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Operational assessment of selected gasoline and LPG vapour injector dosage regularity

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1. Introduction

Growing environmental concerns and the crude oil crisis have contributed to the search for alternative fuels used in the transport sector. Experimental research is underway and simulation models are developed assessing the applicability of different types of alternative fuels such as hydrogen, propane, methane ethanol and methanol [1]. It has been observed that the volumetric efficiency of an engine running on hydrogen is lower by 28% compared to gasoline in the same engine [1]. Gasoline generates more energy than all other tested alternative fuels at a varied Brake Specific Fuel Consumption (BSFC) [2]. A significant reduction of the emission of *HC* and *CO* (65% and 50% respectively) when fueled with LPG (Liquefied Petroleum Gas), at a small reduction of the engine thermal efficiency compared to gasoline, makes this fuel an alternative in engine applications [2, 3]. Increased exhaust emissions, however, are observed at different proportions of LPG - gasoline in some fueling systems [4]. Works are also conducted on multifuel engines where, in order to initiate ignition, gasoline is injected into the intake port and the diesel fuel into the cylinder. The use of KIVA code in connection with the fundamental mechanism of reference fuels has shown a significant reduction of the emission of PM and NOx through local inhibiting of the mixture formation or high temperature regions. However, an elevated emission of *CO* and *HC* was obtained for a wide range of injection times [5].

In many countries, LPG is growing in popularity, mainly because of its low price. Many works have shown the applicability of this fuel for motor vehicles [6] and some of the works positively verified this fuel for application in low temperature climates [7] (cold start [8]). The investigations are also related to the algorithm smooth control [9, 10] or the problem of the flow of liquid phase LPG in the fuel rail [11-13]. The basis for correct operation of each fueling system is the quality of fuel, which, in the case of gasoline, is regulated by law [14]. The situation is not as clear for LPG. Corporate Average Fuel Economy Standard (CAFFE) is an important tool in the policy of improving the BSFC. The Alternative Engines Fuels Act (AMFA) ensures privileges for engines fueled with alternative fuels in calculating fuel consumption, which aims at providing an incentive to CAFEE manufacturers for greater production of alternative fuels [15].

The need to meet the CO_2 emission standards for the entire vehicle fleet of a single manufacturer forced the application of downsizing. For compact vehicles fitted with a 0.8 L engine instead of the 1.6 L base version, the CO_2 reduction is 18% under steady states of operation. Specific torque, obtained at 1250 rpm was gradually increased by 50%. to reach 1.7 MPa Brake Mean Effective Pressure (BMEP), unit power is 83 kW/l. and BSFC is 300 g/kWh [16].

Very often, these types of engines run on very lean (A/F) mixtures for small and partial loads in Gasoline Direct Injection (GDi). At full loads the engine still operates at a stoichiometric mixture, yet extremely lean mixture leads to a high NO_x emission [17]. Direct injected engines (GDi) contribute to an increased total emission of PM from a vehicle [18].

Current literature focuses on liquid phase LPG injection because modern engines require such solutions [8-11, 13]. Many vehicles are of obsolete design in terms of LPG fueling. Gaseous LPG fueling (IV generation - vapour injectors) is not a widely discussed in literature, especially when it comes to vehicles already in use [19].

The research methods used in the analysis of the injection process of both gasoline and LPG are different. Scientists observe the spray of injected liquid phase LPG [20, 21] and compare it with gasoline. They also explore the pulsations of LPG in the fuel rail [20]. The application of the heat flow sensors enables a characterization of the location and strength of the fuel impact after injection [22]. Phase Doppler (laser diffraction technique for the analysis of atomization of multi-ingredient gasoline) also gives good results [23, 24], just like the optical shadowgraphy that characterizes the injection [25, 15]. Influence of selected parameters on the characteristics of the injected fuel is analyzed (distributions of droplet size and velocity of the volumetric flow) through phase Doppler Anemometry (PDA) [26, 27] or through laser diffraction technique [28]. GDI engines, owing to their design, require placing analyzers inside the cylinder in order to explore the injection processes. The crank angle from the beginning of the injection to the end of the compression stroke is presented with an image for each direction of the illumination and injection time using the light fluorescence absorption [29].

In the research, transparent replicas of the injection nozzles are also used to analyze the process [30]. Proposals of new injector solutions [31, 32] and service methods are put forward [33].

