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Suggested research method of the characteristics of piston LPG vapour injectors

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ABSTRACT:

The quality of engine power supply depends on the characteristics of LPG (liquefied petroleum gas) injectors. This paper describes a simple and cheap research method of opening and closing the injectors. The suggested method involves an analysis of individual frames from a video featuring an intermediate movement of the piston. A quick camera helped us to perform a sufficient number of measurements to prepare a graph showing the piston movement in time. This method facilitates a faster and cheaper piston diagnosis than other injector research methods, among other things.

1. INTRODUCTION

4-generation gas installations (sequential installations) belong to the most popular solutions (including both 1, 2, 3-generation installations and the latest liquid gas installations) thanks to their universal character. Unfortunately, apart from some obvious benefits, those installations have numerous drawbacks. One of them is the fact that injectors may delivering the fuel to the engine in an imprecise way, which over time can become disorderly [1, 2]. The main task of injectors is to dose the fuel provided to the engine inlet ducts. The structure of a piston gas injector is slightly similar to the structure of a petrol injector. The volume of LPG vapour is bigger than the volume of liquid petrol. Consequently, the volume of a gas injector has to be bigger than that of a petrol injector [3]. A larger volume means larger inertial power of the moving parts. Maintaining the correct parameters of the injector work, i.e. appropriately short opening and closing times, has made it necessary to enlarge the coil producing the electromagnetic field which opens the injector. A larger coil produces more heat, which can damage the injector in extreme cases [4]. The problem has been partially solved with utilising appropriate characteristics of an electric impulse which monitors the location of the injector piston [5].
The characteristics of the injector piston movement depends on numerous factors. First, it depends on the electromagnetic power produced by the coil. Other factors include: the power of the spring pressure, the power of inertia, the power resulting from the differences in gas pressure (non-existent during the test), the power of friction and the power resulting from environmental disruptions. The resultant of those powers causes the piston movement [6].
It is also crucial to monitor correctly the work of gas injectors. In order to assess the work, a series of measurements analysing the voltage course in gas and petrol injectors were performed [7]. Unequivocally, the results show that the voltage in wires supplying power to the injectors does not drop to zero at the speed of 4,000 RPM (the frequency in power impulses is too high). Additionally, at the speed of 5,000 RPM, LPG injectors do not close and there is constant power supply. An increase in the revolving speed turns off the alternative fuel supply and starts the default petrol supply [8]. That is why during the tests described further in this paper, the injectors were powered with impulses at the speed of 1,000 RPM.
It is difficult to analyse the real characteristics of the injector work. One hindrance is the structure of the injector itself, which makes it impossible to observe the moving parts, among other things, as well as short opening and closing times. There exists some equipment capable of identifying the initial and final motions of the piston (it detects the vibrations of the piston housing or utilises a laser beam measuring the distance to the lower part of the piston); however, such research equipment is incredibly expensive [9, 10]. For this reason, we have attempted at finding a simple and cheap method of registering the piston movements which would be precise enough to conduct necessary analyses.
The suggested research method is based on the analysis of video frames with recorded piston movements and will be used in verification tests of the previously defined mathematical model, among other things [11].

2. THE SUBJECT AND METHODOLOGY OF THE RESEARCH

Research on injector work characteristics required appropriate samples. The samples included injector rails of the same model and producer Valtec 3Ω (Fig. 1). The most important technical data is shown in Table 1.

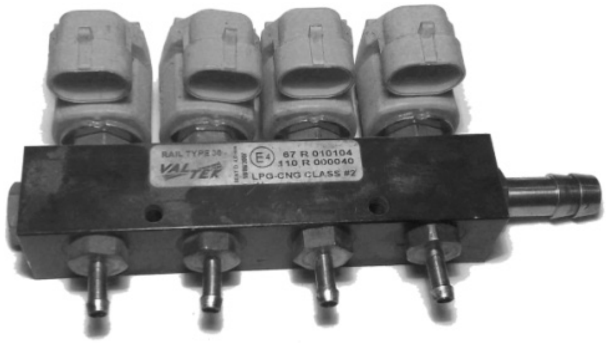


Figure 1 1 A set of tested Valtec 3Ω

Table 1 Basic technological data of the tested injector

Maximum working pressure	0.45 MPa
Working temperature range	-20°C - +120°C
Diameter of gas inlet nipple	12 mm
Coil resistance	3 Ω

