Two-phase mixture formation in transport diesel engine: the control algorithm and the devise for its implementation

Two-phase mixture formation in transport diesel engine: the control algorithm and the devise for its implementation

M V Ryblov, M D Dubin and A P Ukhanov

Penza State Agrarian University, 30, Botanicheskaya Str., Penza, 440014, Russian Federation

E-mail: ryblov.m.v@pgau.ru

Abstract. The article reviews the issues dedicated to improving of energy and environmental indicators of automotive machinery by means of two-phase mixture formation in diesel engine. With this method, the 1st phase of mixture formation proceeds at intake stroke by the supply of the certain dose of fuel activator (gasoline, alcohol, biodiesel, etc.) into engine intake manifold, where a mixture of air and activator is formed. The 2nd phase proceeds at compression stroke by the supply of the major dose of diesel oil with the standard fuel supply system into combustion chamber. For the practical implementation of the described method, the diesel engine needs to be equipped with an automatic system for fumigation of air charge. The system contains electronic control unit (ECU), electromagnetic injectors, electric pump and sensors of engine speed and load mode. An algorithm of ECU operation for program control of injectors, supplying activator at the intake stroke, was developed. The sequence of actuation of injectors, coincident with the engine firing order, was substantiated. A formula for calculation of the duration of control pulse supplied to the injectors was derived. The proposed automatic system performs the activator injection, corresponding to the engine firing order, and the exact activator dosage, depending on engine speed and load mode, at the 1st phase of two-phase mixture formation.

1. Introduction

Automobiles, tractors and specialized machines are powered mostly with internal combustion compression-ignition engines (diesel engines). The main technical requirements for automotive machinery are improving of fuel economy and increasing of environmental safety. There are many different methods and means of enhancement of the diesel engines, such as: turbocharger, electronic management of the fuel supply, exhaust gas recirculation, catalytic convertors, particulate filters, etc. [1]. However, the fuel economy and exhaust emissions requirements are getting tougher, while the mentioned ways of engine enhancement almost spent their potential.

Consequently, at the present days the scientists of the leading countries of the world (for example, USA, China, etc.) renew interest to the method of two-phase mixture formation as a way of improving of energy and ecological parameters of the diesel engine [2]. This method consists in fumigation of air charge by means of the supply of the certain dose (usually 10 to 20 %) of pulverized fuel activator (gasoline, alcohol, biodiesel, etc.) into engine intake manifold at the intake stroke. This is the 1st phase of mixture formation. Then the main dose of diesel oil (80 to 90 %) is supplied with the standard injector into combustion chamber at the compression stroke. This is the 2nd phase of mixture formation. When the engine duty cycle is organized in such way, an air/activator mixture is being formed and arrives into engine cylinders at the intake stroke. Afterwards, at the compression stroke,

this mixture forms ignition centres, which are accelerating pre-ignition preparation and burning of the main dose of the diesel oil. As a result, a completeness of mixture combustion is increasing, the engine power and efficiency are growing, the fuel economy and ecological parameters are improving [3]. The research results [4] showed that the supply of 10% dose of the gasoline RON92 at the 1st phase of two-phase mixture formation contributed to growing of engine power and torque by 7-10%, while break specific fuel consumption was less by 8-11% in the comparison with the conventional (single phase) mixture formation. The supply of 20% dose of RME (rape methyl ester) or blended fuel 50/50 RME/diesel promoted to reduction of the exhaust smoke opacity by 45-50%. In papers [5-6] it is noted that the methanol fumigation at the intake stroke of the diesel engine contributed to reduction of PM and NOx emissions when the engine was running at low load. CO and HC emissions slightly increased at high load. When the dose of methanol was increased from 10% to 30 %, the engine efficiency decreased at low load but increased at high load.

For fumigation of engine air charge at the 1st phase two-phase mixture formation with the activator supply, the different mechanical devices are used: carburetor, evaporator, dispenser or injector placed in the engine intake manifold [7-8]. Other systems perform the activator injection by electromagnetic injectors guided by electronic control unit [9]. All those devices and systems have the common disadvantages: they do not support precise ratio of activator dose and main fuel dose at different engine speed and load modes, while activator injection timing is not synchronized with the intake strokes of the engine cylinders. These disadvantages obstruct introduction of two-phase mixture formation on automotive diesel engines.