Despite extremely advanced research methods, the analyses are conducted for individual, mostly newly manufactured subassemblies or systems. The quantitative assessment (the injector mass flow) is currently construed as a diagnostics of the injector condition carried out at a workshop. The authors found it purposeful to perform an assessment of the injector dosage regularity in a 4-cylinder fueling system. Such investigations were provoked by the fact that in the course of the diagnostic process, an increased number of vehicles with fueling system malfunctions was observed (alternative LPG fueling in particular). The paper only draws attention to the problem while the investigations are underway for further analysis.

2. Preliminary investigations

The operational problems resulting from the application of alternative LPG fueling, concentrate mainly on two components: reducer-evaporator and the injectors. The problems manifest themselves in the loss of power (Fig. 1), misfires and lack of proper cooperation in the transitional states. The reducer-evaporator reacts with delay to the increase in fuel demand (depending on the design), which can excessively raise the pressure. In addition, the LPG vapour injectors, owing to the process dynamics and significant influence of wear on the flow characteristics (especially in a short opening times range) can necessitate lengthening of the injection time, which is why the engine control algorithm is not capable of a dynamic correction of the system when the fuel is fed. The process analysis, using diagnostic testers and exhaust gas analyzers, gives the opportunity of identification of the source of fault without disassembling of the system.

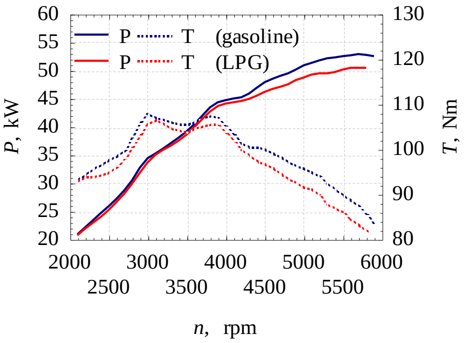


Fig. 1 Full load characteristics performance of a Skoda Fabia 1.2L AZQ engine with traditional fueling system – multi-point injection (fuel RON 95) and alternative fueling system STAG 200 by AC LLC – IV generation LPG (fuel mix of mainly 40% C_3H_8 and 60% C_4H_{10})

Fig. 1 shows a comparison between wide open throttle characteristics of a Skoda Fabia 1.2L engine obtained on the chassis dynamometer (LPS 3000 Maha). It also shows proper work with an alternative IV generation (vapour injectors) LPG powering system. The differences in the maximum values of power and torque are consistent with the average values. During research, occasional misfires were observed and further analysis of the system was conducted in a normalized test procedure ECE83 (engine speed curves shown in Fig. 2).

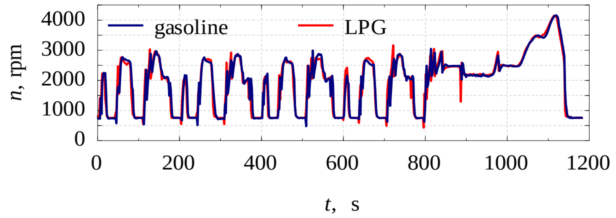


Fig. 2 Engine speed curves during the test procedures on a chassis dynamometer

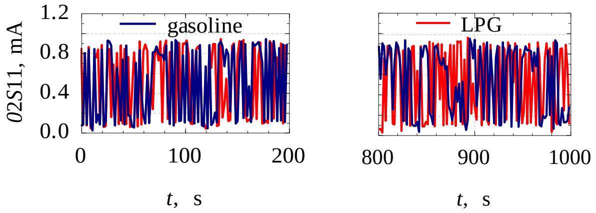


Fig. 3 Free oxygen ions in the exhaust gas ($02S11$) sensor indications during a driving test procedure of Skoda Fabia 1.2L (upstream of the catalytic converter)