The first step in the research of the injector characteristics was to attach a pointer to the lower part of the injector. The pointer made it possible to observe indirectly the piston movements when moving together with the piston. The pointer was a pipe made of synthetic material, with a diameter of 2 mm and 0.1 mm-thick walls, which was attached to the previously disassembled piston. The pipe weight (0.04 g) is very small in comparison to the piston weight (around 4.8 g) so we assume that it has no influence on the characteristics of the injector work. Next the injector was reassembled and installed on a simple test stand. The stand included: a Casio Exilim EX-FH 100 camera (with the possibility of recording 1,000 frames per second; basic technical data shown in Table 2), a tripod for the camera and a magnifying device MG10085 with a built-in lamp highlighting the image (Fig. 2). The injector is powered by a constant power circuit, generating rectangular impulses with a required length (filling) and frequency. The generated impulse, lasting 6 ms and repeated every 120 ms (equivalent to the revolving speed of 1,000 RPM), is shown in Fig. 3.

Table 2 Basic technical data of Casio Exilim EX-FH 100 camera

Maximum definition	3648 × 2736
Number of pixels	10 Mpx
ISO sensitivity	100 - 3200
Focal length (equivalent to 35 mm)	24 – 240
Minimum exposure time	1/1,000 s
Optical zoom	10 x
Lens speed	F/3.2 – 5.7

An image of the pointer movement recorded by the camera (significantly enlarged thanks to the magnifying device) made it possible to observe the piston indirectly. In order to prepare a graph of the characteristics, the recording had to be divided into individual frames, which were then analysed. Only the frames showing the pointer movements were analysed (Fig. 4), so the required amount of work was relatively small.
Analysis of approximately five consecutive opening cycles enabled us to gain sufficient information to prepare a graph showing the characteristics of the tested injector. Due to a blurred image in some of the frames in the recorded film, we decided to extend the analysis to eight consecutive cycles.
The research was conducted without fuel flowing through the injector, and for this reason the characteristics differ from those during real-life work of the injector installed in a vehicle, as there is no pressure force operating on the piston, which is generated by the gas pressure.

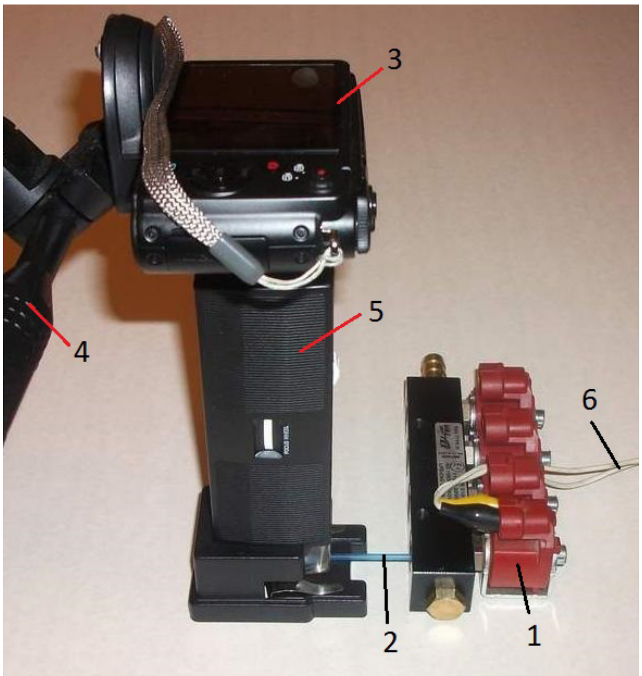


Figure 2 Testing stand used in the second stage of the research:
1 – the tested injector, 2 – the pointer attached to the piston, 3 – EX-FH 100 camera, 4 – the tripod, 5 – the magnifying device MG10085, 6 – power supply wires