To solve this problem, it is necessary to design an automatic system for the fumigation of diesel engine air charge at the 1st phase of two-phase mixture formation. The system must manage electric pump and the electromagnetic injectors by programmable electronic control unit (ECU) according to the signals received from sensors of engine speed and load mode. The ECU should operate according to the algorithm to ensure the exact dosage of activator depending on operating mode and injection strictly at the intake stroke.

2. Materials and methods

For practical implementation of two-phase mixture formation in automotive diesel engine, the following tasks were solved:

- The development of control algorithm of activator injection at the 1st phase of two-phase mixture formation and writing the software for ECU in machine language C++;
- The design of automatic system for fumigation of air charge in the diesel engine at the 1st phase of two-phase mixture formation, based on programmable ECU.

The development of control algorithm included the following steps:

- A substantiation of the sequence of actuation of electromagnetic injectors supplying activator into the engine intake manifold;
- A calculation of necessary activator cycle dose at the different engine operation modes;
- A derivation of formula for calculation of duration of the control pulse, being supplied to the injectors, for the programming of ECU microcontroller.

The sequence of actuation of electromagnetic injectors should to be agreed with the firing order of the engine cylinders. The numbers of branches of the engine intake manifold also need to consider. For example, MMZ D-243 diesel engine (four-cylinder, four-stroke, direct injection compression ignition engine) has only two branches of the intake manifold. Consequently, it is impossible to mount the individual injectors for each cylinder. The activator injection on this engine can be done with two electromagnetic injectors: the 1st injector performs fumigation of air charge incoming into the 1st and the 2nd cylinders; the 2nd injector − into the 3rd and the 4th cylinders. The proposed sequence of

actuation of electromagnetic injectors is presented in round diagram shown at figure 1. To detect the activator injection moment, a phase sensor, mounted on drive gear of high-pressure pump (HPP), is used.

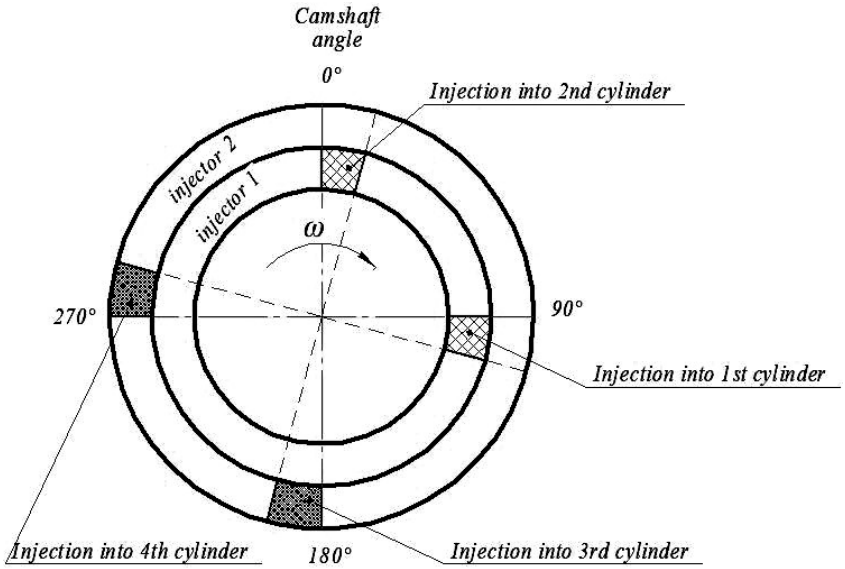


Figure 1. The diagram of control pulses of the electromagnetic injectors for activator fumigation of air charge at the 1st phase of two-phase mixture formation in MMZ D-243 diesel engine.

The formula for calculation of the duration of control pulse T_i (period of activator injection) is included in ECU program. This duration corresponds to activator cycle dose g_c which is a function of engine speed and load mode parameters:

$$g_c = F(G_t, n), \tag{1}$$

Where G_t is hourly fuel consumption (kg/h); n is crankshaft rotation speed (rpm).

The design of ECU contains the buttons for input of coefficient of activator dose K_D (10% or 20% of the main dose of diesel oil) and coefficient of the dose correction K_V. The last one considers change of injector flow rate when the different fuel activators (gasoline, alcohol, biodiesel, etc.) with various physical and chemical properties are used. The data about the current engine speed and load parameters arrives into the ECU from a fuel flow sensor a phase sensor. The phase sensor simultaneously performs a function of the crankshaft speed sensor. The fuel flow sensor generates impulses with the certain frequency f which is proportionate to G_t. Parameter n is detected by the phase sensor through the HPP drive camshaft. After the derivation [11], a formula for the calculation of the injection duration T_i, written to the ECU program, was obtained:

$$T_i = C \cdot K_D \cdot K_V \cdot \frac{f}{n} \tag{2}$$

Where C is a coefficient obtained by multiplication of the constants (number of engine cylinders, frequency of fuel flow sensor impulses per 1 liter of the diesel oil, injector flow rate, diesel oil density, etc.).

