THE STUDY OF NON TRADITIONAL DOSING METHOD OF THE CYCLE FUEL FEED IN DIESEL

Victor Slavutskiy, Evgeniy Salykin
Vadim Slavutskiy, Zakhar Kanygin

Volgograd State Technical University
Auto-Tractor Faculty
Lenin avenue 28, Volgograd, Russia, 400131
tel.: +7 (8448) 248161, fax: +7 (8442) 248182
e-mail: atd304@vstu.ru

Abstract

It is offered to dose out a cyclic portion of fuel by change of duration of the first period of feeding that is reached by regulation of the moment of landing of the delivery valve. The mathematical model of fuel feed system with the steered delivery valve is developed. Numerical and experimental methods defined cyclic fuel delivery at change of the moment of closing of the delivery valve. Within the limits of studying of the feeder of fuel in skilled system, redistribution of a cyclic portion of fuel between the periods of a cycle and quantity of the fuel compressed in separate cavities of a delivery high-pressure pipe was defined. The important feature of the feeder – earlier landing of the delivery valve, than nozzle valve closing is found out. It absence of repeated lifting of a nozzle valve ("secondary injections") speaks all investigated high-speed and loading modes. The offered method of dosing out of fuel feed allows eliminating an essential lack of a traditional fuel system where feeding and dosing out processes are combined. The paper explains the absence of the repeated rise of the injector needle at all calculated regimes. A wave of pressure generated at setting the valve comes to the injector before the fuel feed is over. This excludes additional fuel injections even at high initial pressure in the force main in principle.

Keywords: *the giving period, mathematical model, cyclic giving, a compulsory valve closing, differential steering, repeated lifting of a needle*

The analysis of peculiarities of a fuel feed mechanism at high speed forcing of the high pressure pump shows that the fuel feed into the cylinder begins after the working stroke of the plunger with the growth of shaft rotation speed of the pump the lag of feed start relating to the moment of completing the power stroke (cut off starting) increases. This and other peculiarities of the fuel feed allow to divide the latter into two periods: 1) from the moment of the feed beginning till the moment of setting of the discharging belt of the force valve into the house (disconnecting) injection of the over plunger cavity and the force main-completing the cut off 2) from the moment of the force value setting till ending the fuel feed [2].

During the first period fuel is fed due to the force stroke of the plunger. During the second period only expending fuel is fed into the cylinder, with its having been compressed before in the cavities of the system during the plunger force stroke. When raising the shaft rotation frequency of the pump (n_r), the relative fuel portion fed in the first period also increases. Therefore with raising shaft rotation speed of the pump, the fuel part fed during the time of the plunger force stroke increases. At $n_r \rightarrow 2300$ min^{-1} more than 50% of the cycle fuel portion is fed, but at $n_r = 2800$ min^{-1} – 78% in the first period.

Thus, the great part of the cycle fuel portion is fed in the first period ending at the moment of setting the force valve into the house. This circumstance was taken for the base when developing the proposed method of changing the cycle fuel feed by means of adjusting the moment of force valve setting. It is offered to change the cyclic fuel portion not by the traditional way of changing the working stroke of the plunger but by changing the duration of the first feed period. As the calculation parameters of the force valve moving we have chosen the angle of closing it φ (is calculating from the moving start of the plunger). This is the moment of entering the discharged belt of the valve into the house i.e. that is the moment of disjunction of the overplunger cavity with the cavities of the force main (a pump carbine, a high pressure pipeline, an injector cavity).

An important element of the mathematical model of the fuel feed system with an adjustable force valve is a description of valve moving. The valve moving in the initial model takes place under the action of resulting forces. An arbitrary low of valve rising (as in the standard system) as well as linear law of its lowering has been admitted. The linear low of the valve settings should provide its closure the inlet of the discharging belt into the channel of the valve house at a set moment of time (the shaft rotation angel of the pump φ_3). Moreover, the valve lowering in accordance with the taken accepted methods should begin in its position corresponding to the maximum rise. Such a low of valve force moving is accounted for two reasons. Firstly taken into consideration of pure methodic character, we would rather prefer the variant, according to which the character of valve moving at its rise and the maximum height rise are standard. This allows distinguishing only the factor connected with the moment of valve closing. Secondly, the beginning of force lowering of the valve from the position of its maximum rise considerably lightens the process of adjusting the valve by means of a microprocessor. In this case the moment of including the operating mechanism corresponds to the signal maximum produced by the valve rise recorder. For the same reason the linear low of the force valve lowering was adopted. It is easier to realize such character of the moving in the microprocessor. Thus the second reason deals with the possibilities of an electronic block of control. The changes brought in mathematic model of the traditional fuel feed system have been realized in the view of a separate program (1).

