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Selection of Gas Injector Units for Converting Diesel Engines to Gas

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Abstract*: *Given the rising cost of crude oil and fuels based on it, as well as acute environmental problems, alternative energy sources are becoming increasingly important. Natural gas is the most affordable alternative fuel for Russia. A study was carried out at FSUE NAMI on the conversion of the L6 engine from diesel to natural gas. The study included testing of gas fuel equipment both to determine its performance and to test its stability at low temperatures. The greatest interest was the selection of gas injectors for distributed gas supply to ensure the required cycle flow rate. Motorless tests of electronic gas injectors BOSCH, IMPCO, WOODWARD, as well as gas injectors produced by Concern KEMZ JSC were carried out. Based on the results obtained, the choice of gas injectors for further use in the gas engine was justified.

Keywords*: *Natural Gas, Gas Engine, Gas Injector, Climatic Chamber, Fuel Cycle Mass, Flow Rate, Motorless Bench, Wide Opened Throttle Curve.

I. INTRODUCTION

Currently, in Russia and worldwide, there are problems of depletion of natural resources, and the task is to reduce the negative impact on the environment of emissions of pollutants and greenhouse gases. The cost of crude oil and motor fuels based on it has reached significant values. In this regard, the task of finding an alternative to oil fuels becomes urgent. As an alternative for the Russian Federation, natural gas is of the greatest interest [1].

A. Objective

The objective of the study is to select gas injectors for the engine L6, converted from diesel to gas, and to test their performance and stability at low temperatures.

B. Study object

The study objects are BOSCH model 0280158833, IMPCO model GS2, WOODWARD model 1309-6234 and Concern KEMZ JSC model FG-02.

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II. PROPOSED METHODOLOGY

A. Testing equipment

The tests were carried out on the bench for testing electronic gas injectors IC-010F-01, the bench scheme is shown in Fig. 1.

1 – solenoid valve for the supply of the working body to the bench pneumatic circuit; 2 – reference pressure gauge at the compressor outlet; 3 – low-pressure regulator; 4 – reference pressure gauge at the gas pressure regulator outlet; 5 – gas filter; 6 – gas injector winding; 7 – gas manifold; 8 – gas injector valve; 9 – damping receiver; 10 – gas flowmeter; 11 – electric absolute pressure and temperature sensor; 12 – electronic control unit of gas injectors; 13 – electronic oscillographic unit; 14 – computer; 15 – power switch of the electromagnetic valve 1; 16 – power switch of the electronic control unit 12.

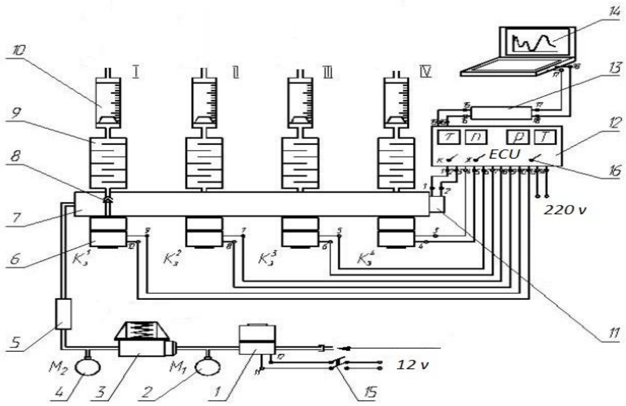

Fig. 1. Scheme of the motorless bench of electronic gas injector units IC-010F-01

In order to determine the tightness of the nozzle shut-off element and the required air flow rate under low temperatures, tests were carried out on the proposed gas injectors in the climatic chamber. The tests were carried out on a unique scientific facility, which is a part of the scientific research complex of climatic tests of vehicle components, the complex of which includes a climatic chamber 12H60/15G, CLIMATS (useful chamber volume 12 m^3).

B. Algorithm

The gas engine has the following characteristics: torque 1,950 N·m at 1,300 min^{-1}, power 326 kW at 1,900 min^{-1}. The torque graph in the wide opened throttle (WOT) curve mode and the cyclic gas flow rate are shown in Fig. 2.

