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Estimating Dynamic and Flow Characteristics of Electromagnetic Dispenser for The Kraz Truck Converted to Gas

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Abstract: The problems of worldwide environmental degradation, global warming, scarcity of fossil fuels has caused the replacement of ICE vehicles with electric ones. For the countries with underdeveloped economy, it is important to find more affordable ways to solve this problem. One of them is to convert the cars with ICE into more environmentally friendly and economical ones, such as gas-powered cars. Yet, the conversion of diesel cars usually results in power loss. The work of the electromagnetic gas dispenser (EGD) of the engine power supply system significantly affects the efficiency of the gas engine. Therefore, the aim of the study was to determine the dynamic and flow characteristics of the EGD of the KrAZ truck (Ukraine) converted to gas, and to provide recommendations for improving the efficiency of its operation. The object of the research was the working processes of the EGD power supply system of 6ChGN13/14 engine, converted from diesel engine and equipped with a gas turbine supercharger. The paper presents the results of experimental studies on determining the effect of operating voltage on the dynamic characteristics of EGD. The dependences of dynamic and flow characteristics of the EGD on the change of the control signal frequency and the dependence of efficiency through the EGD flow nozzle on the control signal duration were obtained; the effect of the return spring stiffness on the dynamic and flow characteristics of the EGD were determined. The results of the work are designed to increase the efficiency of diesel trucks converted to gas.

Keywords: Gas engine, car conversion, electromagnetic gas dispenser, energy efficiency, operating modes

1. Introduction

Environmental degradation, global warming and thinning out fossil fuels are pushing scientists to develop energy-saving and environmentally friendly equipment [1]. To a large extent, this applies to the automotive industry due to the fact that until recently the most common were the vehicles with internal combustion engines (ICE). These vehicles run mainly on liquid fuel during whose combustion in the cylinders of ICE the harmful substances are produced and released into the atmosphere and soil. [2], [3]. In addition, the products of complete combustion - carbon dioxide (CO_2) and water vapor (H_2O), contribute to the harmful greenhouse effect [4]. There are currently several ways to solve this problem. One of the effective ways is to turn down cars with internal combustion engines in favor of electric cars [5],

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[6]. But this method has its drawbacks. It requires large financial investments and the cutting-edge developments. In addition to improving the basic elements of electric vehicles - traction motors [7], [8] and batteries [9], its implementation requires an extensive network of charging and recharging stations [10]. In addition, it is especially difficult to implement this method in the countries with low level of economy.

For example, in the case of Ukraine the most promising are the methods based on the following:

i. development and implementation of various methods to reduce the toxicity of exhaust gases of vehicles (cars, buses [11] and rail transport with locomotive diesel generators [12], [13];
ii. development of hybrid power plants for vehicles together with pneumatic [14] or electric drive [15] for vehicles with alternative power units [16], [17];
iii. introduction of start-stop systems, fuel-air mixture control systems [18];
iv. conversion of cars with internal combustion engines to cars running on gas [19], [20] or other alternative fuels [21].

All of the above is especially true for trucks. To increase the environmental friendliness and efficiency of trucks, much attention is paid to the use of natural gas. The authors of article [22] confirm that liquefied natural gas is the most promising alternative to petroleum fuel. It is particularly topical for high-capacity tractors. The paper states that the authors implemented a pilot project for the production of liquefied natural gas and its consumption by high-capacity BilAZ tractors. However, the authors do not hide that the lack of sufficient technically and scientifically sound solutions and methods for assessing the technical and economic performance of onboard cryogenic fuel systems hinders the work on converting tractors to the gas-diesel mode. Developments towards conversion of a diesel engine of a truck into a gas-diesel one, are also presented in [23]. The authors developed a modular gas supply and electronic engine control systems that can be installed on gas diesel engines. As a result of the study, the gas-diesel engine demonstrated fuel economy and a significant reduction in NO_x and CO_2 emissions. But at the same time its power at low speeds decreased significantly compared to the base diesel engine. This reduction in efficiency is typical of trucks converted to gas.

Significant achievements in the use of natural gas on the trucks with a comprehensive change of the fuel system were made by companies Cummins [24] and MAN [25]. Thus, Cummins has developed the standard size of ISL G engines for trucks and buses that use alternative fuels [24]. Cummins Westport (CWI) specialists managed to increase the torque of the ISL G series engine at idle by more than 30%, the fuel savings were more than 5%. The German company MAN [25] presented the technology of neutralizing exhaust gases for trucks and buses equipped with gas engines that meet the Euro VI environmental standard at the IAA exhibition. The company claims that the load distribution between the two EGR and SCR systems is optimal for efficient fuel flow combined with low flow of AdBlue® (urea solution). Controlled EGR provides low NO_x emissions into the atmosphere. This, in turn, means the low AdBlue® flow required to reduce NO_x in the SCR system. The internal combustion engine is equipped with the sets of electromagnetic gas dispensers, which are developed and manufactured by MAN specialists. But neither the technical characteristics nor the detailed description of these dispensers are publicly available. In addition, the presented studies do not provide any data on the role of electromagnetic gas dispensers (EGD) in the results achieved. The works do not give information on the stability and speed of EGD, dosage accuracy and the impact of vehicle operating modes on the flow and dynamic characteristics of the gas dispenser.