In accordance with the accepted methods the valve closure angle φ_3 has been called the base one at natural valve moving under the influence of spring elasticity forces and inertia forces that is in the case of non interference into its moving. For example, at n_r = 2000 min^{-1} the base one is φ_3 39.69 grades. The limits of its change are from 34.69 up to 43.69 grades. Such great limits of changing φ_3 allowed distinguishing to the utmost some possibilities of the proposed method of the cycle fuel feed by force closing the valve.

As a result of calculations it has been established that to each frequency of the pump shaft rotation there corresponds a definite range of changing the angle of the force valve closure in which the cycle fuel feed remarkably changes. This range is expanding and is removing to the side of increasing the angle of the valve closure, with rising of the valve rotation speed of the pump (Figure 1). So, at n_r = 1600 min^{-1} changing the closure angle φ from 32.4 grades up to 36.4 grades results in the increasing the cycle fuel feed Q_c from 32.8 up to 68 mm^3, if the frequency of the pump shaft rotation n_r = 2000 min^{-1}. At n_r = 3000 min^{-1} the cycle feed increases from 52 up to 61.8 mm^3 which corresponds with changing the valve closure angle from 40 up to 47 grades. At the frequency of the pump shaft rotation of 3600 and 4000 min^{-1} the cycle fuel feed increases from 34 up to 55 mm^3.At that the valve closure angle changes from 36.5 up to 48 grades.

A task of the experimental determination of the cycle fuel feed at different angels of the force valve closure has been set. It is impossible to repeat the calculation low of the valve motion when lowering it without a special operating mechanism. In this case the operating mechanism must be adjusted only by the signals of electronic block.

A simpler task of determining a qualitative change of the cycle fuel feed at the angle change of the valve closure has been solved. The closure angle φ has been changed by installing the springs charging the valve of various rigidity. During the experiment the shaft rotation frequency of the valve has been taken as n_r = 2000 min^{-1}. The displacement of the force valve has been fixed by an induction reader with recording a signal on the oscilograph tape. The installation of rigid springs has allowed only partially cutting off the range of decreasing (against the base one) the valve closure angle admitted during the calculations. Four values of the valve closure angle, including the base one (40.2 grades): φ_3 = 36.5 grades; φ_3 = 37.9 grades; φ_3 = 38.9 grades have been obtained.