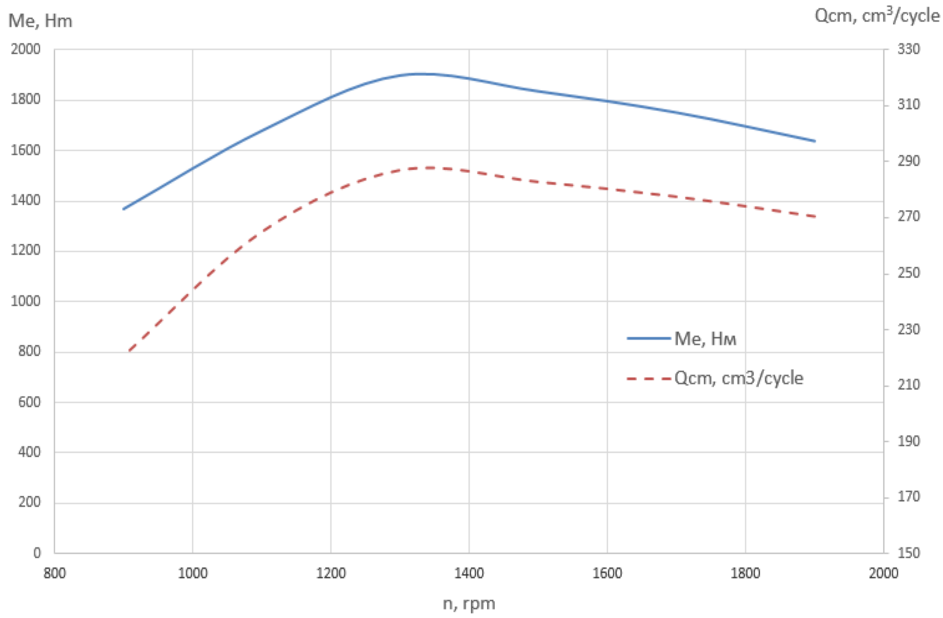

Fig. 2. Torque and cyclic gas supply in the WOT mode

The main factor in determining the duration of gas supply to the engine cylinder is the valves timing [2]. To ensure the minimum consumption of gas fuel and to achieve the minimum emissions of unburned hydrocarbons with exhaust gases, it is necessary to use a distributed gas supply [3] and meet the following conditions:

- the start of the gas supply must be determined by the closing of the exhaust valve;
- the end of the gas supply must be determined by the closing of the inlet valve.

Fig. 3 depicts the gas distribution stages with the maximum permissible duration of gas supply at the crankshaft rotation angle.

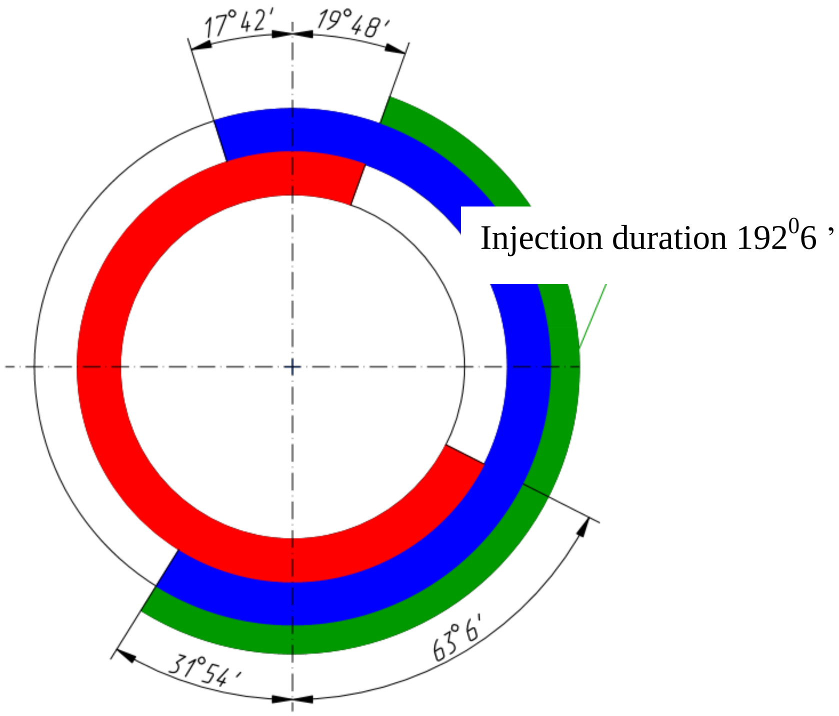

Fig. 3. Valve timing and the permissible duration of gas injection

In accordance with the maximum natural gas flow rate at the crankshaft rotation angle, the maximum gas flow rate (in ms) is calculated depending on the crankshaft speed (see Fig. 4).