In [19] the characteristics of the EGD prototype of the power supply system of 6ChGN13/14 internal combustion engine, converted from YaMZ-236 diesel engine and equipped with a gas turbine supercharger were investigated. The cut-off valve from the low-pressure regulator of the second-generation gas equipment was taken as a basic variant of the EGD prototype. On the basis of the carried out preliminary non-engine tests the most effective ranges of operation of the gas internal combustion engine with rather high technical and economic indicators were chosen. The analysis of the results showed that when organizing the automation of the process of measuring various parameters using modern computer technology, you can determine the instantaneous and hourly fuel flow in real time, which greatly simplifies the processing of the experiment.

According to the analysis of publicly available publications, vehicles that can be converted to work on natural gas in terms of their dynamic properties and energy efficiency do not fully meet modern requirements of emission standards and need significant improvement. This problem is especially related to the gas-fuel equipment of the ICE power supply systems of trucks, which are equipped with gas-cylinder equipment (GCE) of the second or third generation. Modern motor-tractor vehicles have the engines with GCE of the fourth and even fifth generations which are completed with electromagnetic gas dispensers.

The existing convertible vehicle, equipped mostly with naturally aspired gas internal combustion engines with pneumo-mechanical gas supply on the drive wheels (carried out using a gas mixer, which is mass-produced) has: insufficient traction (torque), which leads to unproductive power flow traffic; low indicators of dynamism, maneuverability and energy efficiency [19]. Analysis of the problem of converting diesel cars into gas has shown that the existing ways to increase the efficiency, environmental safety and performance of the vehicle do not completely solve the problem. The conversion of diesel cars on the one hand reduces the harmful effects of vehicles on the environment, and on the other hand, reduces their power. This is especially true for trucks. The studies show that the efficiency of a gas engine is directly influenced by the operation of the electromagnetic gas dispenser of the engine power supply system. Therefore, it is necessary to explore the possibility of improving the dynamic and flow characteristics of the electromagnetic gas dispenser of the engine power supply system, depending on the conditions and modes of vehicle operation. Therefore, the aim of the study is to determine the dynamic and flow characteristics of the engine power supply electromagnetic gas dispenser of the KrAZ truck (Ukraine), which is converted to gas, depending on the conditions and modes of car operation by experimental methods.

The object of the research is the working processes of the prototype of the electromagnetic gas dispenser in the power supply system of 6ChGN13/14 engine, converted from YaMZ-236 diesel engine and equipped with a gas turbine supercharger. To achieve this goal, it is necessary to determine:

i. the effect of operating voltage on the dynamic characteristics of the gas dispenser;
ii. the dependence of the flow and dynamic characteristics of the gas dispenser on the change in the control signal frequency;
iii. the dependence of efficiency (gas flow) through the EGD flow nozzle on the duration of the control signal;
iv. the effect of the return spring stiffness on the dynamic and flow characteristics of the electromagnetic gas dispenser.

The process of obtaining the flow and dynamic characteristics of the EGD prototype was carried out on a universal motorless stand.

2. Design and Operating Principle of The EGD Under Study

The main dosing element of gas supply systems is EGD, which is also called electromagnetic gas injector. To study such power systems, diagnostic equipment is needed to determine the gas-dynamic and flow characteristics of EGD. Let us consider the principle of EGD, which is presented in Fig. 1. The working body - air (WB) - is fed through the fitting 14 into the cavity A of the gas ramp 2. From the ramp the working body is fed into the bypass holes *B* of the mounting screw 1, from which it is fed into the cavity *C* above the core 16. This cavity is formed between the surfaces of the dispenser housing 11, valve body 3 and EGD core 16. When voltage is applied to the contact terminals 10 the current flows through the coil of the electromagnet 4 that creates a magnetic field, which is closed by bracket 5.

