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METHODS FOR DIESEL FEED SYSTEM CONTROL USING DYNAMIC REGULATION OF THE FUEL MIXTURE PERCENTAGE COMPOSITION

The paper presents a circuit of the feed system for Common Rail diesel powered with diesel and biodiesel fuel mixture using dynamic regulation of its percentage composition as well as theoretical foundations of the organization and methods of diesel feed system control when it is switched to operation on diesel and biodiesel fuel mixture with dynamic regulation of its percentage composition.

Key words: *biodiesel fuel, diesel fuel, fuel mixture, dynamic regulation of percentage composition, control methods.*

Introduction. Problem setup

Wide use of internal combustion engines has resulted in increased application of oil fuels and significant deterioration of environmental conditions. Annual emission of harmful substances from internal combustion engines is known to be 39% of the total amount of harmful emissions on the average, while in cities it reaches 70 – 90 %. That is why application of alternative fuels in internal combustion engines has been a relevant problem for a long time.

Physical and chemical properties of alternative fuels, when they are used in internal combustion engines, determine certain special features of working processes in the engine cylinders, which affects technical-economic and ecologic performance of the engines. As a rule, application of alternative fuels without corrections in the organization of working processes causes engine power reduction and worsening of its economic indices. Therefore, researchers pay much attention to elaboration of the recommendations on biodiesel fuel feed system adaptation and improvement of the organizational algorithms of working processes in internal combustion engines when they are switched to operation on alternative fuels.

In order to achieve maximal effect from biodiesel fuel application, advanced technologies should be used. This requirement is satisfied by diesel feed system with dynamic regulation of the mixture percentage composition, depending on the engine operating mode. For most engines wide-range changes of thermal, loading and speed operation modes are characteristic. Most often engines operate in non-stationary conditions such as starting, heating, acceleration, braking, increasing and decreasing load, stopping of the engine. These modes are not dynamically symmetrical [2], i.e. processes occurring with increasing and decreasing load on the engine crankshaft, during engine starting-up and stopping differ from each other. Efficient working processes in diesel cylinders with different fuel mixture percentage compositions and operating modes are provided by a corresponding algorithm, which should be taken into account in the methods of diesel power system control when it is switched to operation on diesel and biodiesel fuel mixture with dynamic regulation of its percentage composition.

Since biodiesel fuel application is rather relevant for diesels, researchers have been actively engaged in solving this problem for many years. In [2 - 9] results of the research on the influence of pure biodiesel fuel application and of its mixture with diesel fuel on the diesel technical-economic and ecologic indicators are presented. Special attention should be paid to work [10], where for improving environmental characteristics of diesel the authors develop methods for estimation of regulation characteristic of optimum fuel mixture components ratio depending on the diesel operation mode.

Application of the developed methods provides reduction of emission of all standardized toxic exhaust gas components: nitrogen oxide NOx emission is reduced by 9 %, carbon oxide CO – by 13.5 %, carbohydrates CmHn – by 36 % as compared with engine operation on diesel fuel.

For implementation of the developed methods, the authors propose circuit of the device for

mixing diesel and biodiesel fuel in different proportions depending on the engine operation modes. In the device fuel mixture composition regulation is performed proportionally to diesel fuel pressure in high-pressure fuel lines. Disadvantage of the developed methods is dependence of the fuel mixture percentage composition on the crankshaft rotation speed, without taking into account loading degree of the engine.

Presentation of the basic material

For efficient application of biodiesel fuel engine feed system was improved (Fig. 1) so that it will provide variable diesel and biodiesel fuel mixture composition depending on the engine operation mode. Modifications, introduced into the improved system, will not cause worsening of diesel operation on diesel fuel and will provide basic power and torque of the diesel. Variable percentage composition of diesel and biodiesel fuel mixture is provided automatically during engine operation. Engine starting-up and stopping are performed using diesel fuel and, therefore, there is a necessity to change the approaches to diesel fuel system control when it is switched to operation on diesel and biodiesel fuel mixture with dynamic regulation of its percentage composition.

In Fig. 2 the following designations are used: 1 – diesel fuel tank; 2 – coarse diesel fuel filter; 3 – low-pressure diesel fuel pump; 4 – fine diesel fuel filter; 6 – high-pressure fuel pump (HPFP); 7 – injector; 8 – electronic control unit (ECU); 9 - fuel feed lever; 11 – sensor of the engine crankshaft rotation speed; 12 – sensor of the cooling liquid temperature; 25 – high-pressure fuel accumulator. In order to improve classic diesel feed system, a number of components were added. An additional biodiesel fuel tank 13 with heater 22, coarse and fine filters 14, 16, low-pressure fuel pump 15, fuel mixer 5, additional tank 17 with heater 22 and fuel level sensor 23, low-pressure pump with additional tank 18, electromagnetic valves 19, 20, check valves 21, 24 and bypass valve 10 were installed.