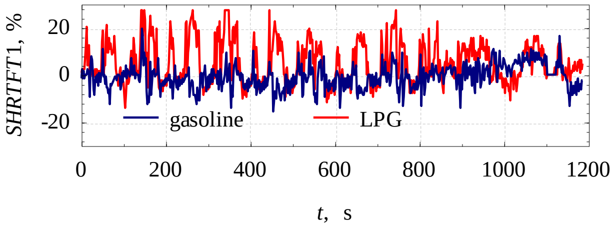
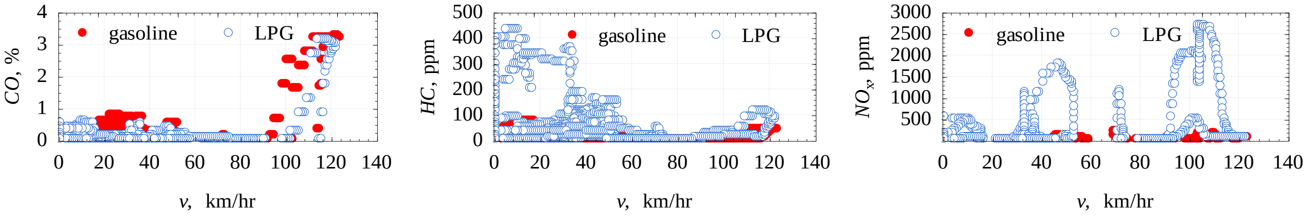


Fig. 4 Curves of short-term corrections during research ($SHRTFT1$) in a test procedure of Skoda Fabia 1.2L



a b c

Fig. 5 Values of individual exhaust components CO (a), HC (b) and NO_x (c) recorded with the MGT-5 Maha analyzer as a function of vehicle speed during the driving test of Skoda Fabia 1.2 L on a dynamometer LPS 3000 Maha

Significant fluctuations of free oxygen ions in exhaust gas $02S11$ sensor indications have been shown in Fig. 3. Amplitudes are similar, but the frequency of changes is higher in the case of LPG fueling, which indicates a need of a more frequent correction of the combustible mixture composition ($SHRTFT1$), as confirmed in Fig. 4.

The assessment of the exhaust emissions during the tests (above) rendered a picture of the vehicle ecological performance. During the diagnostic tests of Skoda Fabia 1.2 L with a scan tool, misfires were recorded when fueled with LPG. The conclusion was that fuel-injecting components were heavily deteriorated. The authors still decided to realize the driving test of a vehicle in use, despite the said malfunctions. The emission values recorded during the tests (Fig. 5) have confirmed the assumptions connected with the influence of fuel dosage irregularity on the exhaust emissions.

To confirm this phenomenon, we can use the

Zimmermann results [34]. As has been proven, the oscillations of the mixture composition around $\lambda = 1 \pm 5\%$ result in a situation when the increments do not compensate the drops, despite the fact that the averaged value may be $\lambda = 1$. This pertains to the external (power and torque), economical (fuel consumption) and most importantly, ecological (CO, HC, or NO_x) parameters.

The research performed on several vehicles has shown similar trends, which is why preliminary comparison of gasoline and LPG injectors dosage regularity was attempted, forecasting discrepancies in the subject question. Irregularity of the fuelling results in an increased exhaust emission.

Simplified test stands are available on the market (equipped with ultrasound cleaning function or laser diagnostics) to check the operation of gasoline injectors. The measurement of both the injector flow and its dosage regularity is possible. It improves its functional capabilities. In the case of LPG vapour injectors simple measurement stands are presented, based on u-tube sensor measurements (the reservoir-pressure). Only selected models are subjected to the regeneration (cleaning) process with renewal of a minimum number of parts. When regenerating the LPG vapour injectors, most elements are renewed, because of their wear during operation.

Unfortunately, the real rating of gasoline injector wear level usually requires dismantling of inseparable connections, which renders the injector useless for further operation. Hence, evaluating the condition of the components is a destructive process. A different situation is in the case of LPG vapour injectors. They are non-destructively disassembled and most of the parts are available on the market as replacement parts.

3. Research objects

Despite the fact, that modern fueling systems are chiefly based on direct gasoline injection systems and in the course of adaptation the original gasoline injectors are used for liquid phase LPG (vapour injectors), the problem remains for commonly operated volatile phase LPG injection systems, used in older designs. The injectors of this type were also subjected to research.

The design solutions of classical electromagnetic gasoline injectors are similar to one another. The fuel flows around the piston to the dosing section and an electromagnet moves the piston in a specified sequence. The tests aimed at merely signaling the problem, hence the number of investigated specimens was limited to five in each wear stage. The research was of a comparative nature. It concerned randomly selected specimens and their results cannot be the basis for assessment of the entire model group of a given manufacturer. Table shows the technical characteristics of gasoline injectors subjected to research.

In the case of LPG vapour injectors, there is a significant diversity of design solutions. It starts with the simplest solutions (similar to electro-valves -most manufacturers) and ends with such similar to gasoline or flap and platter ones. The LPG vapour injectors act in groups (rails) or they can operate individually. Table shows the technical description of LPG vapour injectors, subjected to tests. For lack of available information about flow capabilities, the data was omitted.