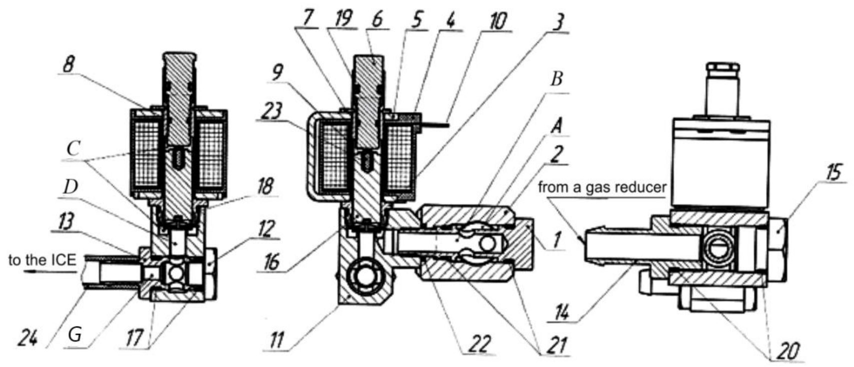

Fig. 1 - Longitudinal and cross section of EGD for engine 6CHGN13/14 power supply systems: 1 - mounting screw; 2 - gas ramp; 3 - valve body; 4 - coil of the electromagnet; 5 - bracket; 6 - adjusting screw; 7 - lock washer; 8 - bracket; 8, 17, 18, 20-22 - rubber sealing rings; 9, 23 - locking springs; 10 - contact terminals; 11 - the dispenser housing; 12 - plug; 13 - flow nozzle; 14 - fitting; 15 - stop plug; 16 - the core; 19 - the body of the core valve; 24 - rubber hose; A - cavity in the gas ramp; B - mounting screw; C - cavity above the center; G - flow channel

When the magnetic force exceeds the force of the locking spring 23, the core 16 is separated from the seat of the dispenser as long as current flows through the electromagnet coil. When the dispenser valve is in the open state, the WB from the cavity *C* located above the core 16 of the EGD is fed to the outlet channel of the valve body 3. Next, from the outlet channel *G* made in the flow nozzle 13, the working body enters the ICE cylinder through the calibrated hole *D* by connecting hose 24. When the voltage is disconnected from the electromagnet coil, the magnetic field is dissipated and the return spring 23 of the core 16 of the dispenser returns to its original position, blocking the channel *G* for leakage of WB and thus stops the supply of WB to the engine. The general view of one section of the EGD prototype is shown in Fig. 2.

a b

Fig. 2 - General view of a one-section EGD prototype (a) the front view; (b) the rear view

3. Design of A Motorless Stand to Study The EGD

To study the characteristics of EGD of existing and new designs, instead of the motorless stand given in [19], a fundamentally new universal motorless stand was made, which provides:

a. EGD operation under pressure in the range from 0 to 0.25 MPa;
b. control of line pressure and gas flow;
c. EGD control in a wide range of engine crankshaft speed and duration of control pulse on the EGD;
d. EGD operation in a wide voltage range;
e. control of the position of the EGD shut-off needle-valve;
f. registration of transient signals and storage of their parameters on the PC;
g. possibility to carry out research both with the four sections, and with the one-section dispenser simultaneously.

The block diagram of the installation to study EGD characteristics is shown in Fig. 3, and the general view of the control panel of the motorless stand is shown in Fig. 4.

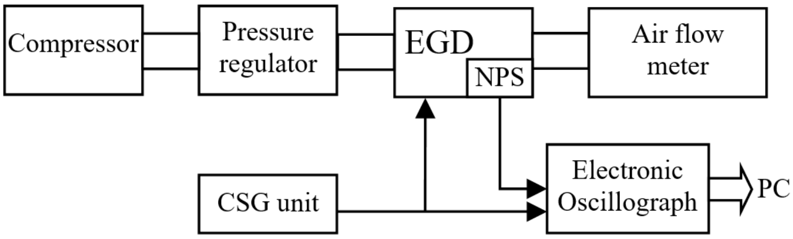

Fig. 3 - The scheme of the structural installation to study EGD characteristics

a b

Fig. 4 - Control panel of the motorless stand (a) the general view; (b) the side view (supply of WB to the motorless stand from the drive compressor)

In the installation for studying the characteristics of EGD the following is used, Fig. 3:

a. pneumatic two-stage compressor of the TM-392M piston type. It is designed to compress the air to the set value and supply it to the gearbox.
b. CSG (control signal generation) unit, which consists of an adjustable power supply and a rectangular pulse generator with adjustable parameters, Fig. 5.

