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Validation of indirect methods used in the operational assessment of LPG vapor phase pulse injectors

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ABSTRACT

Engine adaptation for alternative fueling may generate certain difficulties in terms of configuration or quality of the subassemblies. The main actuator of a modern LPG (Liquefied Petroleum Gas) system is the vapor phase injector. These systems are commonplace because of the possibility of a modification of the mixture composition in order to meet the emission standards. Multitude of injector design solutions and quality of their workmanship frequently make them the main reason for system malfunction, hence, the need to apply simplified research methods in the course of operation that would allow an assessment of their technical condition. The paper directly compares selected research procedures evaluating their applicability. The proposed method of pressure measurement at the outlet of the injector nozzle turned out to be sufficient for a non-invasive assessment of the technical condition of the injector, which was confirmed by the measurement of the injector piston lift by the displacement sensor. The current on the power line and the vibrations of the injector housing have been sufficient to diagnose the subassembly, thus supporting the decision on the extent of the repair.

1. Introduction

One of the most popular alternative fuels used in spark ignition engines is LPG (Liquefied Petroleum Gas). Its popularity is attributed to its low price, which makes its other pros and cons less important. It is the price that was decisive of the success of this fuel in South Korea, Poland, Italy and Turkey. We can still encounter old generation mixing chamber-based LPG systems, yet they have been phased out by liquid and vapor phase injection systems. The increasingly stringent legislation related to emission standards forces the advancement of LPG fueling technologies [1]. This, however, is not convergent with the advancing quality of the LPG fuel, whose contaminants are one of the leading causes of malfunctions of individual fueling system components. Several years ago, engineers thought that indirect injection of a vapor phase LPG with pulse injectors will satisfy the market for years to come. Systems of this type are, as a matter of principle, universal, i.e. they are applicable in a wide model group of engines [2]. The universality, however, has not always been confirmed [3] and the full load indexes may significantly diverge from the classic gasoline fueling [4]. Downsizing [5] in combination with exhaust emission limits have led to the application of liquid phase LPG injection [6]. The results of research confirm that the fueling system of this type may contribute to the obtainment of higher engine power, lower fuel consumption and reduced exhaust emissions [6,7].

Attempts have also been made to fuel diesel engines with LPG in a dual fuel system (diesel fuel + LPG). Both the simulation [8–11] and the experimental [12,13] research confirm such a possibility. There is however an increasing negative trend in literature related to the application of LPG in diesel engines [14]. The investigations confirm only selected diesel engine operating ranges where LPG does not constitute a problem in proper environmental performance.

Knowledge of the process of injection of a vapor LPG fuel is invaluable. Especially now, with new low temperature, combustions technologies, based on combination of multiple fuels, for example RCCI (Reactivity Controlled Compression Ignition), HPDI (High–Pressure Direct Injection) are emerging as possible first solution for meeting future legislation requirements for low carbon, clean combustion engines [15]. More and more new regulations are created related to alternative fuels such as CAFÉ (Corporate Average Fuel Economy), AMFA (Alternative Motor Fuels Act) or CARB2020 (California Air Resources Board) [16–22].

The characteristics of injectors are also necessary for proper modeling of the engine operation. This type of information (opening characteristic) is mainly used for model-based control [23–26], ANN metamodel [27], dual-fuel combustion [28] and emissions [29–31]. As research has shown, even a small difference in the fuel dosage may result in uneven engine operation [32–34]. Therefore, it is necessary to validate research methods serving the purpose of determining the course of injection inside LPG vapor injectors.

In general, research methods on fuel injectors of different fuels can

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Table 1
Research methods on fuel injectors.

Direct methods	Indirect methods
– Observation and analysis of images obtained via high speed cameras [35–40] – Use of transparent nozzle replicas for process analysis [41] – Application of needle lift sensors [49,51] – Optical sensors	– Utilization of the Doppler effect (optical laser) for a simultaneous measurement of the velocity and size as well as the concentration and mass flow of particles [42–46] – Use of heat flow sensors enabling a characterization of the location of the fuel impingement and its rate after injection [47] – Analysis of injector housing accelerations (vibrations) for the assessment of the opening and closing times of the injectors [48,49] – Pressure in the sensors placed on the outlet line downstream [50] – Pressure sensors at the outlet of the injector nozzle [49] – Optical sensors [52] – Assessment of the course of current in the power line for the assessment of the delay of the injector opening [48,49] – Gravimetric measurement of the liquid fuel rate of the injector [53] – Measurement of the gas injector fuel rate by the 'fuel tank refill' method [53,54]