Table

Makes and models of injectors used in the research

No.	Code	Designation in catalogue	Pressure measur. p, bar	Mass flow (producer) Q, cm^3/min	Examples of application	The operational status
Gasoline						
1.	B1	17 121 646	3	136	DAEWOO Lanos	used
2.	B2	0 280 150 208	3	155	BMW 325	used
3.	B3	0 280 150 929	3	158	VW Golf VR6	used
4.	B4	0 280 150 447	3	214	Audi 1,8T	new
5.	B5	0 379 060 31E	3	214	VW Golf GTI	used
LPG vapour						
1.	LPG 1	blue	n.d.	n.d.	universal	new
2.	LPG 2	blue	n.d.	n.d.	universal	new
3.	LPG 3	24	n.d.	n.d.	universal	used
4.	LPG 4	black	n.d.	n.d.	universal	used
5.	LPG 5	silver	n.d.	n.d.	universal	new

4. Research methodology

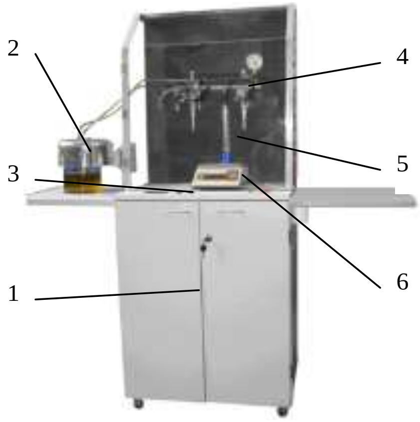
The research was performed on original stands of own design. For the investigations of gasoline injectors, gasoline was used as the medium, for LPG vapour injectors – the medium was air. The injector opening was simulated with special control modules. The initial conditions of the onset of measurement were specified based on literature data and own experience.

4.1. The stand for the evaluation of gasoline injectors dosage irregularity

The essence of test stand operation is to simulate the engine control module that originally controls the frequency and time of injector opening through own control unit based on a microcontroller. Initially, the fuel system of FSO CB 1600 engine was used (engine fitted with a multipoint injection system). The universal character of injection systems allows fitting any injection components of the likes of BOSCH or DELPHI. The fuel from the tank is supplied to the injection rail *4* through a fuel pump - *2* - figure 6a where the manometer shows the pressure while the regulator is responsible for the pressure value. The research conditions are maintained using an injector control system communication panel *3*. With specified frequency and opening duration, the injectors dose the fuel to the burette set on the scales *6*.

The tests were conducted for the injector opening times 0 - 50 ms. In the range (0 ... 10) ms the measurements were taken every 2 ms, in the range (10 – 50) ms the measurements were taken every 10 ms. The injector opening pulse realized by the test stand controller was rectangular and was not PWM modulated. The setting of the opening time by the controller was done with the accuracy of 0.1 ms. In order to precisely determine the unit fuel dose, at the scale accuracy of 0.2 g, in each trial (the set injector opening time) 1000 injections were performed and an average fuel dose per one injection was calculated.

The actuator, which is an electromagnetic injector, subjected to the test on the aforementioned stand, provides the information about the mass of the injected fuel (Fig. 6, b). Additionally, it is possible to evaluate the irregularity of the fuel dosage through comparison of the fitted injectors. Using the algorithm, the program reads the mass of the injected fuel from the electronic scales *6* (Fig. 6, a) on a regular basis and computes the injector flow in [g/s] (e.g. the unit mass of fuel [g] per one injector cycle).



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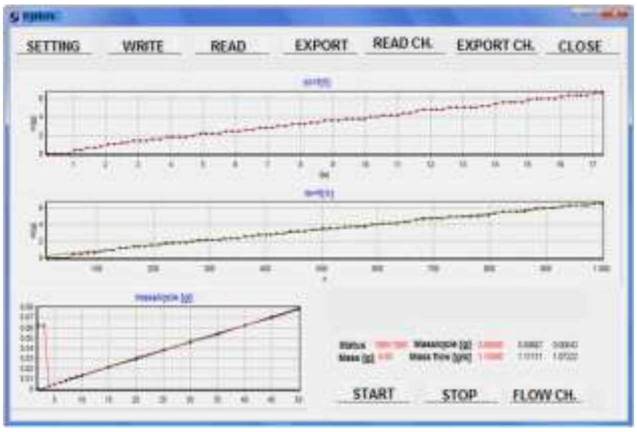


b

Fig. 6 The stand for injector research of a gasoline engine fueling system: a - overview: *1* – base with covers, *2* – tank with fuel pump and fuel lines, *3* – injectors control unit (driver), *4* – tested injecting component with a mount, *5* – measuring burette, *6* – WPT5 scales; b - communication panel [35]