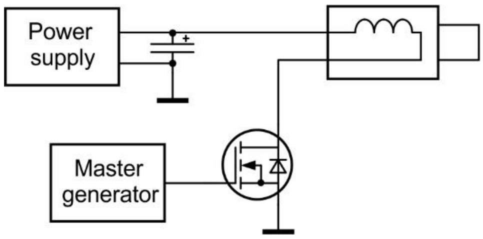

Fig. 5 - Schematic diagram of the CSG unit

The master generator has an operating frequency range from 1 to 50 Hz (from 120 to 6000 min-1) and allows changing the pulse duration from 0 to 100% duty ratio, which completely overlaps the values of the signal parameters required for the study. The power supply enables to set any voltage value in the range of 0… 60 V.

i. The Tomasetto AT-09 Alaska pressure regulator is designed to regulate and maintain (stabilize) the pressure at the inlet to the EGD in a given range. The main technical characteristics of the pressure regulator are given in Table 1.

Table 1 - The main technical characteristics of the Tomasetto AT-09 Alaska pressure regulator

Parameter	**Unit of measurement**	**Parameter index**
Weight	kg	1.5
Maximum inlet gas pressure	MPa	3.0
Gas pressure at the outlet of the gearbox	kPa	90 - 180
Electromagnet valve power	W	17
Engine power	kW	100 - 184

ii. NPS - (needle-valve position sensor) is designed to display the current state of the movable shut-off rod of the electromagnet injector. An inductive sensor, a Hall sensor or an optical sensor can be used as an NPS. However, the presence of an alternating electromagnetic field has an additional effect on the signals of the induction sensor and the sensor that works on the Hall effect. This makes their use inefficient, as it is much more difficult to determine the useful signal against the background of the electromagnetic field of the EGD coil. Therefore, it was decided to use an optical sensor of the infrared light spectrum. This sensor detects a change in the luminous flux in the controlled area, associated with the change in the position in space of any moving parts and mechanisms, the absence or presence of objects. The optical contactless sensor consists of two functional units: the emitter and the receiver. Infrared LED BIR-BM1331 was used as the emitter. The receiver is a photodiode BPW41N VD2. The radiation source and the receiver are located in separate cases. The emitter and receiver are mounted on the opposite walls of the working cavity of the housing in special holes made strictly on one axis perpendicular to the axis of movement of the locking rod [19]. In the closed state, the rod is pressed against the rubber seal of the flow hole under the action of the spring and thus completely covers the optical channel between the emitter and the receiver. When a signal is applied to the electromagnet of the dispenser, the magnetic flux overcomes the force of the spring and the locking rod is retracted, opening the optical channel.

iii. The Fluke 190B digital dual-channel electronic oscilloscope is connected to a personal computer.

iv. The time of the EGD open state depends on many factors: the drop in pressure across the needle-valve of the EGD, the inductance of the electromagnet winding, the mass of the valve, the spring stiffness, the working stroke of the needle-valve of the EGD, the position of the EGD in space and others. Therefore, in practice, the duration of the open state of the dispenser does not correspond to the duration of the control pulse. The imperfection of the technology of manufacturing EGD components and their unstable operation do not determine the identity of the flow and dynamic characteristics of each EGD. The identity of the flow characteristics of the EGD depends on such important parameters of the vehicle as the number of harmful substances in the exhaust gases, technical and economic indicators, the constant operation of the engine at idle and more.

EGD flow characteristics are also affected by the length and cross-section of the connecting hoses and pipes, the location of the gas supply fitting in the intake manifold, the cross-section of the hole in the flow nozzle, etc. It is these factors that cause the need to be able to assess the identity of the flow characteristics for each EGD during the current and overhaul repair and regulation of the gas supply system. Fig. 6 presents a pneumatic diagram and control panel of a motorless stand for studying electrically controlled gas dispensers (EGD). The compressed air is used as the working body for taking flow characteristics of the dispenser which is forced in the air line of the stand by the independent drive compressor.

