DEVELOPMENT OF PROMISING SYNTHESIS-TECHNOLOGY AVENIR GAZ CONVERTING DIESELS TO GAS ENGINES WITH SPECIAL IGNITION

Serhii Kovalov[1]
[1]Research Laboratory for Fuels Use and the Ecology, State Enterprise «State Road Transport Research Institute», Kyiv, Ukraine
skovalev257@gmail.com
http://orcid.org/0000-0002-3107-530X

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ABSTRACT

The object of research is the multifunctional synthesis technology Avenir Gaz (of various levels of complexity), intended for converting transport diesel engines into spark-ignited gas internal combustion engines (ICE) for operation on liquefied petroleum gas (LPG).
Investigated problem: the creation of an affordable synthesis technology in terms of complexity and price, which allows converting operating diesel engines into gas internal combustion engines operating on cheaper and environmentally friendly gas fuel - LPG.
Main scientific results: Avenir Gaz synthesis technology (two levels of complexity, qualified as levels "A" and "B") for converting diesel engines into gas internal combustion engines is developed and created. It is shown that the conversion of diesel engines according to the Avenir Gaz synthesis technology is carried out on the basis of the developed electronic microprocessor control systems. And the basis of the control systems is the developed and manufactured two electronic microprocessor control units Avenir Gaz 37 (hereinafter – ECU Avenir Gaz 37). ECUs in accordance with the levels of complexity of synthesis technology are qualified as – ECUs Avenir Gaz 37 "A" and Avenir Gaz 37 "B". It is shown that Avenir Gaz synthesis technology of level "A" allows converting diesel engines into gas internal combustion engines with LPG supply through a gas-air mixer into the inlet pipeline. At the same time, the Avenir Gaz 37 "A" ECU, using the signal from the Hall sensor of the distributor, limits the maximum speed of the gas engine, thereby ensuring its safe operation. And the synthesis technology Avenir Gaz 37 of level "B" allows converting diesel engines into gas internal combustion engines providing group or sequential injection of LPG by electromagnetic gas nozzles (injection system of the Common Rail type) into the intake manifold in the area close to the intake valve.
Area of practical use of the research results: converting diesel vehicles, including agricultural machinery (powerful wheeled and tracked tractors, combines, etc.) into spark-ignited gas combustion engines operating on LPG.
An innovative technological product: Avenir Gaz synthesis technology, which allows converting the transport diesel engines in operation into gas internal combustion engines for operation on LPG.
Scope of application of the innovative technological product: naturally aspirated and supercharged diesel engines with the number of cylinders from one to six, in-line and V-shaped, with a uniform alternation of working strokes.

1. Introduction

1. 1. The object of research

The object of research is the multifunctional synthesis technology Avenir Gaz 37, intended for converting diesel engines of vehicles in service into gas internal combustion engines (ICE) with spark ignition.

1. 2. Problem description

It is known that in order to increase the share of alternative fuels in the total structure of fuel consumption of transport in order to reduce its operating costs, it is advisable to convert (re-equip) diesel engines into ICEs with spark ignition. At the same time, taking into account the losses of society from environmental pollution by transport, the use of environmentally friendly and cheap gas fuel as a motor fuel becomes obvious. Among the many types of gas fuels, the most common is liquefied petroleum gas (LPG) [1].

The use of LPG in the conversion of diesel engines into gas internal combustion engines allows to ensure: a decrease in the level of harmful emissions of oxides and carbon dioxide, nitrogen oxides and particulate matter in the exhaust gases [2]. Also, as a result of the transition from work on the diesel cycle to the Otto cycle, the level of external noise generated by transport also decreases [3]. In addition, diesel fuel is completely replaced by cheaper LPG.

1. 3. Suggested solutions to the problem

It is known that a significant number of the world's leading manufacturers of diesel engines, as well as manufacturers of vehicles, produce gas internal combustion engines or equip their vehicles with these engines [4]. These include diesel manufacturers such as: Cummins Westport Inc. (USA – Canada); Caterpillar Inc. (USA); Perkins Engines (UK); Deutz, MWM GmbH and MTU Friedrichshafen (Germany); Wärtsilä (Finland); Doosan Group (South Korea) and many others [4, 5]. Gas internal combustion engines of these companies, as a rule, are created on the basis of diesel engines produced by them. This principle of creating gas internal combustion engines significantly reduces the cost of their production, since it does not require the creation of a new complete production complex, but only allows changes in the design of individual parts or systems. As a result, gas internal combustion engines, created on the basis of diesel engines, are reliable and durable, the parts of which are designed to work under heavy loads typical of engines with a high compression ratio.