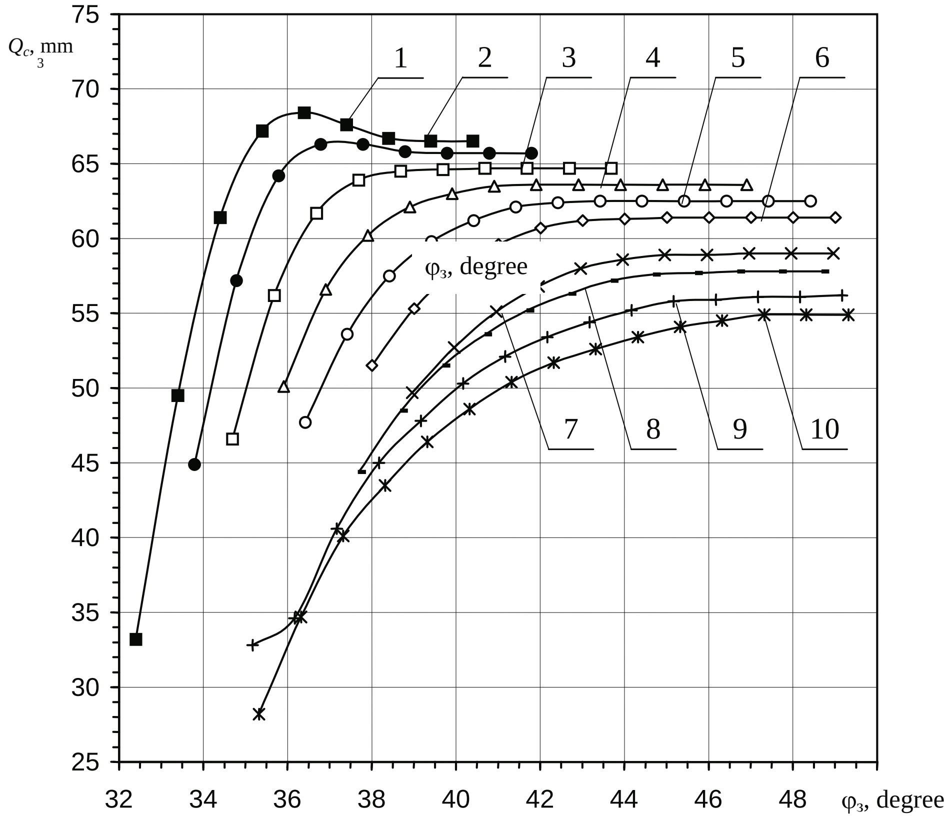

Fig. 1. The dependence of the cycle fuel feed Q_c on the closure of the force valve φ_3 at different frequencies of the pump shaft rotation n_r: 1 – n_r = 1600 min^{-1}, 2 – 1800 min^{-1}; 3 – 2000 min^{-1}, 4 – 220 min^{-1}, 5 – 2400 min^{-1}, 6 – 2600 min^{-1}, 7 – 3000 min^{-1}, 8 – 3200 min^{-1}, 9 – 3600 min^{-1}, 10 – 4000 min^{-1}

It has been determined that the divergence of the calculation results and the experiment increases with decreasing the valve closure angle, that is with rising ring rigidity. Lowering the cycle speed against the calculated one is mainly accounted of the decreasing the height of the valve rise, to our opinion. It is important that the natural experiment qualitatively but confirmed the possibility of changing the cycle fuel feed by adjusting the force valve. An attempt has been made as far as increasing the valve closure angle at the expense of installing weak springs forcing the valve. The peculiarity calculation of valve moving forced by a weak spring consists in due regard to the force, acting on the surface of conus along the valve axle (a supporting force). In this case the supporting force is commensurable with the forces of the system acting of the valve.

The system of differential equations for determining the pressure gradients along the axles OX and OY [3]: is as follows:

$$\left.\begin{aligned}\frac{\partial P}{\partial x} &= -\left(U\,\frac{\partial U}{\partial x} + V\,\frac{\partial U}{\partial y}\right) + \frac{1}{R_e}\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right);\\ \frac{\partial P}{\partial y} &= -\left(U\,\frac{\partial V}{\partial x} + V\,\frac{\partial V}{\partial y}\right) + \frac{1}{R_e}\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right),\end{aligned}\right\}. \tag{1}$$

Where: U and V are projections of fuel speed on to the axles OX and OY. Having changed in the calculated point finally different presentations of right part in the equation of the system (1) by F_i and F_j, we obtain:

$$\left.\begin{aligned} P_i &= P_{i-1} + 0{,}5HX\left(F_i + F_j\right); \\ P_j &= P_{i-1} + 0{,}5HY\left(F_i + F_{j-1}\right). \end{aligned}\right\} \tag{2}$$

On the account on asymmetric current the fuel pressure force acting along the valve axle (the supporting force) is defined as:

$$F_\partial = 2\pi\rho V_x^2 \int_{R_N}^{R_G} P(R)\cdot R\cdot dR\,, \tag{3}$$

where: R_G, R_N and small and large radius of the valve conus.

The force of liquid friction caused by the presence of contact tensions in fuel:

$$\tau_T = \mu\frac{V_x}{D_x}\cdot\frac{\partial c}{\partial n}\,, \tag{4}$$

where $\frac{\partial c}{\partial n}$ is a gradient of fuel speed in normal to the conus surface.

$$\frac{\partial c}{\partial n} = \frac{\partial c}{\partial x}\cos\beta + \frac{\partial c}{\partial y}\sin\beta\,, \tag{5}$$

where β is the angle of the working part of the angle.

Since C = U·sinβ + V·cosβ, so we have for $\beta = 45^0$:

$$\tau_T = \mu\frac{V_x}{2D_x}\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial y}\right), \tag{6}$$

where $\frac{D_x}{2}$ is a clearance between the valve conus (the part of great diameter) and the house.

For the calculation of the supporting force, acting on the valve F_d, border conditions of the pump in the mathematical model have been added by the expressions (1-6).

The necessity to take into account the supporting force has been confirmed. The calculation results on the account of this force have been more approaching the experimental data. Due to a small rate of valve setting one has succeeded in realizing two values of the valve closure angle φ_3 exceeding its basic value (φ = 39.69 grades): φ = 42 grades and φ = 44 grades.