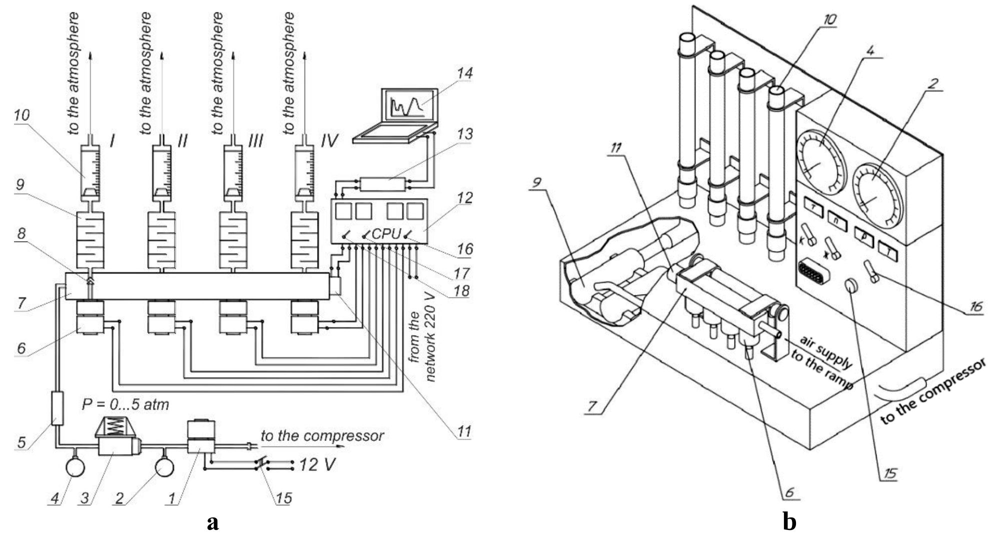

Fig. 6 - Motorless stand for testing gas dispensers (a) the pneumatic scheme; (b) the stand control panel (1, 5 - gas filters; 2 - exemplary manometer MO-16; 3 - low pressure gas regulator; 4 - exemplary manometer MO-5; 6 - transition hole of gas dispenser; 7 - gas ramp; 8 - bypass valve of working fluid; 9 - receiver-calmer; 10 - gas rotameter PM-04 6.3 GUZ; 11 - pressure and temperature sensor; 12 - electronic control unit (ECU); 13 - oscilloscope attachment; 14 - PC; 15-18 - toggle switches)

4. Experimental Study of the Effect of KRAZ Truck Operating Modes On the Dynamic and Flow Characteristics of The EGD

4.1 Research Methods

The main method of estimating the flow characteristics of EGD, which was used in this work, is the volumetric method. This method is more accurate because the volume of gas consumed is determined directly by the flow meter [19]. This method is best suited for regulatory work and basic research. An objective comparison of the flow characteristics of EGD is possible only in dynamics, by providing conditions that are as close to the real ones as possible. These conditions are:

i. gas pressure at the needle valve (core valve) of the EGD;
ii. duration of control pulses;
iii. engine crankshaft rotation speed and others.

All studies were performed at a nominal working pressure for EGD (R_{EGD} = 0.18 MPa).

When analyzing how the operating voltage affects the dynamic characteristics of the gas dispenser, the parameter under study was the dependence of the delay in the start of the EGD valve stroke on the value of the control pulse voltage. The control pulse voltage varied in the range from 40 to 60 V with a fixed step of 10 V.

Researching into the flow and dynamic characteristics of the EGD depending on the change in the control signal frequency, the parameters of the study were the dependence of the delay of the valve full stroke and the dependence of the delay of the EGD valve complete closing on the voltage of the control pulse. The study was conducted at a variable value of the control signal duration, in the range of simulation angular frequencies of the ICE crankshaft rotation from 700 to 2100 min^{-1}.

In the study of the dependence of efficiency (gas flow) through the EGD flow nozzle on the control signal duration, the studied parameters were the time intervals of the core valve relative to the control signal and efficiency (gas flow) of EGD through the flow nozzle installed in the dispenser outlet. The change in the duration of the control pulse with the electronic control unit varied in the range from 4 to 24 ms with a fixed step of 2 ms. For the study, four variants of fittings were made for gas supply to the cylinders of internal combustion engines, with nozzle diameters of 4.5, respectively; 5.0; 5.5 and 6.0 mm. The influence of the return spring stiffness on the dynamic and flow characteristics of the EGD was studied in the following way. In the course of the experiment, six variants of springs were made (wound) with different diameters of hardened heat-treated steel wire with a winding step and variable stiffness relative to 0.5; 0.6; 0.7; 0.8; 0.9 and 1.0 N/mm.

Each spring modification was sequentially installed in the EGD and its effect on the change of flow and dynamic characteristics of the EGD prototype was monitored. During the vehicle operation, the stiffness of the pre-compressed springs in the EGD kit constantly changes. Therefore, researchers must have the valid information about the technical condition of the EGD moving parts during its operation on the vehicle.

4.2 The Results of Experimental Research

The results of studying the effect of operating voltage on the dynamic characteristics of the EGD prototype are shown in Fig. 7. The studies have shown that when the control pulse voltage increases to a value of 40 to 60 V, the performance of the dispenser increases with improvement of dynamic characteristics. However, the increase in the voltage of the control pulse rises the temperature of the EGD coil windings, and significantly reduces the reliability and durability of the dispenser.