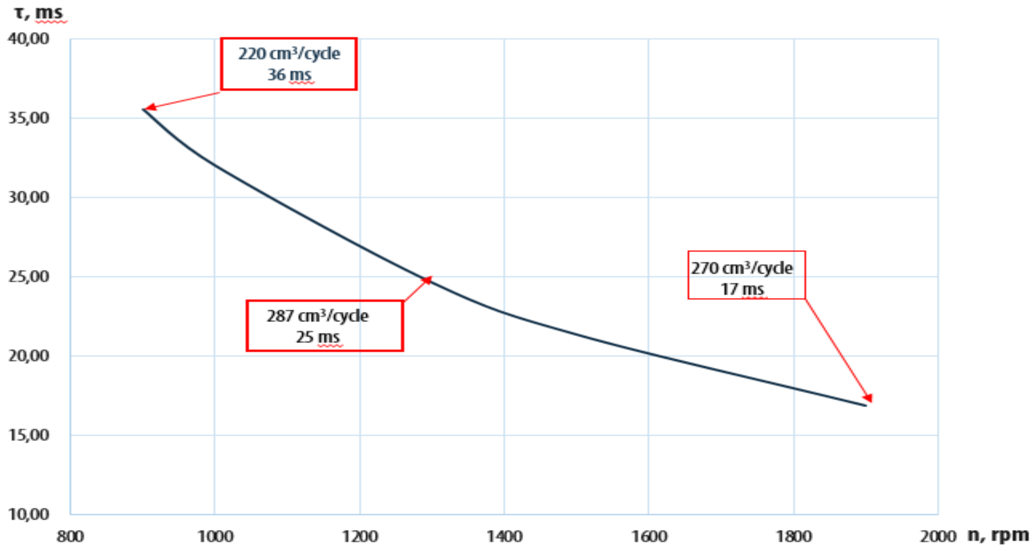

Fig. 4. Permissible duration of gas injection depending on the crankshaft speed

The maximum cyclic gas volume is 287 cm^3 at 1,300 rpm, and the permissible duration of the gas injection is 25 ms (Fig. 3). At maximum power at 1,900 rpm, the cycle flow is 270 cm^3, while the maximum allowable gas flow time is reduced to 17 ms, which places increased demands on the performance of gas injectors.

Having analyzed the gas injectors available in the Russian market, the gas injectors BOSCH model 0280158833 [4], IMPCO model GS2 [5], WOODWARD model 1309-6234 and Concern KEMZ JSC model FG-02 were selected and tested on the motorless bench in the climatic chamber to determine their performance and stability of gas injection at low temperatures.

The cooling of the chamber during the tests was carried out within 3 hours between each series of experiments.

In addition to the gas injectors, the compressed air cylinder and the gas pressure regulator were also cooled down, as not only the gas injectors but also the working medium itself had to be cooled down for the accuracy of the experiment. The measuring equipment and test bench are located outside the climatic chamber.

On the test bench IC-010F-01 (see Fig. 1), after the power supply with the toggle switch 16, the crankshaft speed ***n***, the duration of the gas injector opening ***τ***, the voltage, the opening duration of the "boost" and the average valve 8 (Fig. 5) [6] hold-down voltage, which is transferred to the gas injector winding 6, are set on the electronic control unit 12. The toggle switch 15 supplies power to open the solenoid valve 1, which ensures the supply of air under pressure from the compressor to the gas pressure regulator 3. Mechanical adjustment on the gas reducer 3 sets the operating air pressure determined by the pressure gauge 4, which is supplied to the valve 8. The air passes through the damping receiver 9, designed to smooth out the air pulsations flowing from the gas injector valve 8, and gets into the gas flowmeter 10. After stabilization of the gas flowmeter oscillations, the level mark on the flowmeter scale is fixed, proportional to the hourly volume of gas flow rate, then it is recalculated into absolute values in accordance with the passports of the flowmeters and their metering characteristics presented in Fig. 6 for four types of gas flow meters.