The closure angles of 42 grades and 44 grades are beyond the range limits of changing φ_3, in which the cycle fuel feed is changed. The experimental values of the cycle feed are 72 mm^3 and 79 mm^3, which correspond with the valve closure angle 42 grades and 44 grades. The calculated values of the cycle feed are the same at such closure angles and are equal to 65 mm^3 (Figure 1). Greater values of the cycle fuel feed obtained experimentally can be accounted for by our opinion, the great height of the valve rise forced with a weak spring [1].

An important index is the rate of the force valve during its setting. In Figure 2 the speed changing (calculated values) is represented in the function of the valve closure angle for three values of pump shaft rotation frequency n_r. Using these calculation results one can estimate loading the mechanism of the valve drive firstly and secondly choose the range of changing the closure angle φ_3 in which (the range) the rate of valve moving little differs from the rate at the base value φ. While choosing the change of the range φ, it shall be measured with the frequencies of the pump shaft rotations as well as the cycle feeds. So at n_r = 2000 min^{-1} the moving rate of the valve C_v does not exceed 9 m/s, if the valve closure angle a little bit less than 36 grades (Figure 2).

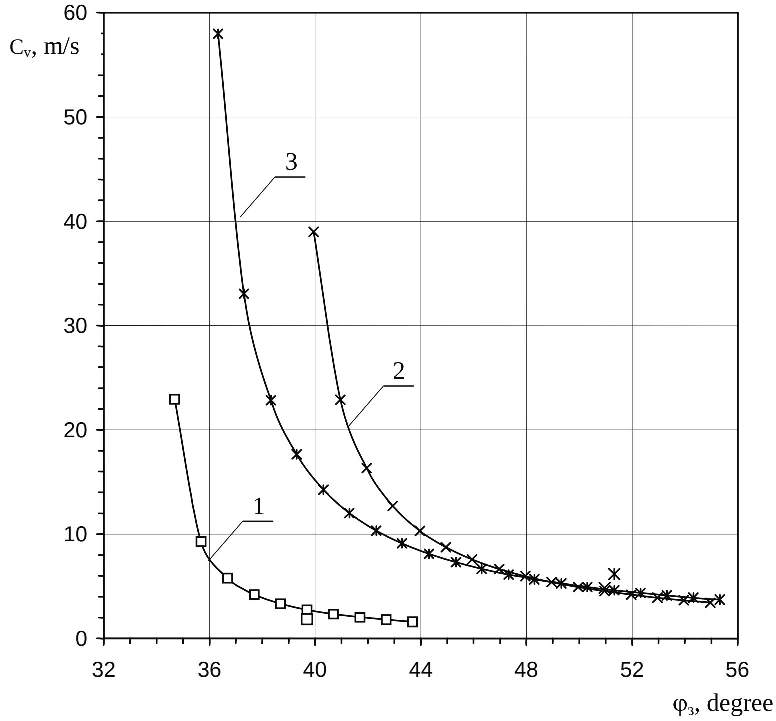

Fig. 2. The dependence of setting rate of the force valve on its closure φ_3 at different frequencies of the shaft rotation pump n_r: 1–n_r = 2000 min^{-1}; 2–n_r = 3000 min^{-1}; 3–n_r = 4000 min^{-1}

At that the range of changing φ provides a marked change of the cycle feed (Figure 1).
If n_r = 4000 min^{-1}, then the valve rate C_v does not exceed 10 m/s at the range of changing φ from 44 up to 55 grades. However, this is only a part of the range change φ_3, in which the cycle feed changes noticeably. When expanding the range φ_3, the valve rate increases considerably. (Figure 2, curve 3).

In the limits of studying the mechanism of the fuel feed under changing the closure angle of the force valve a redistribution of the cycle fuel portion between the fuel feeding periods. As well as quantity of fuel burnt in the system cavities have been determined. The state of the latter one has been estimated in the course of two periods of feeding and after the closure of the injector needle (initial conditions).

The comparative analyses of the traditional and proposed methods of changing the cycle fuel feed have been carried out.