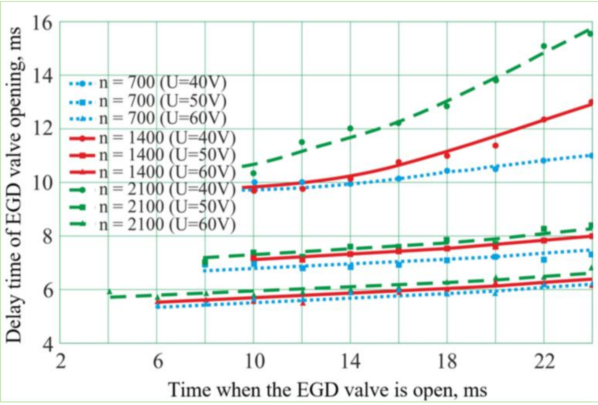

Fig. 7 - Dependence of the delay in the start of the EGD valve stroke on the value of the control pulse voltage

At low speeds of the ICE crankshaft, at n = 700 min^{-1}, the delay time of the start of the EGD valve stroke depends on the value of the control pulse voltage and is from 5.5 to 6.5 ms. Accordingly, in the modes of the average speed of the ICE crankshaft, at n = 1400 min^{-1} the delay time of the start of the EGD valve depending on the voltage of the control pulse is from 7 to 8.2 ms. And in the modes of nominal speeds of the ICE crankshaft, at n = 2100 min^{-1}, the delay time of the start of the EGD valve depending on the value of the control pulse voltage is from 10 to 15 ms. The results of the studied dependence of the dynamic and flow characteristics of the EGD on the change in the frequency of the control signal are shown in Fig. 8 and Fig. 9.

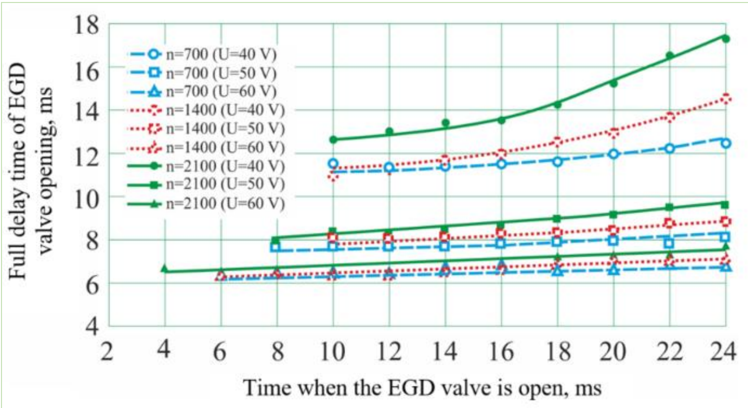

Fig. 8 - Dependence of the delay of the EGD valve full stroke on the value of the control pulse voltage

The analysis of the results showed that the characteristics of the flow rate of the working fluid through the EGD indicated some jump in gas flow rate at small time values of the control pulse t_{pulse}. At low speeds of the crankshaft of the internal combustion engine, at n = 700 min^{-1}, the total delay time of the start of the EGD core valve stroke depending on the value of the control pulse voltage is from 6.0 to 7.0 ms. Accordingly, in the modes of average speeds of the internal combustion engine crankshaft, at n = 1400 min^{-1} the total delay time of the start of the EGD core valve stroke depending on the value of the control pulse voltage is from 7.5 to 9.0 ms. In the modes of nominal speeds of the crankshaft of the internal combustion engine, at n = 2100 min^{-1} the total delay time of the start of the EGD core valve stroke depending on the value of the control pulse voltage is from 11 to 17.5 ms.

The resistance of the magnetic circuit does not have time to change and the energy accumulated by the coil is slightly higher than in the following cases, when the movement of the valve results in the air gap in the magnetic circuit, which causes a change in the magnetic flux. As the open state of the EGD core valve increases (Fig. 9), the total delay time of the dispenser valve opening also increases. The restraint of the core valve of the dispenser grows. Fig. 9 monitors the oscillating jump, which is stipulated by the fact that the movement of the EGD valve begins after the end of the control pulse, due to the energy accumulated in the magnetic field of the electromagnet coil.

The value of the control pulse voltage, as was already emphasized, has the greatest effect on the delay time of the dispenser valve. At a constant frequency and duration of the control signal, an increase in voltage leads to a decrease in the delay time of the dispenser valve, but the closing delay time increases (Fig. 9). This is primarily due to the increase in the rupture current of the EGD electromagnet, which determines the amount of energy stored in the coil. And, since the time constant in the scattering of the accumulated energy does not change, the total time has an oscillating form in the interval from 2 to 12 ms. As the time interval (from 12 to 20 ms) of the open state of the EGD core valve increases, the amplitude of oscillations decreases, and in the time interval of 20-22 ms it passes into a horizontal line. The results of studying the dependence of efficiency (gas flow) through the EGD flow nozzle on the duration of the control signal are shown in Fig.10.