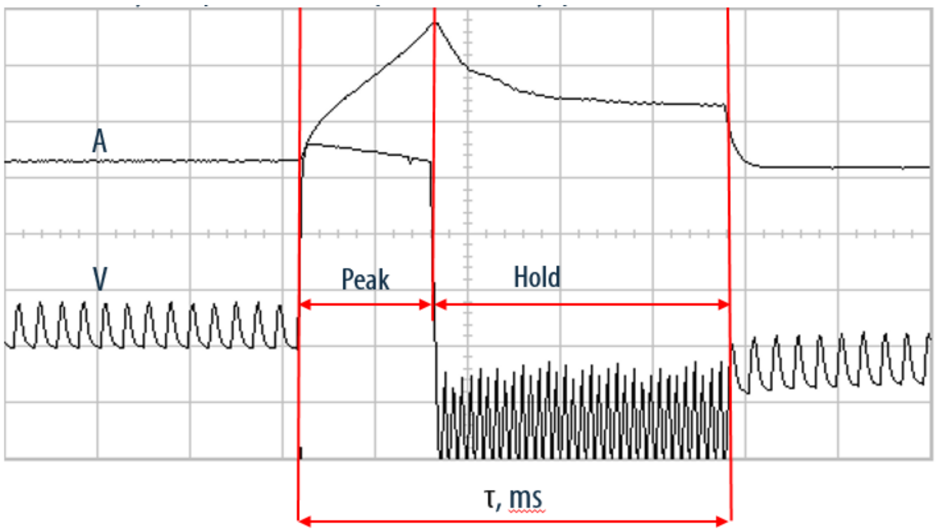

Fig. 5. Control signal form of the electronic gas injector

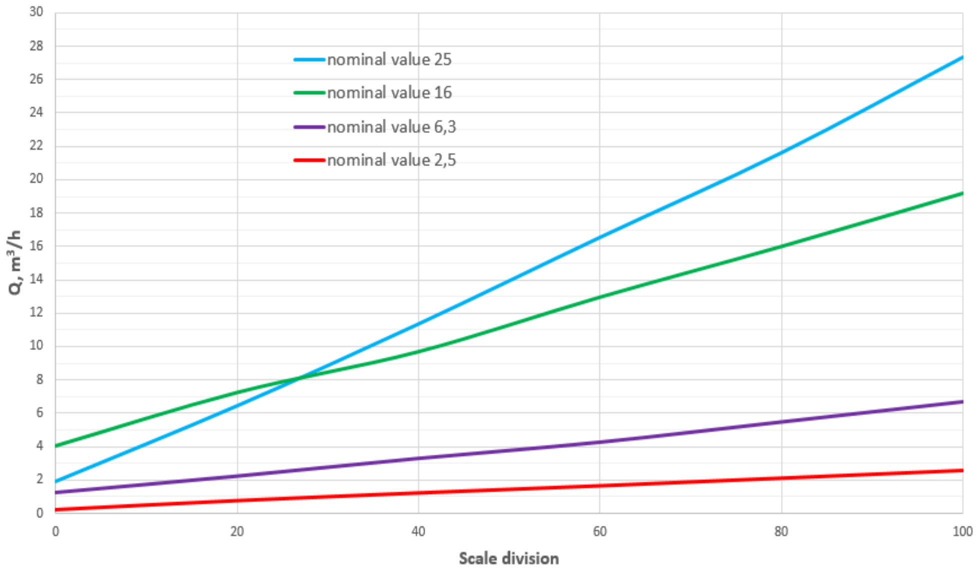

Fig. 6. Metering characteristics of gas flowmeters

The measuring ranges are shown in Table 1 [7]. In the future, the concept of "differential pressure" will be used – it is the difference in gas pressure at the inlet of the injector unit and the pressure of the gas at the outlet of the injector unit [8]. This is due to the pressurization and throttle in the engine [9], which makes the pressure at the outlet of the injector different from the atmospheric pressure, and, accordingly, affects the gas flow through the injector.