At the same time, the created gas internal combustion engines, as a rule, are completed with control systems developed and manufactured by specialized firms. Often these firms also specialize in the production of diesel control systems, in particular, speed controllers, and in some cases, gas diesel control systems. Firms producing gas ICE control systems include: Woodward and Alternative Fuel Systems (USA), Bosch and Heinzmann (Germany), Westport Fuel Systems (Canada) and others [5, 6].

Control systems for gas internal combustion engines can be mechanical, hydromechanical, electronic (analog), combined (with electronic control of mechanical or hydromechanical elements) [2, 7], as well as microprocessor (with electronic control of executive elements and devices) [2, 8]. However, due to the fact that converted gas internal combustion engines must provide high energy and environmental performance close to diesel engines, modern control systems must be electronic microprocessor systems to ensure them.

At the same time, one should pay attention to the fact that gas internal combustion engines, by almost all their manufacturers, are produced under factory production conditions – as new engines. In turn, control systems for gas internal combustion engines are also produced with a focus on what will be installed on new engines. Therefore, at the stage of preparation for the production of gas internal combustion engines, manufacturers make the necessary changes to the design of those parts and systems on which the elements or units of the control system set are installed.

However, most of the control systems intended for installation on new gas internal combustion engines are practically impossible to install on diesel engines that are especially in long-term operation for their conversion into gas internal combustion engines.

It is also necessary to pay attention to the fact that almost all control systems for gas internal combustion engines are produced for operation on natural gas [5, 6].

Therefore, the aim of research is to develop a multifunctional synthesis technology Avenir Gaz intended for converting diesel engines of vehicles in operation into gas internal combustion engines for operation on LPG.

2. Materials and Methods

According to the Avenir Gaz synthesis technology (different levels of complexity), the conversion of diesel engines is carried out on the basis of the created electronic control systems for gas internal combustion engines, which are based on electronic microprocessor control units (hereinafter – ECU).

It should be added that the use of the Avenir Gaz synthesis technology for any of the levels of technology complexity requires a certain list of different types of work. In general, these include three main types of work, such as:

– preparation of a diesel engine for re-equipment;

– making appropriate changes to the ICE design;

– additional equipment of the engine with main and additional systems, as well as an electronic control unit and, in some cases, additional sensors.

The first type of work includes work on partial disassembly of a diesel engine, including a complete dismantling of the power supply systems and diesel fuel injection. In the process of preparation, diesel fuel tanks, pipelines, filters, a high-pressure fuel pump (hereinafter referred to as a HPFP) are dismantled together with a speed controller and the like.

The second type of work includes work on making changes to the design of the diesel engine. The work consists in the refinement of the diesel cylinder head for the installation of spark plugs, as well as in the installation of modified standard or new pistons to reduce the compression ratio. Methods for reducing the compression ratio by changing the diesel shape of the chamber are described in detail in [9].

The third type of work includes work on retrofitting a gas internal combustion engine with main and additional systems or subsystems. The number of these systems depends on the level of complexity of the Avenir Gaz synthesis technology.

In this regard, Avenir Gaz synthesis technology is divided into two levels of difficulty. The first level of complexity of the Avenir Gaz synthesis technology (classified as level "A") corresponds to the equipment of a gas internal combustion engine with two such main systems: a power supply system and a LPG supply (through a gas-air mixer) to the intake manifold, as well as a contactless electronic ignition system with a movable voltage distributor (hereinafter – CEIS). In addition, the gas internal combustion engine is equipped with a control system for filling the cylinders with a charge of the working mixture. The system consists of an intake manifold, a mechanically driven throttle device of the model, an adapter and a gas-air mixer. In addition, due to the absence of a speed regulator in the gas internal combustion engine, which was dismantled together with the injection pump, in order to avoid exceeding the maximum speed, the Avenir Gaz 37 "A" microprocessor ECU is developed and manufactured. The ECU Avenir Gaz 37 "A" is built on the platform of the 8-bit PIC16F microcontroller (Microchip Technology Inc.) with a clock frequency of 20 MHz. The computing power (performance) of the microcontroller reaches 5 DMIPS. The main purpose of the Avenir Gaz 37 "A" ECU is to limit the maximum speed by controlling the operation of remotely controlled shut-off valves (integrated into the multivalve, gas filter and reducer-evaporator) of the LPG power supply system. To calculate the current speed, the ECU uses the signal from the Hall sensor of the ignition distributor [10].