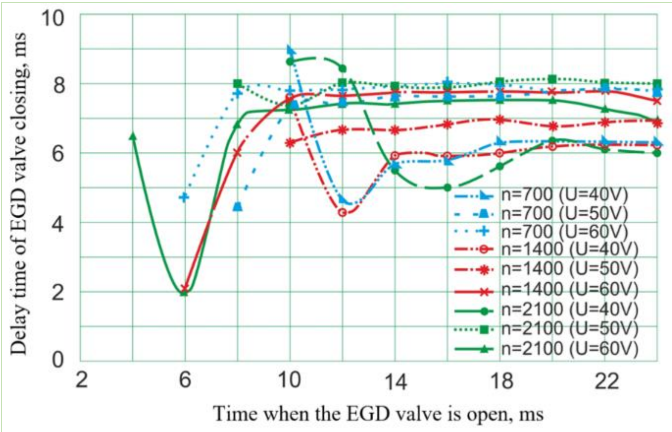

Fig. 9 - Dependence of delay of the EGD valve full closing on the value of the control pulse voltage

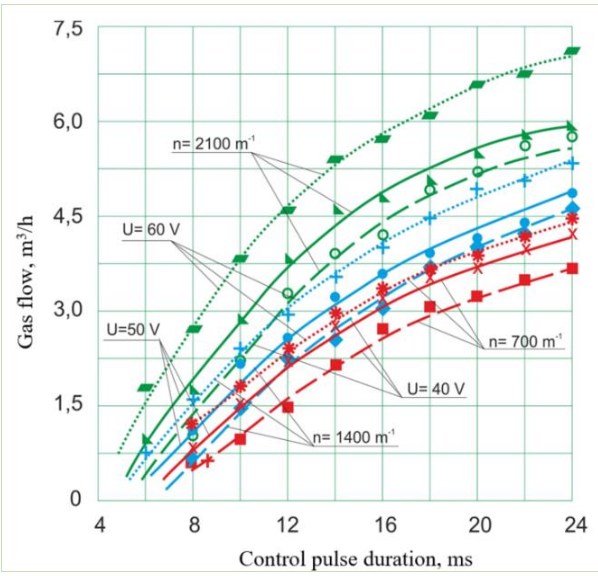

Fig. 10 - Characteristics of gas flow depending on the control pulse duration at a voltage of 40, 50 and 60 V

Experimental study of EGD was performed with four variants of flow nozzles, whose inner diameter is 4.5; 5.0; 5.5 and 6.0 mm. The most rational flow characteristics were obtained with a flow nozzle, whose inner diameter was 5.0 mm. The flow characteristics of the EGD are strongly influenced by: simulated angular speed of the ICE crankshaft, the duration of the control pulse and increase of the voltage applied at the end of the EGD electromagnetic coil winding, Table 2. Experimental study showed that the effect of the simulated angular speed of the ICE crankshaft on the flow characteristics of the EGD in contrast to the control pulse is more effective than the voltage applied at the end of the gas dispenser electromagnetic coil winding.

Table 2 - Flow characteristics of EGD in different modes of operation at the duration of the control pulse from 5 to 24 ms

Voltage, V	ICE crankshaft speed, min^{-1}	EGD flows, m^3/h
	700	0.3 - 3.5
40	1400	0.4 - 4.5
	2100	0.75 - 5.4
	700	0.35 - 3.8
50	1400	0.5 - 4.8
	2100	1.1 - 6.0
	700	0.4 - 4.0
60	1400	0.75 - 5.3
	2100	1.75 - 7.2

The Fluke 190B dual-channel digital oscillograph was used in the EGD study. It allowed not only to see various established periodic processes on the screen, but also to store the oscillograms of various transient processes in electronic form. Fig. 11 shows an oscillogram of the signals taken from the ends of the EGD electromagnetic coil winding at t_{pulse}. where the curve of core valve changing movement in the time interval of open and closed state of EGD is channel A; and the voltage change curves at the ends of the EGD electromagnetic coil winding in the time interval of the open and closed state of the EGD is channel B. The oscillogram shows that the movement of the EGD core valve depends mainly on the moment of inertia that occurs when the valve moves, is determined by its mass, and depends on the stiffness of the return spring, Fig. 11.