Table 1. Measurement ranges

Parameter name	Designation	Values
Differential pressure, MPa	***P***	0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1
Injector opening time, ms	τ	10, 15, 20, 30, 40
Rotation speed, min^{-1}	***n***	1,000, 1,500, 1,900
Temperature of the working gas and gas injectors, °C	***t***	+20, -20, -30, -40

III. RESULT ANALYSIS

A. Test results of gas injectors under low-temperature conditions

When testing gas injectors in a climatic chamber, the characteristics of the hourly air flow rate at temperatures of +20, -20, -30, -40 °C were obtained. The dispersion of the volumetric consumption characteristics of all injectors at changing temperatures is within 5%, which is within the measurement error and indicates that the consumption characteristics of injectors do not change when operating at negative temperatures. An example of experimentally obtained consumable characteristics of gas injectors depending on the differential gas pressure is shown in Fig. 7. The differential pressure ranges of the injectors correspond to the manufacturer's specifications.

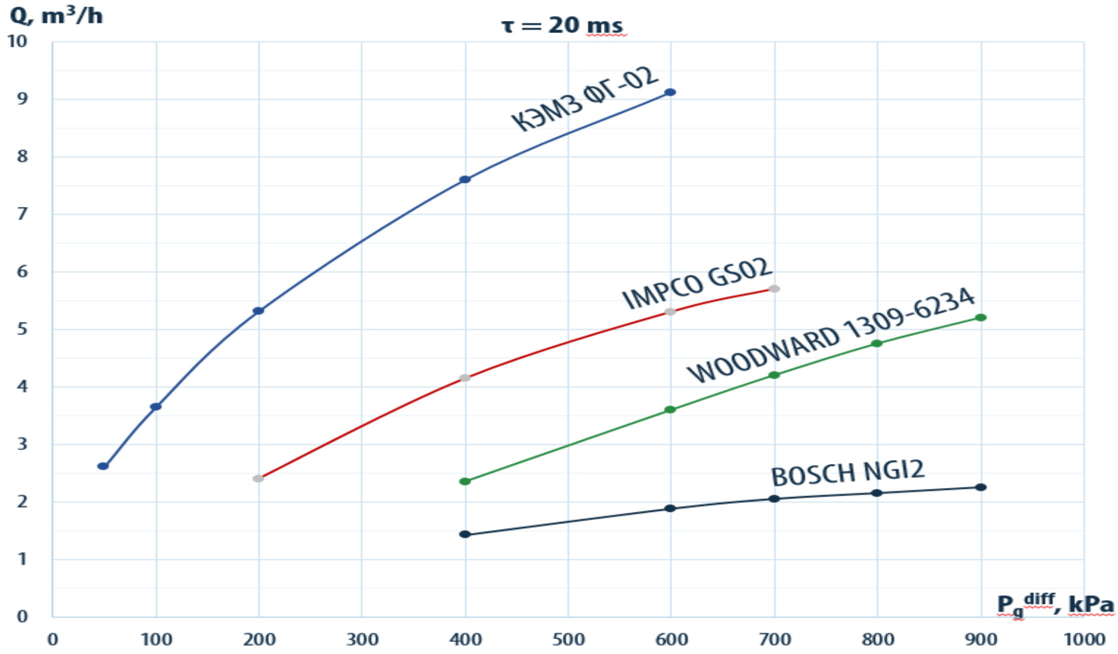

Fig. 7. Experimental gas injector flow characteristics

In order to determine the possibility of using L6 engine injectors, the experimentally obtained hourly flow rates were converted into volume cycle feeds at the maximum allowable pressures specified in the manufacturer's specification.

B. Calculation results

The calculation results are shown in Fig. 8. The injection duration depending on the speed corresponds to the graph shown in Fig. 4. For clarity, a graph of the required cyclic feed for the engine under study was added.