The developed control algorithm (figure 2) for two-phase mixture formation in the diesel engine represents a command set written in machine language. After the vehicle driver switches on ECU to connect it to vehicle circuit board, then he enters coefficients K_D and K_V with the help of the buttons placed on control panel. After input of K_V the electric pump turns on automatically. ECU microcontroller starts data processing of the signals obtained from the sensors. If the signal from any sensor is not detected, the electric pump automatically turns off in 5 seconds. If the signals from sensors are detected, the ECU computes the duration T_i, defines camshaft angle (CA) for injection

timing and actuates electromagnetic injectors. After injection, the ECU detects the signals from sensors again and the cycle repeats.

3. Results

A program for the ECU microcontroller based on the developed algorithm was written in machine language C++. The algorithm and the program are universal for all types of the diesel engines. Depending on the number of the engine cylinders, only coefficient *C* in formula (2) may change.

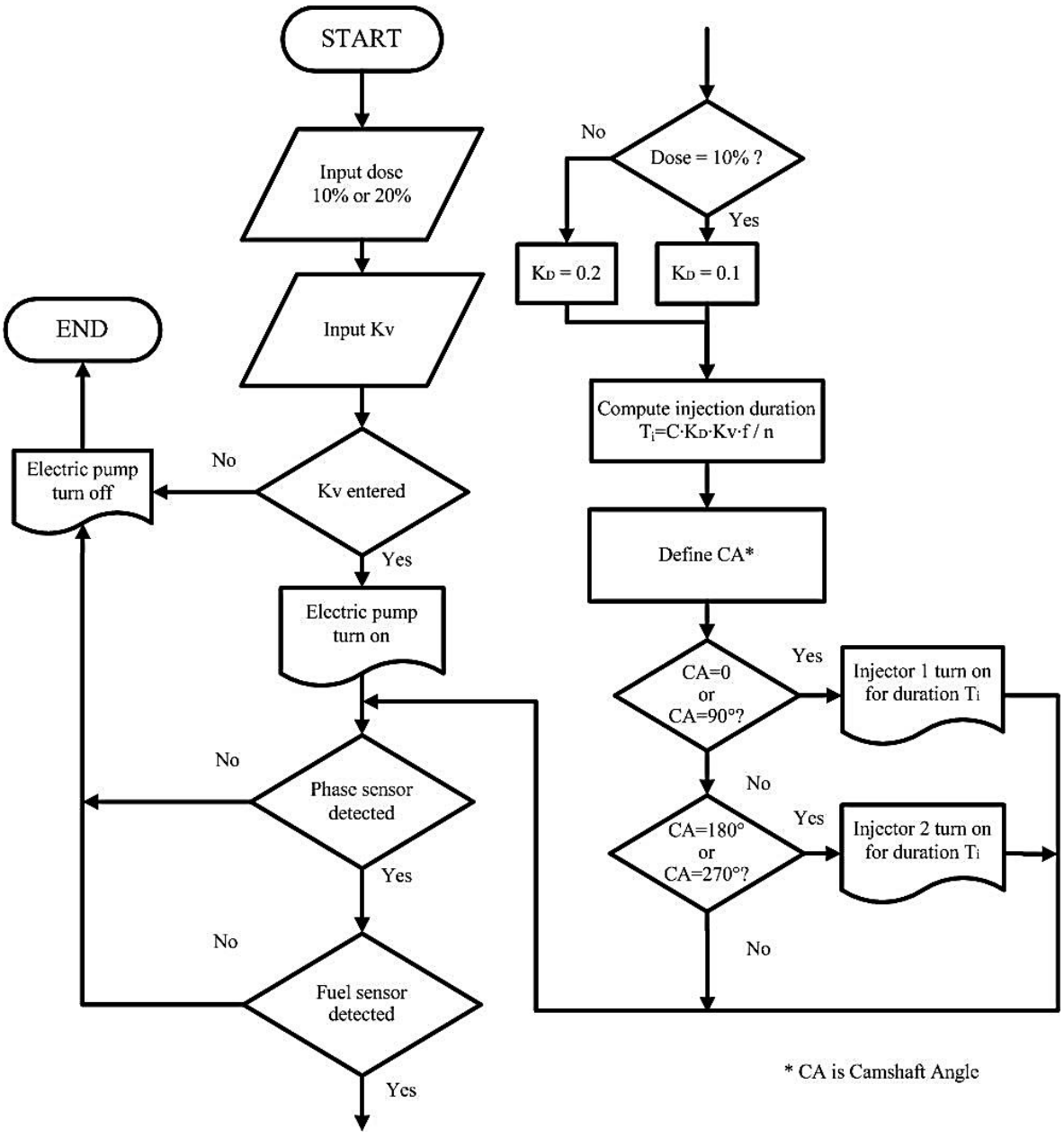


Figure 2. A flowchart of the control algorithm for two-phase mixture formation in the diesel engine.

The results of computation show that depending on required activator dose (10% or 20%) and on engine speed and load mode, the cycle dose of activator, injected at the 1st phase of two-phase mixture