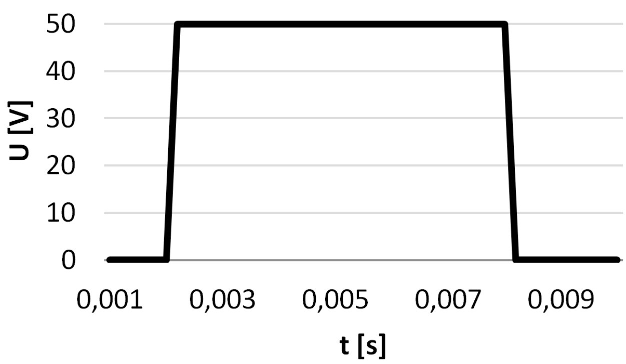


Figure 3 The graph showing the impulse powering the tested injector, equivalent to revolving engine speed of 1,000 RPM

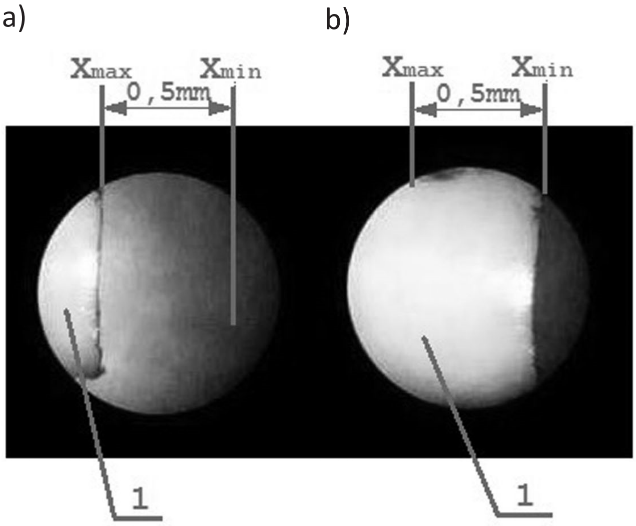
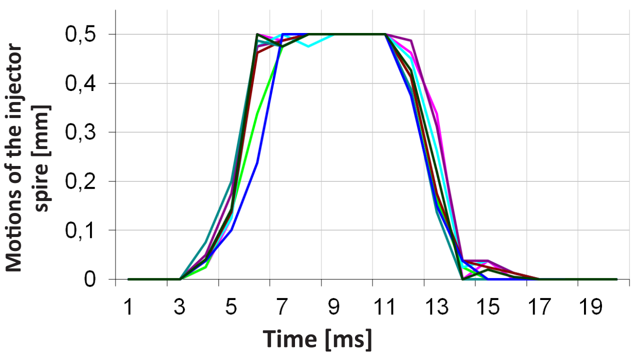


Figure 4 Frames of video recorded during the work of a brand new injector.
a) injector open; pointer moved to extreme left;
b) injector closed, pointer moved to extreme right;
1 – the pointer reflecting the piston movements,
X_{max} – location reflecting the opening of the injector
X_{min} – location reflecting the closing of the injector

3. RESEARCH RESULTS

The result of the research, whose aim was to define the injector characteristics, is a collection of data specifying the location of the piston in a given moment. The appropriate power supply, reflecting the revolving speed of the engine of 1,000 RPM, and the analysis of the registered image of eight consecutive opening cycles, enabled us to prepare a graph family as shown in Fiure 5. Next, with the help of statistics, the characteristics of the injector were defined. The procedure made the sampling time of 1 ms sufficient.



Rysunek 5 Results of eight measurements of the injector piston movements

The developed research method was verified by comparing the results coming from the analysis of the video frames and the results achieved by the method developed by Szpica [9], which involves the measurements of acceleration of the external housing of the injector (Fig. 6).