The maximum fuel amount fed at n_r = 2000 min^{-1} was 64.67 mm^3. At that the valve closure angle φ = 40.69 grades (Figure 1). The fuel portion fed at that closure angle in the first period is only 40% (Figure 3). If n_r = 3000 min^{-1}then only 58.97 $mm^3$of fuel is fed at the needle closure of 47.96 grades. The relative fuel portion fed in the first period is 58.09%. Consequently, the maximum fuel amount is refed in the sprayer before setting the injector needle. This accounts for the fact that the expansion range of the valve closure after achieving the maximum feed does not change the latter one (Figure 1). The amount of compressed fuel in the cavities determines potential possibilities of the system that is possibility of the system to feed fuel at the experience of its expending in force main, when the system after the force valve closure turns out to be disconnected with the overplunger cavity. At the end of the first period at n_r = 2000 min^{-1} to the moment of stabilizing the cycle feed in the pipeline there is maximum amount of compressed fuel and its noticeable increase in the injector cavity begins. Judging by the amount of the compressed fuel the main source feeding the injector in the second period is a force pipeline.

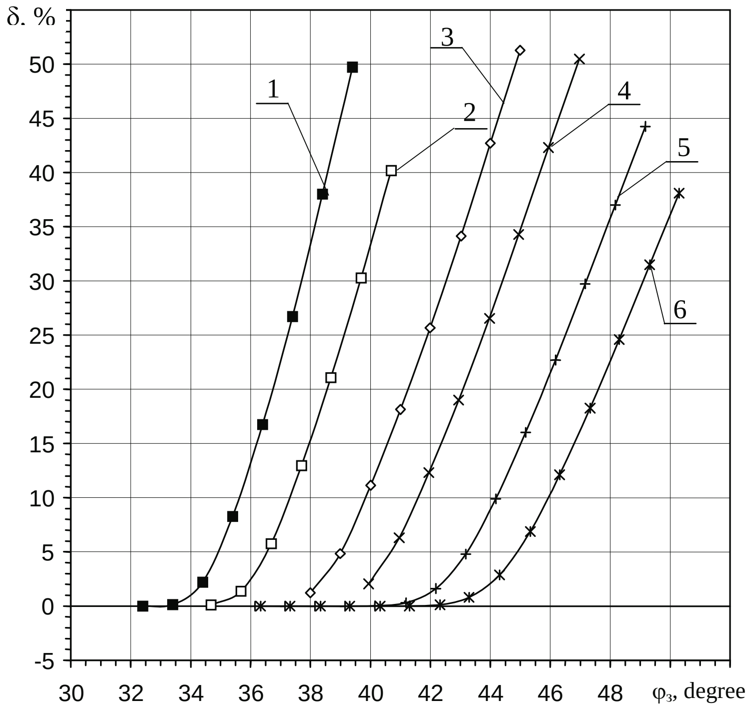

Fig. 3. The dependence of the relative fuel portion δ fed in the first period on feeding of the closure angle of the force valve φ_3 at different frequencies of the pump shaft rotation n_r:
1–n_r = 1600 min^{-1}, 2 – 2000 min^{-1}, 3 – 2600 min^{-1}, 4 – 3000 min^{-1}, 5 – 3600 min^{-1}, 6 – 4000 min^{-1}

An important peculiarity of the feed mechanism when adjusting by the force valve – it is earlier setting into the house than the closure of the injector needle. Due to this we explain the absence of the repeated rise of the injector needle (additional injections) at all calculated regimes. A wave of pressure generated at setting the valve comes to the injector before the fuel feed is over. This excludes additional fuel injections even at high initial pressure in the force main in principle.

References

[1] Zayad, M. S., *Formirovaniye skorostnoy haraktyeristiki toplivopodachi v dizyelye pootyem oopravlyeniya nagnyetatyel'nim klapanom*: dis. … kand. tyehn. naook: 05.04.02: / M.S. Zayad. – Volgograd, 198 p. 2003.

[2] Salikin, Ye. A., *Ooloochshyeniye pokazatyelyey protsyessa toplivopodachi v dizyelye pootyem skorostnogo forsirovaniya nasosa visokogo davlyeniya:* dis. … kand. tyehn. naook: 05.04.02: zashshishshyena 25.04.03: ootv. 11.07.2003 / Ye.A. Salikin. – Volgograd, 264 s, 2003.

[3] Troosov, V. I., *Matyematichyeskaya modyel' i nyekotoriye ryezool'tati tyeoryetichyeskogo isslyedovaniya tyechyeniya topliva v zazorye myezhdoo konoosom nagnyetatyel'nogo klapana i yego syedlom*/V. I. Troosov, D. M. Smirnov//Rabochiye protsyessi i konstrooktsiya avtotraktornih dvigatyelyey vnootryennyego sgoraniya: sb. naooch. tr. MADI. – M., p. 24-35, 1984.