The research results were analyzed in the form of graphs of linear mass growth versus time of the injectors opening (Fig. 6, b). For the assumed supply pressure and the injector sets, a hypothesis was assumed that the relation between the time of the injector opening and fuel mass growth can be presented with a linear graph.

Determination coefficient R^2 was designated in Excel from the graph presenting the trend line of the relation between the fuel mass growth and the injection time.

4.2. The stand for the evaluation of the LPG injector dosage regularity

For the tests performed on the LPG vapour injectors, the research process gets complicated because the LPG in its volatile phase is dangerous and requires additional protection and insulated exhausts. In the course of the study, an indirect container method was applied in which the flow was forced by the pressure difference (of up to 2 bar) between the empty tank and the filling tanks. The value of the pressure at the onset was determined based on the results of tests in the driving cycle on a chassis dynamometer (LPS 3000 Maha (Fig. 7)). In the course of the calibration of the system fitted in the vehicle, the value of (1.12. - 1.15) bar was set, which, as seen in figure 8, was maintained under the conditions of variable loads. In order to extend the scope of the research, the range of pressures was set at (2 to 0) bar during the tests.

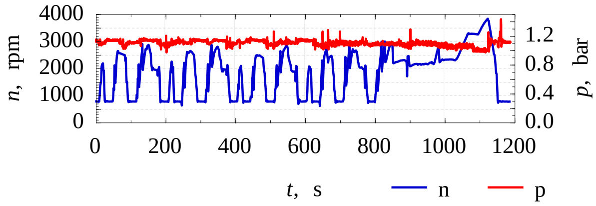
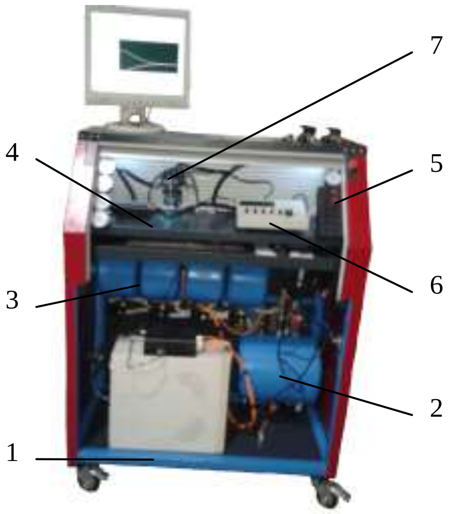


Fig. 7 Course of pressure in the fuel rail (regulator) during the performance of the driving cycle of a Seat Leon 1.4 16V APE, LPG STAG 200 by AC LLC – IV generation, data recorded with the calibration software

The filled container acted as a flow meter. The injection rail was placed on the way of the flowing air. The supply from one large container was connected to the inlet rail connector and the injector nozzles to four small containers. The openings were realized by the original pulsator simulating actual LPG system operation. After 2.5 ms of the opening time, the PWM signal stimulation took place. The actual operating conditions were, thus, simulated (during research the opening is commonly realized by a rectangular signal).

A prototype was built (Fig. 8), based on the applied design assumptions and proposals of a mathematical model describing the phenomena occurring within the test stand. After filling the container *2*, the required injector opening times were realized through the actuation system *6*, a result of which was the filling of the containers *3*. The courses of the pressure change in containers *2* and *3* were registered using Honeywell sensors (accuracy - 0.25%; full scale - $6 \cdot 10^5$ Pa,), a measurement board by National Instruments (NI-USB 6215) and LabVIEW 8.5 Developer Suite software. The opening times of the injectors as well as the engine speed, were a result of the pulsator settings. Each time before the measurement, the rail was "heated" (it was activated for approximately 10 minutes).

