Development of a bi-fuel power supply system for a diesel engine

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Abstract. The relevance of the study is due to the lack of systems in which the proportions of the used fuels in the mixture and the values of the cycle supply are simultaneously controlled depending on the load-speed mode of the diesel engine. The aim of the research is to develop a design for a bi-fuel power supply system for a diesel engine, which allows for the simultaneous regulation of the proportions of the components of a mixture consisting of alternative and diesel fuels, as well as the values of the cyclic supply of this mixture to the diesel cylinders. As a result of the research, an algorithm was calculated for the simultaneous control of the proportions of the components of a mixture consisting of alternative and diesel fuels, as well as the values of the cyclic supply of this mixture to the diesel cylinders. As a result of the operation of the fuel supply system on mixtures of diesel and alternative fuels according to the developed algorithm, it made it possible to achieve the identical operation of a diesel engine on pure diesel fuel at all load-speed modes of diesel operation. Also, in the course of the research carried out, a bi-fuel power supply system for a diesel engine was developed, which makes it possible to simultaneously regulate the amount (cycle supply) and the composition of a mixture consisting of diesel and alternative fuel supplied to the diesel cylinders, depending on the speed and load modes of operation.

1. Introduction

Alternative fuels used in diesel engines today occupy a special place among other renewable energy sources around the world [1]. They owe their attention to the stable long-term positive global price dynamics of traditional diesel fuel and the annually stricter environmental requirements for diesel engines [2].

Among the named alternative fuels, liquid alternative fuels such as benzene, alcohol, oils, ethers, glycerin, etc. have become quite widespread. One of the main and indisputable advantages of using alternative fuels in comparison with diesel fuel is their environmental friendliness, which provides an incentive for the further development of diesel engines in the era of "green technologies" [2]. Along with high environmental friendliness, the use of such fuels is associated with the deterioration of the effective performance of diesel engines [1, 2]. Their use in their pure form is difficult due to the difference in their properties compared to diesel fuel [2].
Today, the method of using liquid alternative fuels in conjunction with diesel fuel is gaining more and more scientific interest [2]. The most common way here is the joint use of both alternative fuels and traditional diesel fuel [2].

In studies [3-6], the supply of alcohol-containing and vegetable fuel was carried out together with diesel fuel by pre-mixing them in certain proportions until a homogeneous mixture was obtained, followed by refueling of the diesel engine.

In works [7-11], studies were carried out on the use of various alternative fuels in diesel engines together with diesel fuel simultaneously in different proportions and different load-speed operating conditions.

In the studies carried out [12-14], diesel fuel supply control systems were developed and applied, in which the cyclic fuel supply was regulated depending on the proportion of fuels used in the mixture and the load-speed operating mode.

However, at this point in time, there are no systems in which the proportions of the used fuels in the mixture and the values of the cycle supply are simultaneously controlled depending on the load-speed mode of operation. Therefore, the development of a design for a bi-fuel power supply system for a diesel engine, which will allow the above-described regulation to be carried out, is very relevant.

2. Research objectives
The purpose of our research is to develop a design of a bi-fuel power supply system for a diesel engine, which allows simultaneous control of the proportions of the components of a mixture consisting of alternative and diesel fuels, as well as the values of the cyclic supply of this mixture to the cylinders. To achieve this goal, it is necessary to solve the following tasks. First, to develop an algorithm for the simultaneous control of the proportions of the components of a mixture consisting of alternative and diesel fuels, as well as the values of the cyclic supply of this mixture to the diesel cylinders. Secondly, to develop a design of a bi-fuel power supply system for a diesel engine to implement the above-mentioned operation algorithm.

3. Materials and methods
Normal operation of a diesel engine on various mixtures of alternative and diesel fuel seems to be quite problematic without introducing a number of design changes to the fuel supply control system.

After analyzing the characteristics of the fuel supply shown in figure 1, it can be seen that with the fuel supply equipment installed by the manufacturer, the dependence of the heat \( Q \) introduced into the diesel engine with clean diesel fuel on the stroke of the high-pressure fuel pump rack \( h \) is represented by line 1.

When the fuel supply equipment operates on various mixtures of diesel and alternative fuels, the characteristic of the high-pressure fuel pump changes in comparison with the operation on pure diesel fuel. Taking into account that the specific lower design heat of combustion of a mixture consisting of diesel and alternative fuels is less than that of pure diesel fuel, the dependence of heat input into diesel cylinders on the rail travel is represented by line 2 in figure 1.

After analyzing these two dependences of lines 1 and 2 shown in figure 1, it can be seen that at the same position of the rail of the high-pressure fuel pump, the heat introduced into a diesel with a fuel consisting of a mixture of diesel and alternative fuels is less compared to pure diesel fuel. Consequently, when the rail of the fuel pump of weighty pressure is in position, taking into account the action of the regulator of the corresponding nominal flow and the overload mode, the required amount of heat with fuel set by the manufacturer of the fuel supply equipment will not be introduced into the diesel engine.