In order to prevent mixing of the fuel mixture with pure fuels, changes were introduced into the pipelines, which provide supply of unused fuel from injectors and HPFP to the system after fuel mixer before HPFP. Fuel mixer, controlled by ECU, provides regulation of the fuel mixture percentage composition in the process of diesel operation. Diesel feed system with dynamic regulation of the fuel mixture percentage composition provides the possibility of diesel operation on diesel fuel, biodiesel fuel and their mixtures of various percentage compositions. With improvements, introduced into the feed system, efficiency of diesel operation on diesel fuel remains unchanged.

Organization of diesel power system control, when it is switched to the operation on diesel and biodiesel fuel mixture with dynamic regulation of its percentage composition, must ensure the following:

- technical indices, maximally close to basic ones, and improved ecologic performance;
- reliable start-up;
- coordinate cyclic supply of fuel and percentage composition of the fuel from loading moment;
- diesel operation under low-temperature environmental conditions;
- minimal inertia of the system operation;
- long-time operation.

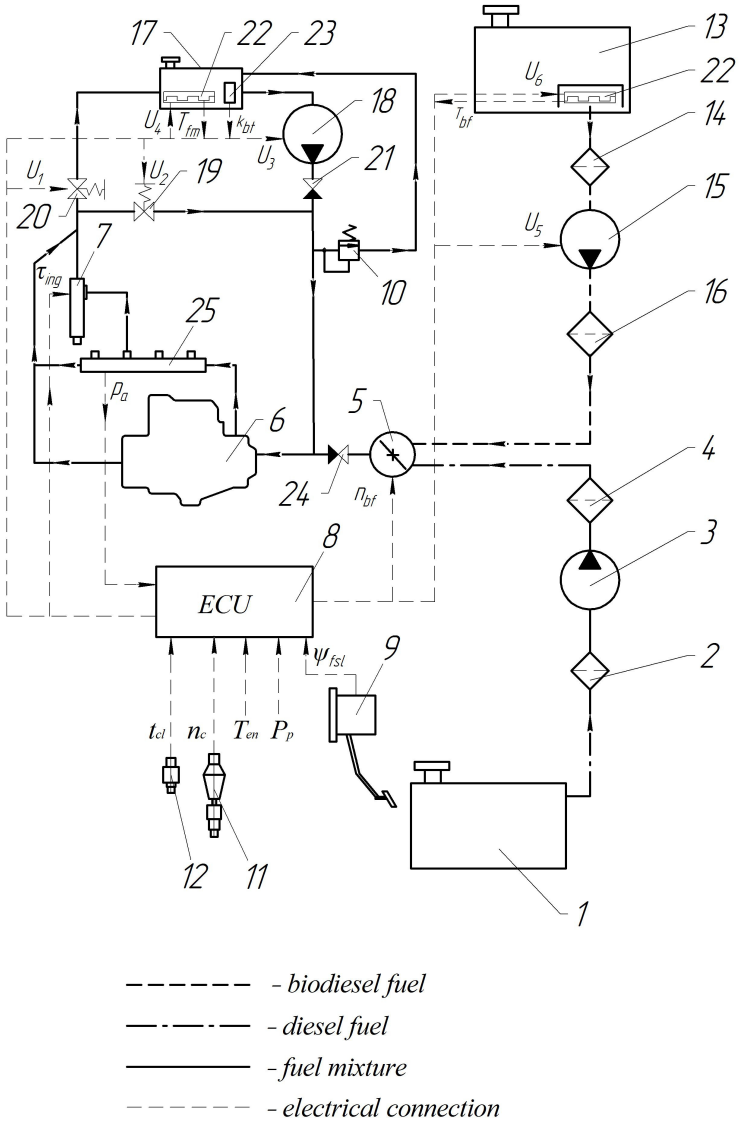

Fig. 1. Circuit of Common Rail diesel power system with the application of diesel and biodiesel fuel mixture and dynamic regulation of its percentage composition

Diesel feed system control, when it is switched to operation on the mixture with dynamic regulation of its percentage composition, is characterized by the necessity to control the mixer and the components of the unused fuel bypass system. Diesel and biodiesel fuel is supplied to the mixer from individual pipelines and low-pressure pumps. Depending on the position of regulation device, fuel mixture with corresponding percentage composition is created and supplied to HPFP.