In order to evaluate the flow of individual injectors (the dosage regularity), a mathematical model was developed, where, upon assuming the simplifications, the flow was based on an isentropic flow in an adiabatic



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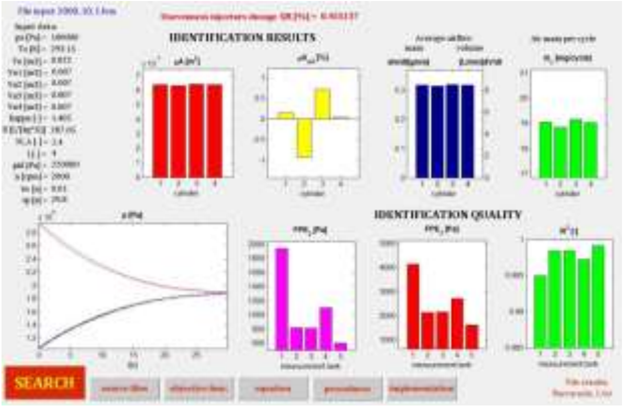


b

Fig. 8 Research stand: *1* – frame with equipment, *2* – measurement supplying reservoir, *3* – filled reservoirs, *4* – rotary vise, *5* – control system of reservoir power and outlet electro-valves, *6* – system forcing the injector opening (STAG Premium by AC LLC), *7* – tested injecting component, additional – connecting lines (a), Software panel for the identification of the flow parameters created in the Matlab–Simulink-Guide (b) [36]

shield. Based on a constant temperature, the following was assumed:

- speed of sound propagation in stationary gas:

$$v_m = \sqrt{\kappa RT}\text{ , m/s} \tag{1}$$

- air density:

$$\rho = \frac{p}{RT},\ \text{kg/m}^3 \tag{2}$$

- dimensionless function of flow - the form according to Miatluk – Avtuszko (Eq.(3)). In the description, flow function was used with a changed parameter $a = 1.4$ (original value $a = 1.13$). This function applies in the full flow range i.e. subcritical and supercritical.

$$\varphi(\sigma) = a\frac{1-\sigma}{a-\sigma} \quad \text{where} \quad \sigma = \frac{p_{out}}{p_{in}} \tag{3}$$

- St` Venant and Wantzel function maximum value:

$$\varphi_{max}(\sigma) = \sqrt{\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} = 0.578 \tag{4}$$

The system of differential equations describing the change in pressure inside the measurement reservoirs takes the form Eq. (5).

Using the recorded courses, the authors searched for changes in the pressures in the measurement tanks in subsequent iterations of the model tracings using the ode23tb system of differential equations by Eq. (5).

While searching for the conductance, a method of non-linear regression was used, minimizing the FPE_1 index by Eq. (6). The minimization was performed numerically through a gradientless method of Nelder–Mead simplex. The minimization was performed with the use of Matlab–Simulink-Guide, fminsearch procedure [37, 38, 40].

$$\left.\begin{array}{l}
\dfrac{dp_{t0}}{dt} = \dfrac{\kappa RT_{t0}}{V_{t0}}\left(\begin{array}{l}
-(\mu A)_1\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_{t0}}\,0.654\dfrac{1-\dfrac{p_{t1}}{p_{t0}}}{1.4-\dfrac{p_{t1}}{p_{t0}}}-(\mu A)_2\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_{t0}}\,0.654\dfrac{1-\dfrac{p_{t2}}{p_{t0}}}{1.4-\dfrac{p_{t2}}{p_{t0}}}-\\
(\mu A)_3\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_{t0}}\,0.654\dfrac{1-\dfrac{p_{t3}}{p_{t0}}}{1.4-\dfrac{p_{t3}}{p_{t0}}}-(\mu A)_4\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_0}\,0.654\dfrac{1-\dfrac{p_{t4}}{p_{t0}}}{1.4-\dfrac{p_{t4}}{p_{t0}}}
\end{array}\right)\\
\dfrac{dp_{t1}}{dt} = \dfrac{\kappa RT_{t0}}{V_{t1}}(\mu A)_1\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_0}\,0.654\dfrac{1-\dfrac{p_{t1}}{p_{t0}}}{1.4-\dfrac{p_{t1}}{p_{t0}}};\quad \dfrac{dp_{t2}}{dt} = \dfrac{\kappa RT_{t0}}{V_{t2}}(\mu A)_2\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_0}\,0.654\dfrac{1-\dfrac{p_{t2}}{p_{t0}}}{1.4-\dfrac{p_{t2}}{p_{t0}}}\\
\dfrac{dp_{t3}}{dt} = \dfrac{\kappa RT_{t0}}{V_{t3}}(\mu A)_3\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_0}\,0.654\dfrac{1-\dfrac{p_{t3}}{p_{t0}}}{1.4-\dfrac{p_{t3}}{p_{t0}}};\quad \dfrac{dp_{t4}}{dt} = \dfrac{\kappa RT_{t0}}{V_{t4}}(\mu A)_4\dfrac{p_{t0}}{RT_{t0}}\sqrt{\kappa RT_0}\,0.654\dfrac{1-\dfrac{p_{t4}}{p_{t0}}}{1.4-\dfrac{p_{t4}}{p_{t0}}}
\end{array}\right\} \tag{5}$$