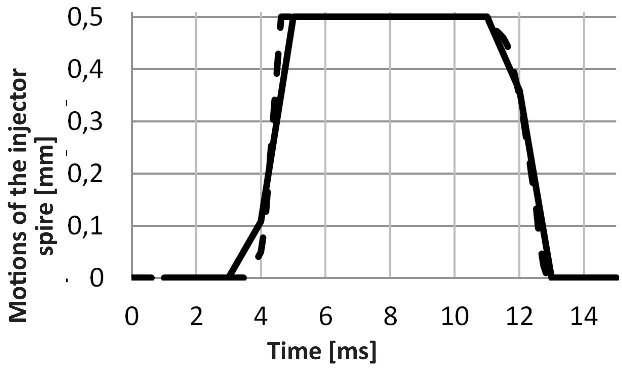


Figure 6 A comparison of the results achieved in the analysis of video frames (-) and the method of measuring the vibrations of the injector rail (- -) [12]

A significant difference in the initial stage of the piston movement can be noticed. The difference results from a considerably higher frequency of sampling utilised by other researchers. The piston movement characteristics during closing are very similar in both methods. Determination ratio for one injector, tested both ways, equals to R^2=0.955.
If it is necessary to achieve more precise results, the method of frame analysis can utilise a camera with a greater recording speed. However, such cameras are expensive. This would mean a higher cost and prolonging the research time (in order to analyse a larger number of frames in the recorded video).

4. SUMMARY

This paper suggests a simple and cheap method of measuring the work characteristics of pulse LPG injectors, utilising the analysis of video frames which record indirectly the movements of the piston. The method was used to test twenty-four injectors (six sets) of the same producer, which were powered by the same engine type (this paper presents only a sample result for one of the injectors). It was concluded that the suggested method can be successfully used in verification tests or diagnostic tests (especially during workshops), among other things, as well as in test research of prototype injectors. Thanks to a short time necessary to conduct measurements, an easy-to-serve stand and the availability of its components, the above mentioned method will prove useful in teaching, since it facilitates quick measurements enabling you to specify the influence of the shape of the supply impulse and its length on the process of opening and closing of the injector.

Afiliation

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LITERATURE

[1] Szpica D., Fuel dosage irregularity of LPG pulse vapor injectors at different stages of wear, Mechanika, 2016, 22 (1), 44-50.
[2] Raslavičius L., Keršys A., Mockus S., Keršiene N., Starevičius M., Liquefied petroleum gas (LPG as a medium-term option in the transition to sustainablefuels and transport, Renew, Sust. Energ. Rev., 2014, 32, 513-525.
[3] Mohamad T. I., Jermy M., Harrison M., Experimental Investigation of a Gasoline-to-LPG Converted Engine Performance at Various Injection and Cylinder Pressures With Respect to Propane Spray Structures, Applied Mechanics and Materials, 2013, 315, 20-24.
[4] Erkus B., Sürmen A., Karamangil I. M., A comparative study of carburation and injection fuel supply methods in an LPG-fuelled SI engine, Fuel, 2013, 107, 511-517.
[5] Majerczyk A., Taubert S., Układy zasilania gazem propan-butan, Warszawa, Wydawnictwo Komunikacji i Łączności, 2006.
[6] Czarnigowski J., Teoretyczno-empiryczne studium modelowania impulsowego wtryskiwacza gazu, Lublin, Monografie – Politechnika Lubelska, 2012.
[7] Borawski A., Wituszyąski K., Problemy sterowania praca wtryskiwaczy LPG, Silniki Gazowe, Częstochowa, Wydawnictwo Politechniki Częstochowskiej, 2010.
[8] Borawski A., Modification of a fourth generation LPG installation improving the power supply to a spark ignition engine, Eksploatacja i Niezawodność – Maintenance and Reliability, 2015, 17(1), 1-6.
[9] Szpica D., The influence of selected adjustment parameters on the operation of LPG vapor phase pulse injectors, Journal of Natural Gas Science and Engineering, 2016, 34, 1127-1136.
[10] Czarnigowski J., Barański G., Wendeker M., Duk M., Zyska T., Method to measure injector opening and closing lag times, Combustion Engines, 2011, 1(144), 20-28.
[11] Borawski A., Simulation studies of LPG injector used in 4th generation installations, Combustion Engines, 2015, 1(160), 49-55.
[12] Szpica D., Modeling of Current Limitation through the PWM Signal in LPG Injectors, Proceedings of 20th International Scientific Conference. Transport Means, 2016: 536-539.