Basic parameter to be controlled, which is absent in the classic power system, is fuel mixture percentage composition. Its estimation and control is main distinguishing feature of the developed feed system. Depending on the fuel mixture percentage composition, there is a necessity for variable cyclic supply and fuel injection timing angle in order to provide technical indices of the diesel.

While operating on diesel fuel, engine and its feed system work according to the algorithms set by the manufacturer. Control changes take place when engine is switched to the operation on diesel and biodiesel fuel mixture.

In the developed feed system there is an additional low-pressure biodiesel supply line, where it is necessary to control low-pressure pump and fuel heater. When biodiesel fuel is used, its heating is necessary especially under low-temperature environment conditions. When biodiesel fuel is heated from 20 to 50°C, its viscosity decreases by 51 % [11]. Indicators of density, surface tension, etc. are also changed, but not so radically. With cold engine, fuel evaporation and combustion processes

become worse, there is higher probability of the fuel getting into the engine crankcase, where it dilutes the lubrication oil. Biodiesel fuel has greater negative influence on lubrication oil, than diesel fuel [12]. Biodiesel fuel properties determine its higher carbonization ability, which is manifested especially if fuel spraying is bad (if biodiesel fuel is not heated).

Heater is switched on after the start of the motor and maintains the necessary temperature of biodiesel fuel. Low pressure pump is switched on only when the temperature of biodiesel fuel reaches the value admissible for its usage and is switched off on condition of temperature decrease of biodiesel fuel below the admissible value or before the stop of diesel operation, when the supply system is filled with diesel fuel.

Supply system provides the supply of diesel and biodiesel fuel to the mixer independently, however the pressures of both fuels at the inlet of the mixer are the same, after that they are mixed and are considered as the mixture of fuels with corresponding percentage composition.

After the improvement of the system of not used fuel removal there appears the necessity in its control as a number of new components was added to the system.

The given system is responsible for not used fuel discharge:

– in the low pressure pipeline between low pressure fuel pump and mixer;
– in case of engine stop in an additional tank.

There appears the necessity to heat the mixture of fuel in additional tank and the supply of the fuel in supply system. Mixture of fuels from additional tank is used when the engine functions at operation temperature and fuel in the tank has been heated to the required temperature.

New parameter to be controlled and that is not available in classic system is percentage composition of the fuels mixture, determination and control of which is basic characteristic feature of the developed supply system. Also, there is the necessity to change the indices of cycle supply and advance of fuel injection in case of operation at various percentage compositions of fuels mixture at the same operation modes of the diesel.

Technique of diesel supply system control in case of its transition to operation on the mixture of diesel and biodiesel fuels with dynamic regulation of its percentage composition

To provide the control of diesel supply system in the process of its transition to operation on the mixture of diesel and biodiesel fuels with dynamic regulation of its percentage composition the additional sensors and actuators are installed (Fig 1).

Usage of biodiesel fuel and its mixture with diesel fuel results in the change of technical, economic and ecological indices of the diesel. Low heat value of biodiesel is less than the diesel fuel, it means that in case of the complete combustion of biodiesel fuel less energy is obtained than in the process of combustion of the same amount of diesel fuel. To maintain technical characteristics of the diesel it is necessary to increase cyclic supply of fuel. This, in its turn, leads to the increase on hour-long fuel consumption. The increase of cyclic fuel supply results in the increase of the duration of its injection, evaporation and burning, thus, having reached critical duration, the fuel, injected in the cylinder of the engine, would have no time to be burnt down during the allotted time. In case of large cyclic supplies of the fuel and high rotation frequencies of the engine crankshaft the fuel would not be burnt down completely, that will have negative impact on technical, economic and ecological indices of the diesel.

Using the supply system with dynamic regulation of percentage composition of the mixture of fuels on diesels requires special approaches to the organization of supply system operation, for this purpose the technique of its control must be developed.

Regulation of percentage composition is realized, proceeding from two considerations:

- to provide necessary efficient torque;
- to provide the running of operation processes.