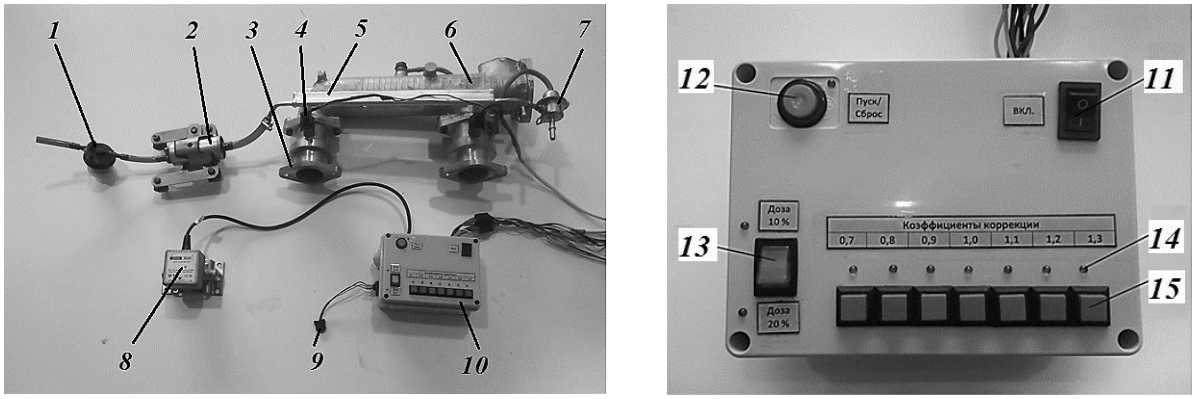
formation for MMZ D-243 diesel engine, is equal from 1 to 13 mg per cycle while the duration of control impulse supplied to the electromagnetic injectors varies from 0.27 to 3.47 ms (table 1).

Table 1. The duration of control impulses T_i (ms) of activator injection at different speed and load modes of MMZ D-243 diesel engine (numerator and denominator are the duration T_i at the activator dose 10% and 20% respectively).

Load mode	Speed mode				
	n=1400 rpm	n=1600 rpm	n=1800 rpm	n=2000 rpm	n=2200 rpm
Full load	1.73 / 3.47	1.72 / 3.34	1.66 / 3.32	1.60 / 3.19	1.45 / 2.90
Load 90%	1.20 / 2.41	1.22 / 2.43	1.26 / 2.53	1.28 / 2.56	1.28 / 2.57
Load 80%	0.97 / 1.94	0.98 / 1.97	1.03 / 2.07	1.05 / 2.10	1.09 / 2.19
Load 60%	0.81 / 1.62	0.78 / 1.56	0.78 / 1.56	0.82 / 1.64	0.88 / 1.77
Load 40%	0.62 / 1.25	0.63 / 1.26	0.63 / 1.26	0.65 / 1.29	0.69 / 1.37
Load 20%	0.44 / 0.87	0.44 / 0.87	0.45 / 0.90	0.47 / 0.94	0.47 / 0.94
Idle speed	0.27 / 0.53	0.29 / 0.57	0.30 / 0.61	0.33 / 0.66	0.36 / 0.72

As a result of performed theoretical studies, an automatic system for fumigation of air charge in the diesel engine at the 1st phase of two-phase mixture formation was designed (Figure 3). The system contains filter 1, electric pump 2, electromagnetic injectors 4, rail 5, pressure governor 7, fuel flow sensor 8, phase and crankchaft speed sensor 9 and ECU 10.