The second level of complexity of the Avenir Gaz synthesis technology (classified as level "B") corresponds to the configuration of a gas internal combustion engine with two such main subsystems as: an accumulative power supply subsystem and multipoint injection of LPG of the Common Rail type into the intake pipeline to the zone close to the intake valve, and non-contact electronic ignition system (same as for level "A"). In addition, the control system also includes a subsystem for controlling the filling of the cylinders with the charge of the working mixture, consisting of a throttle valve and an idle speed regulator with a conical damper. To ensure the operation of the control system, a multifunctional electronic microprocessor ECU Avenir Gaz 37 level "B" is developed and manufactured. The ECU is built on the platform of a high-performance 16-bit microcontroller PIC24F (Microchip Technology Inc.) with nanoWatt XLP technology, which provides ultra-low power consumption. The device includes advanced power saving features including low voltage mode. The maximum clock frequency is 32 MHz. The computing power (performance) of the microcontroller at the operating frequency reaches 16 DMIPS. As a result, the Avenir Gaz 37 "B" ECU performs such basic functions as:

– providing group or sequential LPG injection;

– regulation of the amount of starting gas fuel supply depending on the temperature of the engine coolant;

– regulation of the rotational speed of the gas engine in idle mode, depending on the temperature of the coolant and the connection of additional devices (for example, an electric fan, air conditioner, etc.);

– limiting the maximum rotational speed of a gas internal combustion engine by forming an external regulatory characteristic.

At the same time, the Avenir Gaz 37 "B" ECU, depending on the software version (classified as – level "B1" or "B2"), implements group or sequential LPG injection.

3. Research results

Work on the Avenir Gaz synthesis technology of level "A" was carried out on a gas internal combustion engine of the D-240-LPG-"A" model, converted on the basis of the D-240 diesel engine (4 Ч 11/12.5). So, in accordance with the first type of synthesis technology works associated with the preparation of a diesel engine for re-equipment, a complete dismantling of the power supply and diesel fuel injection systems was carried out. Further, in accordance with the second type of work, new pistons with an open combustion chamber in the form of an axisymmetric "truncated cone" were installed on the gas internal combustion engine, which ensured a decrease in the compression ratio from ε=16 to ε=9.5. Changes were made to the internal combustion engine air supply system by installing a mechanically actuated throttle valve. In accordance with the third type of work, a system for feeding and supplying LPG to the intake pipeline was installed on the gas internal combustion engine. The system consists of: a GreenGas gas cylinder with a GreenGas AT02 multivalve, a high pressure gas pipeline, a BRC ET98 MY07 cut-off filter valve, a Tomasetto AT07 MOD evaporator reducer, a mechanical gas meter, a gas-air mixer and a filling unit.

All elements of the LPG power supply and supply system installed on the D-240-LPG-"A" gas internal combustion engine comply with the requirements of UN Regulations No. 67 [11] and DSTU 7434: 2013 [12]. In addition, a CEIS with a movable voltage distributor and an Avenir Gaz 37 "A" ECU were installed on the engine. The external view of the gas internal combustion engine with the main and additional systems, as well as their elements is shown in (**Fig. 1**).