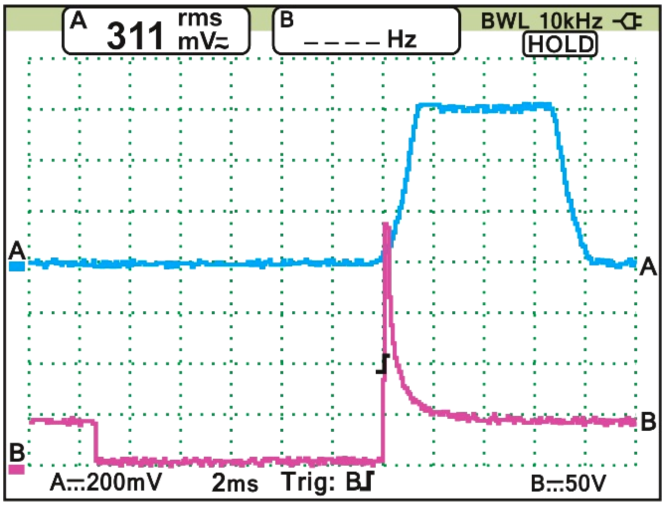

Fig. 11 - Oscillogram of signals at pulse of the electromagnetic gas dispenser

The results of studying the effect of the return spring stiffness on the dynamic characteristics of the EGD are shown in Fig. 12. This graph presents the results of the operation time of the EGD electromagnet, which depend on the pre-compressed return springs with variable stiffness, varying from 0.5 to 1.0 N/mm. Preference is given to the springs with a stiffness of 0.6 N/mm. The operation time of the EGD at a voltage of 60 V and a speed of 2100 min^{-1} with such a spring is from 4.2 ms. With this spring stiffness, the core valve in the opening state of the valve opens quickly enough. In the state of EGD closure, the pre-compressed spring with a stiffness of 0.6 N/mm, constantly presses on the upper end of the core valve, moves it and closes the EGD bypass hole faster than the spring, whose stiffness is 0.5 N/mm.

Conversely, pre-compressed springs with a stiffness of 1.0 N/mm and more delay (inhibit) the process of opening the EGD core valve very much. With increasing stiffness from 0.5 to 1.0 N/mm, the closing delay time and the full opening time change proportionally, by about 40 - 50%. According to the results of the experiment shown in Fig. 12, the most rational (flow) results are obtained with the springs whose stiffness is from 0.5 to 0.6 N/mm After non-motorized experimental studies, the EGD was installed on a six-cylinder non-inflatable gas engine 6CHNG 13/14. The gas engine was placed on an extended research stand equipped with a bench microprocessor control system. The studies on the deployed stand have shown that the engine starts easily, however, does not develop sufficient power and torque reserve on the crankshaft of the gas internal combustion engine at the modes of maximum torque and rated power. The obtained performance, flow and dynamic characteristics and EGD oscillograms can be used to determine the average and instantaneous speeds and acceleration of the core valve, which depend on the change of voltage and current at the contacts of the EGD coil, using computational and experimental methods.

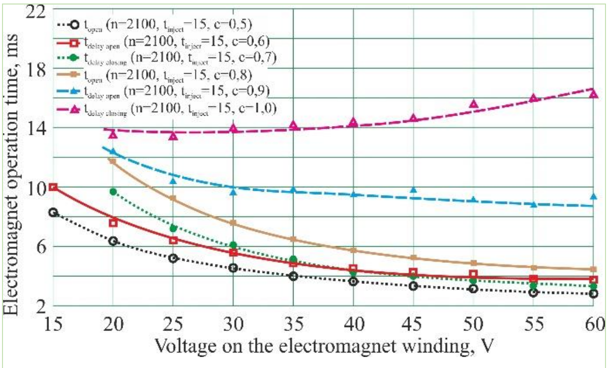

Fig. 12 - Graphs of the dependence of time intervals on the voltage in the circuit of the EGD electromagnetic coil winding and the stiffness of the return spring

5. Conclusion

The experimental study of the dynamic and flow characteristics of the EGD prototype was carried out, which showed that the change in time characteristics depends on the voltage of the control pulse. As the control pulse voltage increases from 40 V to 60 V, the EGD efficiency increases with the dynamic performance, but the 60 V voltage applied at the end of the EGD electromagnet coil is insufficient because the core valve speed is only 6.2 ms. In order for a multi-cylinder internal combustion engine to work efficiently and reliably in start-up and low-load modes, it is necessary to increase the speed of the core valve to approximately 3.5 ms. The studies of the dependence of flow and dynamic characteristics of EGD on the change of the control signal frequency showed that with increasing time interval (12 to 20 ms) of the core valve open state, the amplitude of EGD oscillations decreases, and in the time interval of 20-22 ms it turns into a horizontal line. The gas flow characteristics of the EGD, which depend on the duration of the control signal, are affected by the simulated angular speed of the ICE crankshaft, the duration of the control pulse and voltage increase applied at the end of the EGD coil, the diameter of the flow nozzle. The stiffness of the EGD return spring has the greatest effect on the flow characteristics of EGD. It is established that the most rational (flow) characteristics are obtained with the springs whose stiffness is from 0.5 to 0.6 N/mm. The preference is given to the springs with a stiffness of 0.6 N/mm. All recommendations are developed during the study of the KrAZ truck converted to gas. The results of this work are designated to improve the dynamic and flow characteristics of diesel trucks converted to gas.

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