraday's and Kirchoff's laws). An important question is the determination of the basic parameters i.e. the inductance and the impedance under the actual conditions of pulse feed. For a more accurate mathematical analysis, it is also necessary to determine the capacitance. Under investigations, the research scope must be extended in order to determine the functional relations and variability of the significant parameters [18].

Pulse LPG injectors are designed to supply the fuel at an exact moment in a specified amount resulting from their opening time [19]. This triggers certain functional problems, such as the short opening times at idle or the opening times at sudden mixture enrichment when changing the engine load. Not all fuel systems can react quickly enough under given conditions. According to the manufacturers' technical specifications, injectors are selected depending on the engine power output. This is not always justified, particularly in the case of supercharged engines that, compared to the naturally aspirated ones, with the same power output need twice as much fuel. This results from the differences of the engine displacement, hence fuel demand.

When analyzing literature, one can get the impression that LPG systems, the IV generation ones in particular, have been developed in manufacturers' engineering offices and artificial laboratories. We can see a deficit of availability of scientific works treating on this matter. This pertains not only to complex research, but also to tests of individual components such as the LPG injectors, particularly in the comparative form under uniform conditions. Manufacturers, in their commercial brochures, present the functional parameters, but the conditions, under which the tests were carried out are frequently varied. The information on the basic operating parameters allows not only a comparative evaluation (under the same conditions) but also provides the possibility of determining the input parameters for simulation research. Additionally the information on the response times in the pulse – response relation, allows a validation of the simulation models.