$$FPE_1 = \frac{m+l}{m(m-1)} \sum_{i=l}^{m} \left(p_e - p_m\right)^2 \text{ , Pa}^2 \tag{6}$$

The FPE_2 index representing the average error has been determined by:

$$FPE_2 = \frac{1}{m} \sum_{i=1}^{m} \left| p_e - p_m \right| \text{, Pa} \tag{7}$$

The maximum FPE_3 error value (Eq. 8) was:

$$FPE_3 = MAX \ \left| p_e - p_m \right| \text{, Pa} \tag{8}$$

The coefficient of determination adjusted to the degrees of freedom R^2:

$$R^2 = 1 - \frac{m-l}{m-1} \cdot \frac{\sum_{i=1}^{m} \left(p_e - p_m\right)^2}{\sum_{i=1}^{m} \left(p_e - \overline{p_m}\right)^2} \tag{9}$$

Computational procedures were written in the Matlab-Simulink environment code [39], Guide supplement (Fig. 8, b).

5. Results analysis

The supplying irregularity was described by the dependence:

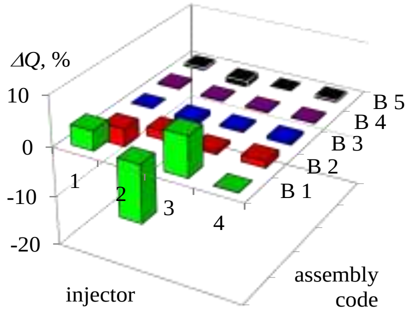
$$Q_R = \frac{\sum_{i=1}^{c} \left| q_i - q_{śr} \right|}{\sum_{i=1}^{c} q_i} \text{, \%} \tag{10}$$

In the case of gasoline injectors, the mass flows were used for evaluating the irregularity. The determination coefficient is the basis for the qualitative evaluation of the flow. As can be seen, its values are above 99.9%, which confirms the assumption about flow characteristics linearity against the opening time. The discrepancies can be seen in flows up to ca. 15%, contrary to the values given by the manufacturers. The technical data sources are not included in the official brochures, but they are available at websites of repair workshops and distributors of spares.

The measurements results were shown in a graphical form (Fig. 9, a). As can be seen, in the case of B1 injecting set the significant irregularity of dosage occurs at nearly 6%, B2 – 1.7% and the other are approx. 0.5%. Except B1 and B2, the other researched sets are capable of meeting the regulation ranges of combustible mixture composition, which is maintained in about (0.5…1)% of the air excess coefficient value.

The LPG injection sets research showed that their irregularity mostly exceeds the value showed as maximum in the case of gasoline injectors. The tests were conducted with the opening time of 5 ms and the engine speed n = 760 rpm, which was caused by a prolonged research and identification process in this case. The preliminary research has shown that from 5 ms on, the LPG injector characteristics is close to linear and can be deemed representative. On the other hand, testing vehicles with worn injectors has shown significant deviations of the exhaust composition at a minimum engine speed.

In one of the tested sets (LPG 3), the irregularity exceeded 50%, which resulted in a permanent misfiring registered by the vehicle on-board diagnostics system (Fig. 9, b). The other LPG injectors were characterized by an irregularity at the level of (5…7)%. In turn, the LPG 1 injection set insignificantly exceeded the irregularity level of 1%.



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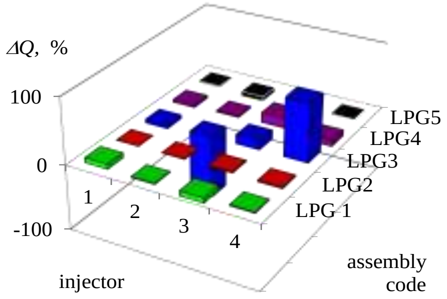

b

Fig. 9 The diversity against the mean value: a - gasoline, b - LPG vapour

Qualitatively considering the identification process of flow parameters of LPG injecting sets, we can see that non-linear regression coefficient only in one of the researched cases had a value of 92%. In the other cases, it exceeded 99%, which can be considered as satisfactory, when identification is run based on the dynamic characteristics and a description of system of differential equations.