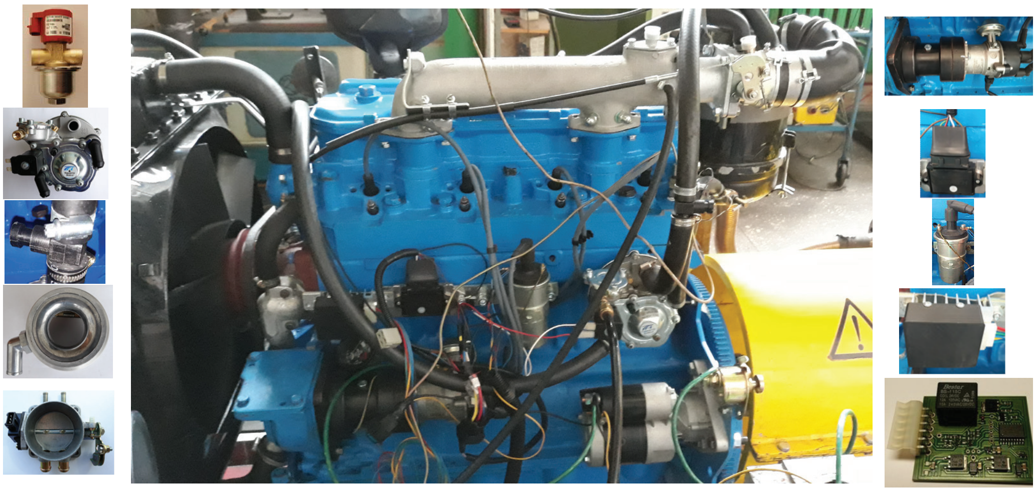

Fig. 1. External view of the D-240-LPG-"A" gas internal combustion engine with the main and additional systems, as well as their elements and the Avenir Gaz 37 "A" ECU

The energy and economic indicators of the D-240-LPG-A gas internal combustion engine converted using the Avenir Gaz synthesis technology of level "A" were determined during its bench tests. The tests were carried out on an electric load stand Zöllner (Germany) type 350AC with a microprocessor-based measurement and control system. During the tests, the external speed and five load characteristics were taken. The results of bench tests showed that the maximum power of the gas D-240-LPG-"A" is 57.5 kW (78 hp) at a nominal crankshaft speed of 2200 min^{-1}. So, the rated power of the D-240-LPG- "A" gas internal combustion engine was 97 % of the rated power of the D-240 diesel. The maximum effective torque is 304 N·m, with n_d= 1300 min^{-1}. The torque reserve was 22 %. The rest of the parameters of D-240-LPG- "A", obtained as a result of the tests, are described in detail in [9]. The high energy and economic parameters of the gas internal combustion engine, obtained as a result of the use of the Avenir Gaz synthesis technology of the "A" level, testify to the effectiveness of its application.

Work on the study of the Avenir Gaz synthesis technology of the “B” level was carried out on a D-240-LPG-”B” gas engine. The transition from the complexity of the Avenir Gaz synthesis technology of level “A” of the D-240-LPG- “A” gas engine to the level “B” multipoint injection of LPG type Common Rail. The LPG multipoint injection subsystem consists of: a GreenGas gas cylinder with an integrated GreenGas AT02 multivalve, a BRC ET98 MY07 shut-off valve with an integrated filter, a BRC single-stage reducer-evaporator, Genius MB 1500 mbar, a gas vapor phase filter, Certools, a gas rail (Common Rail) BRC brand with 4 gas electromagnetic injectors BRC IN03 MY09 LPG/CNG model, 4 gas nozzles and a filling unit. In addition, the engine is retrofitted with a subsystem for filling the cylinders with a charge of the working mixture with a bypass air flow control mechanism. The idle speed regulator of the PXX-40 model is used as a mechanism. In addition, the gas engine is equipped with an Avenir Gaz 37 “B” ECU. The external view of the D-240-LPG- “B” gas internal combustion engine with the main and additional systems and their elements is shown in (**Fig. 2**).

Tests of the D-240-LPG-”B” gas internal combustion engine, converted using the Avenir Gaz synthesis technology of the B level, were also carried out at the Zöllner electric load stand.

Bench tests of a gas engine model D-240-LPG-”B” with ECU Avenir Gaz 37 “B” showed that when the ECU is operated with the software version of the “B1” level, LPG group injection is provided, and when working with the “B2” version, sequential injection. In addition, the tests confirmed the efficiency of the Avenir Gaz 37 “B” ECU and showed that the block allows to control the operation of a gas engine in real time.

At the same time, Avenir Gaz synthesis technology of level “B” with ECU Avenir Gaz 37 “B” and software version of level “B1” provides group injection of LPG without the presence of a traditional camshaft position sensor and a special master disk installed on the camshaft.