This circumstance will lead to a decrease in the nominal torque safety factor and a decrease in the ability to overcome the overload, as well as a violation of the high-speed operation of the diesel engine.
Figure 1. Fuel supply characteristics: 1 - dependence $Q = f(h)$ for diesel fuel; 2 - dependences $Q = f(h)$ for a mixture of diesel and alternative fuels; 3 - dependences $Q = f(h)$ for a mixture of diesel and alternative fuels, taking into account changes in the design of the high-pressure fuel pump.

Elimination of this circumstance is possible by making changes to the design of the high-pressure fuel pump, the dependence of which is determined by line 3 in figure 1. Analysis of this dependence shows that in the nominal operating mode the amount of heat introduced into the diesel with fuel corresponds to the fuel supply equipment installed by the manufacturer. However, in the overload mode, there is also a decrease in the nominal torque safety factor and a violation of the high-speed operation of the diesel engine in the partial load mode, as well as the impossibility of turning off the supply. The moment when the regulator starts to operate, set by the manufacturer of the fuel supply equipment, will also not allow the diesel to be brought to the nominal operating mode.

Therefore, it is necessary to make changes in the design of the high pressure fuel pump, which will lead to the operation of the fuel supply system according to the following algorithm. With the position of the high pressure fuel pump rack corresponding to the rated operating mode of the diesel engine and overloading, clean diesel fuel will be supplied to ensure the performance specified by the manufacturer. In the range of the rack positions from the minimum feed to the nominal feed, the mixture of fuel, consisting of diesel and alternative, will change proportionally. That is, the greater the stroke of the rack $h$, the greater the content by weight of diesel fuel in the mixture. With the minimum rack stroke $h$ in the mixture, the content by mass of the alternative fuel will be maximum. With a subsequent increase in the stroke of the rack $h$ up to the nominal one, the content of diesel fuel in the mixture increases up to 100%.

As a result, the operation of the fuel supply system on mixtures of diesel and alternative fuels in compliance with the calculated ratios will make it possible to achieve the identical operation of a diesel engine on pure diesel fuel at all load-speed modes of operation.
4. Results and discussion
A significant difference between the proposed design of the diesel power system from all previously known solutions is that a groove is made on the forked lever 7 for the possibility of free movement along it of the hinge end of the intermediate link 8, which is connected with the hinged end of the main lever 3 with the help of an additional spring 21, moreover, the drive lever 19 through the two-arm lever 20 is connected to the articulated end of the main lever 3 in figure 2.

![Figure 2. Bi-fuel power supply system of a diesel engine: 1 - centrifugal sensor; 2 - movable coupling; 3 - the main lever; 4 - control lever; 5 - spring; 6 - dosing organ; 7 - forked lever with a groove; 8 - intermediate rods; 9 - mixer-dispenser of fuels; 10 - case; 11 - channel for supplying diesel fuel; 12 - channel for supplying alternative fuel; 13 - mixing chamber; 14 - channel for removing a mixture of fuels; 15 - wall; 16 - mixer; 17 - shaft; 18 - disk; 19 - drive lever; 20 - two-armed lever; 21 - additional spring.](image_url)

The control system of a multi-fuel diesel engine works as follows in figure 2. Depending on the speed and load mode of the diesel engine and the position of the control lever 4, the centrifugal sensor 1 with the movable clutch 2 sets the main lever 3 to the position of the dynamic balance of the spring force 5 and the force of the centrifugal sensor 1. Main lever 3 through a forked lever with a groove 7 and an intermediate rod 8, depending on the position of the control lever 4 with the help of an additional spring 21, dynamically set the kinematic relationship between the intermediate rods 8, depending on the position of the control lever, thereby providing automatic correction of the amount of mixed fuel supply by the metering element 6. In this case, the control lever 4 through the hinged end with the help of the two-armed lever 20 moves the drive lever 19 in the mixer-dispenser 9, forcing the working shaft 17 with the disc 18 with slots attached to it to rotate. The disc 18 with slots, turning, changes the flow cross-sections of the holes in the wall 15 of the housing, thereby changing the volumetric amount of diesel and alternative fuel entering the mixer-dispenser through channels 11 and 12. As a result, the movement of the main lever 3, depending on the position of the control lever 4, is
simultaneous regulation of the quantity and composition of the mixture at all high-speed and load modes of operation of the diesel engine.

The operation of such a system will make it possible to simultaneously regulate the amount (cycle supply) and the composition of the mixture, consisting of diesel and alternative fuel, supplied to the diesel cylinders, depending on the speed and load modes of operation.

5. Conclusion
As a result of the research, the algorithm of operation of the fuel supply equipment, which is part of the general diesel power system, was calculated, which allows you to simultaneously adjust the proportions of the components of the mixture consisting of alternative and diesel fuel, as well as the values of the cyclic supply of this mixture to the diesel cylinders. The design of a bi-fuel diesel power supply system for the implementation of the above-mentioned operation algorithm has been developed.

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