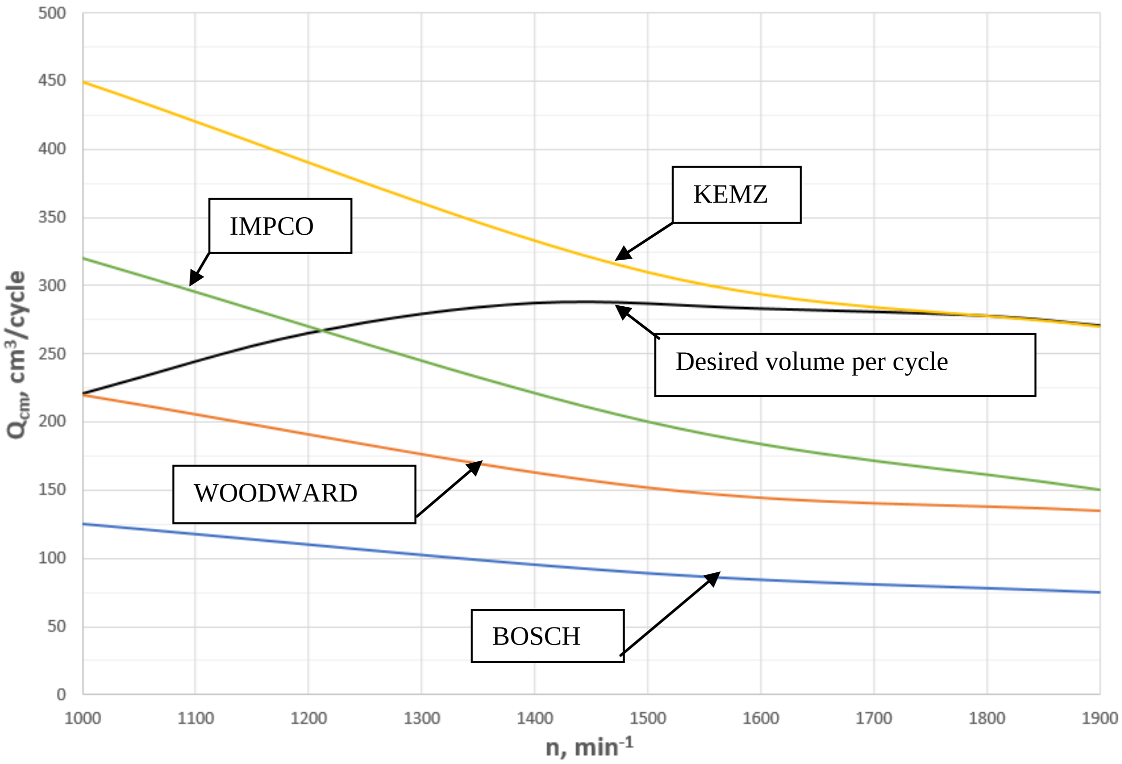

Fig. 8. Volume cyclic gas injection at the maximum allowable rated pressures and maximum allowable gas supply time depending on crankshaft speed

As can be seen from Fig. 8, KEMZ injectors fully provide the required cycle gas supply. However, during the research, irregularities in the operation of these injectors were noticed. At -20°C, the tightness of the locking device is compromised, and the lower is the temperature, the greater is the leakage in the absence of a control signal, which violates safety requirements for the fuel system.

This problem is related to the design of the injector and requires further development. It was also noticed that as the temperature decreases, a correction of the control signal of the KEMZ electronic injector is required.

The KEMZ injector has the most flow rate (Fig. 5) out of the four gas injectors under test with comparable overall dimensions, the cyclic gas supply from the KEMZ injectors is several times higher than that of the BOSCH, WOODWARD and IMPCO injectors, which is an advantage for engines with a high required cyclic volume [10].

IV. CONCLUSION

The use of more than two injectors per cylinder requires the use of central gas supply due to engine inlet manifold layout design. If more than two injectors per cylinder with distributed supply are used, the design becomes much more complicated and results in higher costs, lower reliability and more complicated maintenance. The use of central gas supply reduces the environmental performance of the engine, which requires more expensive aftertreatment system [11].

Thus, the use of four BOSCH gas injectors, which provide the required gas injectors per cylinder in cycles, is not practical. The use of two WOODWARD or IMPCO injectors without central supply is possible with the maximum pressures specified by the manufacturer. The use of KEMZ gas injectors is possible in the amount of one injector per cylinder, in case the leakage in the shut-off device at negative temperatures will be eliminated.

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