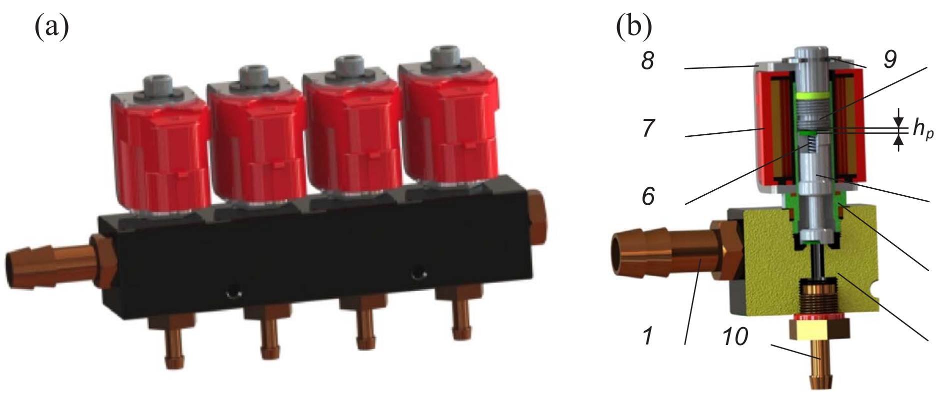

Fig. 1. Subject of the research – Valtek Rail Typ 30 injector (description in text).

Table 2
Basic technical data of the tested objects – Valtek Rail Typ 30.

Parameter	Unit	Value
Max flow rate at 1.2 bar	Nl/min	110
Nozzle size	mm	max. 4/min. 1
Coil resistance	Ω	3
Opening time	ms	3.3
Closing time	ms	2.2
Max working pressure	Pa	$4.5 \cdot 10^5$
Operating temperature	°C	$-20 \div 120$
Operating voltage range	VDC	12
Connector	SuperSeal	
Homologation	E8 67R-01 6407; E8 110R-00 6408	

be classified as direct and indirect (Table 1).

The above-presented methods can be used for the qualitative and quantitative evaluation of LPG injectors in operation. The first four are costly and the investigations are time consuming. The most popular method is the gravimetric measurement [53], which, unfortunately, in the case of vapor phase, is difficult to apply. The 'fuel tank refill' method is rather novel in the research of this type of subassemblies and, as investigations have shown, it works fine for the measurement of flow rate and fuel dosage regularity [53]. It allows the assessment of the influence of certain parameters such as the diameter of the outlet nozzle or operational wear on the fuel dosage regularity [54]. Bearing in mind the minimization of any invasiveness in the LPG injector (as the basis for the operational assessment) one should construe the use of the measurement of current in the power line and the housing vibrations as the most reliable [48]. The method of pressure measurement using two

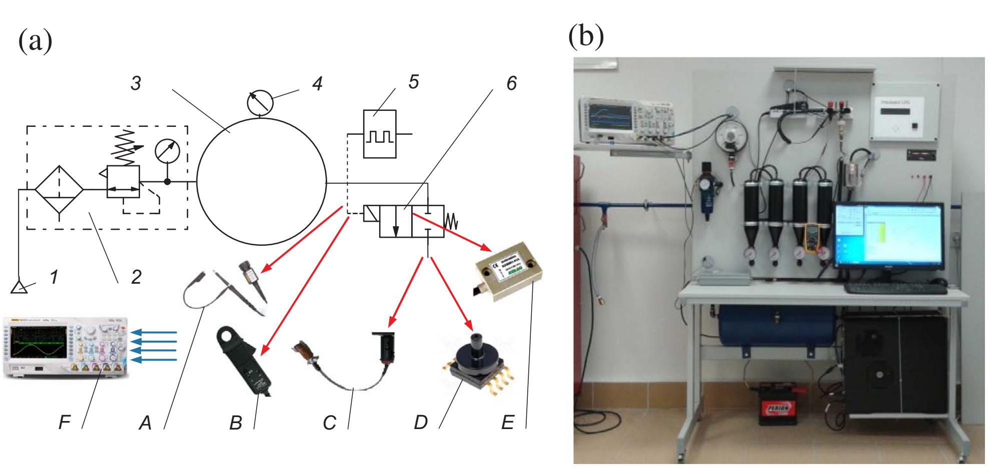

Fig. 2. Test stand: a – diagram, b – practical realization, 1 – source of compressed air, 2 –conditioner of air, 3 – tank, 4 – manometer, 5 – STAG AC LLC based opening pulse induction system, b – tested vapor phase injector; A – RIGOL voltage terminal, B – HAMEG HZ050 current clamps, C – ZEPWM Marki CL 80 induction displacement sensor, D – pressure sensors at the base MPXH6400A, E – KELAG KAS903-02A acceleration sensor, F – RIGOL MSO4014 oscilloscope.