The electromagnetic injectors 4 are placed in insertions 3 at the branches of the standard intake manifold 6 of MMZ D-243 diesel engine. The upper flanges of the insertions 3 are connected with the branches of manifold 2. The lower flanges of the insertions 3 are connected with inlet ports of the engine cylinder head. The input channels of the injectors 4 are placed at outlet pipes of the rail 5, which is used as a pipeline for activator supply. The pressure governor 7 is placed at the dead end of the rail 5.



(a) (b)

Figure 3. The automatic system for fumigation of air charge at the 1st phase of two-phase mixture formation in the diesel engine: a) the design of system; b) ECU; 1 – filter; 2 – electric pump; 3 – insertion; 4 – electromagnetic injector; 5 - rail; 6 – standard intake manifold; 7 – pressure governor; 8 – fuel flow sensor; 9 – phase and crankchaft speed sensor; 10 – ECU; 11 – tumbler switch for ECU connection with vehicle circuit board; 12 – button «Start/Stop»; 13 – button for input activator dose; 14 – control luminodiodes; 15 – buttons for input correction of activator supply.

The fuel flow sensor 8 is used as a sensor of engine load mode and serves to match the activator dose with the main dose of diesel oil. The phase sensor 7 serves to activator injection timing strictly at

the moment when in one of cylinders the intake stroke proceeds. In addition, this sensor performs a function of the engine speed sensor (crankshaft speed rotation).

The design of ECU 10 based on the programmable microcontroller. The following elements are placed on the control panel of ECU: tumbler switch 11 for ECU connection with vehicle circuit board; button 12 «Start/Stop» for turning on/off the electric pump; button 13 for input activator dose (10% or 20% of the fuel supply); buttons 15 for input correction of activator supply. For visual control of entered coefficients K_D and K_V, the indicative luminodiodes are mounted. In addition, the ECU is fitted with the plugs for programming and for connection with the sensors, the injectors and the electric pump.

4. Discussion

The presented automatic system for fumigation of air charge at the 1st phase of two-phase mixture formation in the diesel engine operates in the following order.

After switching on the tumbler 11, electric power is supplied in ECU 10 from the vehicle circuit board. After engine start and warm-up, the vehicle driver enters the numerical values of the coefficient K_D by the switch 13 and coefficient K_V by the buttons 15. The indicative luminodiodes 14 corresponding to the selected coefficients light up. For power supply to the electric pump the driver presses the button 12 "Start/Stop". The electric pump 2 turns on and delivers activator into the rail 5.

The ECU starts data processing of the signals obtained from the sensors 8 and 9 (parameters f and n) and of entered values of the coefficients K_D and K_V. As a result, ECU computes the value of control pulse duration T_i by formula (2) and defines the intake strokes for injection timing. The control impulses formed by ECU arrive into the electromagnetic injectors which supply the activator into the branches of the engine intake manifold according to diagram shown at Figure 2.

As the engine speed and load mode varies, the signals from the phase sensor and fuel flow sensor change. Then the ECU computes new value of duration T_i based on changed parameters f and n according to entered coefficients K_D and K_V.

When the engine is running at low-load mode or at idle-speed mode, the injector flow rate may be less than the performance of the electric pump. If activator pressure in the rail 5 grows, the pressure governor 7 actuates and bypasses excess activator back to the tank. The pressure in the rail stabilizes.

To stop activator supply, the tractor driver presses the button 12 « Start/Stop » again. The electric circuit breaks, the electric pump and the electromagnetic injectors turn off. After the engine stop the driver disconnects ECU from the vehicle circuit board with the tumbler 11.

5. Conclusion

As a result of performed studies, a control algorithm for two-phase mixture formation in the diesel engine was developed. The algorithm allows to implement high-precision and well-timed activator injection at the intake stroke of the diesel engine. Depending on speed and load mode of MMZ D-243 diesel engine, the activator mass supply is equal from 1 to 13 mg per cycle while while the duration of control impulse supplied to the electromagnetic injectors varies from 0.27 to 3.47 ms. The algorithm is written to the program of the ECU of the automatic system for fumigation of air charge at the 1st phase of two-phase mixture formation in the diesel engine. The performed studies solve the problem of the practical realization of two-phase mixture formation in the diesel engine as a way improving the power capacity, fuel economy and environmental indicators of the automotive diesel engines.

Acknowledgments

The reported study was funded by RFBR according to the research project № 20-38-90194.

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