Technique of control over the diesel supply system, if it operates using the mixture of diesel and

biodiesel fuels with dynamic regulation of its percentage composition is realized in the following way. Start and stop of the diesel is carried out on diesel fuel, for this purpose, prior to its stop, the mixture of fuels is removed from supply system into additional tank. This stipulates the necessity of diesel operation still for some time after the operator or the driver transfers the engine in stop mode of its operation.

Process of engine starting takes place on diesel fuel, as at present moment supply system is filled with diesel fuel. It is stipulated by the fact that high viscosity and great surface tension of biodiesel fuel increase the loading on the elements of supply system, worsen atomization process and burning of fuel and also there appears the danger of injector nozzles carbonization. Supply system operates in accordance with algorithm installed by manufacturer.

Further, the temperature of cooling liquid and biodiesel fuel are controlled, if they are lower than admissible ones, supply system of the diesel provides its operation on diesel fuel in accordance with the algorithm, installed by manufacturer and biodiesel fuel and engine continue to be warm up. If the temperature of the cooling liquid and biodiesel fuel reach the admissible level, the supply system of the diesel can use biodiesel fuel or its mixture with diesel fuel. In case if in the process of engine operation the temperature of biodiesel fuel decreases lower the admissible level, the engine transfers to operation on diesel fuel.

Determination of percentage composition of fuels mixture is performed by means of evaluation of crankshaft rotation angle value, at which termination of fuels mixture burning takes place. Fig. 2. shows the determination algorithm of percentage composition of the mixture of diesel and biodiesel fuels in the process of transition of diesel engine on the operation on fuels mixture with dynamic regulation of its percentage composition.

Determination of percentage composition of fuels mixture n_{bf} takes place in the following [13]. Low heat value of fuels mixture Hu and its cyclic supply q_c are determined. Cyclic supply of fuels mixture – this is such amount of fuel, that will provide the amount of heat, obtained while diesel fuel burning at the given engine operation mode.

Further the duration of fuels mixture injection φ_{inj} is determined, it depends on the characteristics of the nozzle (consumption coefficient of through partitions of nozzle holes μ_n and cross-section size of nozzle holes f_n), pressure of fuel mixture injection in the cylinder of the engine ΔP and viscosity of fuels mixture ρ_n.

After that the delay period of ignition $\Delta\varphi_i$, is determined, that depends on the average piston speed c_n , energy of fuel activation E_a, universal gas constant R, temperature T_s and gases pressure at the moment of injection start P_s, compression ratio ε and compression polytropic index n_1. Knowing the ignition delay period $\Delta\varphi_i$ the correction of advance angle of fuels mixture ignition θ_{ig} takes place.