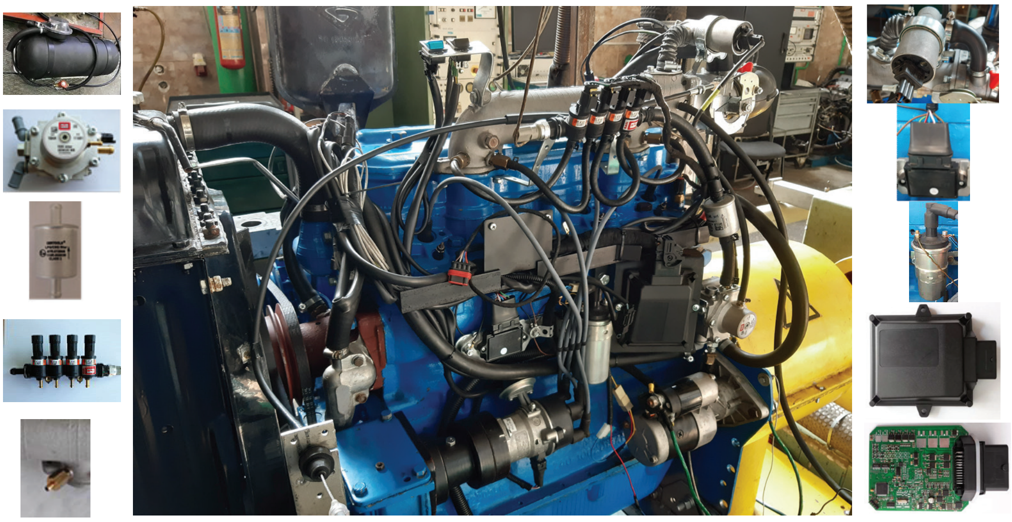

Fig. 2. External view of the D-240-LPG- “B” gas internal combustion engine with the main and additional systems, as well as their elements and the Avenir Gaz 37 “B” ECU

For this, the ignition system has been modified. The modification consisted in making changes to the design of the standard master disc of the distributor by increasing the arc length of the sector of the circle of the opening of the first cylinder. Due to this, the ECU receives a signal from the Hall sensor of the distributor, which determines the moment of the position of the piston in the first cylinder relative to the top dead center.

Tests have shown that the control system with the Avenir Gaz 37 “B” ECU performs all the functions assigned to it and ensures the efficient operation of the D-240-LPG-”B” gas engine.

In turn, the content of carbon monoxide and hydrocarbons in the exhaust gases of the D-240-LPG- “B” internal combustion engine meet the requirements of DSTU 4277 [16] and have significantly lower indicators than the maximum permissible for engines without catalysts.

According to the World LPG Association [1], it is known that in terms of consumption, LPG is the third largest motor fuel for vehicles in the world. Therefore, taking into account the low cost of LPG [17] in comparison with diesel fuel, the conversion of diesel engines into gas internal combustion engines using the Avenir Gaz synthesis technology is an effective way to reduce the operating costs of diesel vehicles.

4. Discussion of research results

The developed Avenir Gaz synthesis technology allows converting transport diesel engines into spark-ignited gas internal combustion engines. Its first feature is the ability to use for converting transport diesel engines in service. The second feature is the possibility of using LPG as a motor fuel, in contrast to most control systems for gas internal combustion engines produced for operation on natural gas [5, 6].

It should be noted that today the use of the Avenir Gaz synthesis technology of level "B" has the following limitations. Firstly, the technical capabilities of the Avenir Gaz 37 "B" ECU make it possible to control gas internal combustion engines with no more than six cylinders. Secondly, due to the use of a contactless electronic ignition system with a movable voltage distributor in the control system of a gas internal combustion engine, synthesis technology makes it possible to convert diesel engines that have only a uniform alternation of working strokes.

A further direction of work is related to the expansion of the functions of the Avenir Gaz synthesis technology of the "B" level by completing the D-240-LPG-"B" gas internal combustion engine with an exhaust gas neutralization system. To control a gas internal combustion engine with an exhaust gas aftertreatment system for the Avenir Gaz 37 "B" ECU, it is necessary to develop a new version of the "B3" level software.

5. Conclusions

The advantages and expediency of using gas motor fuels, in particular LPG, by vehicles in comparison with traditional diesel fuel are shown.

The expediency of converting diesel engines of vehicles in operation into spark-ignited gas internal combustion engines for operation on LPG based on the use of the developed modern synthesis technology Avenir Gaz has been substantiated.

A special ECU Avenir Gaz 37 "A" has been developed and manufactured, which, as part of the Avenir Gaz synthesis technology, limits the maximum rotational speed of a gas internal combustion engine. As a result, the ECU does not allow to exceed the maximum speed set by the manufacturer for this diesel model.

A special multifunctional ECU Avenir Gaz 37 "B" has been developed and manufactured, which, as part of the Avenir Gaz synthesis technology, depending on the software version, is capable of implementing group or sequential LPG injection.

Experimental studies have shown that the conversion of diesel engines into gas internal combustion engines using the Avenir Gaz synthesis technology is an effective way to reduce vehicle operating costs by replacing diesel fuel with cheaper LPG.

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