Significant irregularity of the dosage of the injectors makes the control system (based on the indications from free oxygen ions in exhaust gas sensor) correct the ratio of total air to fuel mass ratio by a dosage of individual sections (injectors). High deviation of fuel dose of one injector causes improper mixture composition in all cylinders. It results in engine speed variations; hence, a malfunction is registered (a misfire), after exceeding the difference threshold declared by the manufacturer. Misfires do not occur in each case. It is mostly dependent on the values of the original engine control unit, as declared by the manufacturer.

The research had a comparative nature, represented by randomly selected specimens. The results are not a basis for the evaluation of the entire model group of a given manufacturer.

6. Conclusions

1. The research of the injector dosage irregularity, performed on the original measurement stands, allows an evaluation of the operational capability of a component.

2. The dosage irregularity of gasoline injectors, both new and used, exceeded 5% in one case only. It mostly oscillated around 1%.

3. The dosage irregularity of the LPG vapour injectors exceeds that of the used gasoline injectors (over 5%), which can be a reason for reliability issues of vehicles fitted with alternative fueling systems.

4. The research of LPG vapour injectors was conducted using a replacement medium (air). It greatly idealizes the process because the air is less polluted than LPG, but is sufficient for the evaluation of the fueling regularity.

5. The irregularity of 5%, determined in the course of the research can result in misfires as a response to weakening/enrichment of the combustible mixture in individual engine cylinders.

6. The research was of a comparative nature, represented by randomly selected specimens. The results cannot constitute a basis for the evaluation of the entire model group of a given manufacturer.

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BENZINO IR SUSKYSTINTŲ DUJŲ GARŲ DOZAVIMO REGULIARUMO PURKŠTUKŲ OPERACINIS VERTINIMAS

Reziumė

Straipsnyje analizuojamas įpurškimo dozavimo nereguliarumas klasikinėse ir alternatyviose motorinių transporto priemonių kuro sistemose. Tyrimams pasirinkta naujai pagaminta posistemė, kuri sukuria idealias variklio (naujo) veikimo sąlygas. Abejota ar tyrimui reikia panaudoti dėvėtas posistemes, bet jų panaudojimas leidžia geriau vertinti esamą išmetimą emisiją. Autoriai nagrinėja kuro padavimo nereguliarumo problemą didinančią gedimų automobiliuose su suskystintomis dujomis skaičių, kurie yra labai populiarūs Lenkijoje. Siekiant parodyti dozavimo nereguliarumo skirtumus, tyrimų metu buvo išbandyta keletas purkštukų. Tyrimų užduočių įvykdymui buvo sukurti skirtingi bandymo stendai su programine įranga. Bandymams parinkta keletas įpurškimo vienetų komplektų įvairiose jų sudilimo stadijose. Rezultatai parodė, kad benzininiai purkštukai charakterizuojami apytikriai 0.5% nereguliarumu, labai sudilę – 6%. Suskystintų dujų garų purkštukai pasiekdavo 5% lygį, o labai sudilę – 50%.

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OPERATIONAL ASSESSMENT OF SELECTED GASOLINE AND LPG VAPOUR INJECTOR DOSAGE REGULARITY

Summary

The paper analyzes the problem of injector dosage irregularity in classical and alternative fueling systems in motor vehicles. An adoption of a newly manufactured subassembly as a starting point for the research creates idealized engine operating conditions (new engines). The question of investigating used subassemblies is rather difficult but it provides a better and clearer picture of the existing situation - the exhaust emissions. The authors have undertaken the problem of fueling irregularity as a response to a growing number of vehicles with malfunctions of LPG fueling systems that are currently very popular in Poland. In the course of the analysis, several injectors were tested to present the differences in their dosage irregularity. To realize the research tasks, different test stands with software were designed. To fully visualize the problem, several sets of injecting units were selected at different stages of their wear. The results have shown that gasoline injectors are characterized by approx 0.5% irregularity and if heavily worn - 6%. LPG vapour injectors reached the level of 5% and heavily worn ones - 50%.

Keywords: regularity of engine fueling, fuel injectors, flow research.

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