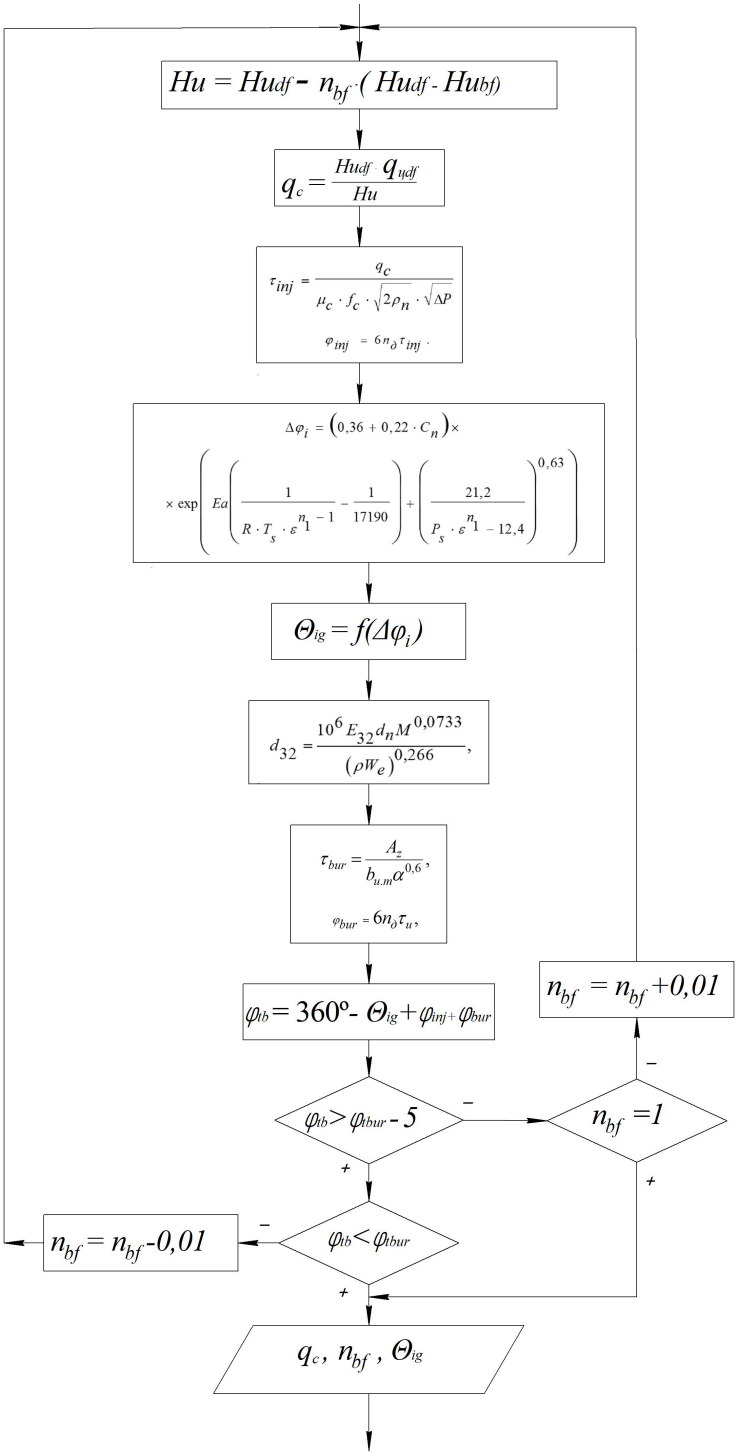

Fig 2. Scheme of the algorithm of fuels mixture percentage composition determination

Average diameter of fuels mixture drops, injected in the engine cylinder d_{32} is determined, it depends on the construction of the nozzle (E_{32} – empirical coefficient), diameter of nozzle injector hole d_n weber number W_e, ratio of air tightness to fuel density ρ and criterion, that characterizes the ratio of surface tension forces M.

Duration of evaporation and combustion of large drops depends on the constant of large drops evaporation time A_z, coefficient of air excess α and relative theoretical constant of fuel evaporation $b_{u.m}$, that in its turn, depends on average diameter of fuels mixture drops d_{32}.

Taking into account the above- mentioned, the moment of fuels mixture burning termination φ_{tb} is determined. If it is less than the admissible value of φ_{tbur} percentage composition of the mixture

n_{bf}, is verified, if the content of biodiesel fuel in the mixture equals 100 % then final for this stage cyclic supply and mixture composition are obtained, if the content of biodiesel fuel in the mixture is less than 100 % then the content of biodiesel fuel in the mixture increases by 1 %. Further, the value is calculated again at this stage and the condition of correspondence of the moment of fuels mixture burning termination to admissible valves is verified again and such procedure is performed until the condition will not be satisfied. The step of biodiesel fuel content change in 1 % is sufficient to provide the regulation of percentage composition of fuels mixture with required accuracy.

If the value of burning termination moment φ_{tb} is greater than the admissible value of φ_{tbur}, the content of biodiesel fuel in the mixture decreases by 1 %, further the condition of correspondence of the moment of fuels mixture burning termination to admissible values is verified and this procedure is performed until the condition will be satisfied or the content of diesel fuel in the mixture will be equals 100 %.

After the stop of the engine, for its further start the supply system is filled with diesel fuel. Mixture of fuels from the supply system is sent to additional tank. Part of the fuels mixture is sent to additional tank and another portion is burnt down in the cylinders of the diesel during operation. Supply system is filled with diesel fuel and the engine stops. Mixture of fuel from additional tank is used immediately when diesel operates on the mixture of fuels.

Conclusion

Application of the technique of diesel supply system control in the process of its transition to operation on the mixture of diesel and biodiesel fuels with dynamic regulation of its percentage composition enables to provide the operation of the engine with basic technical indices of the diesels, considerably improving its ecological indices. The technique of diesel supply system control takes into account the peculiarities of diesel supply system control at different operation modes of the engine.

Main peculiarity of the technique is determination of percentage composition of the mixture of diesel and biodiesel fuels depending on the mode of diesel operation and the control over new components, that were added to diesel supply system in the process of its transition to operation on the fuels mixture with dynamic regulation of its percentage composition.

In this case the ability of the engine to operate on two fuels remains, i.e. diesel and biodiesel fuels and their mixture is efficiently used in diesel engine. In the case of operation on diesel fuel at all engine operation modes its basic characteristics remain.

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