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DEVELOPMENT AND ANALYSIS OF THE LOADING CHARACTERISTIC OF ACCUMULATE FUEL INJECTION SYSTEM COMMON RAIL OF THE ENGINE 50RT-FLEX

The object of research are hydrodynamical processes in fuel delivery system of marine diesel engine of type RT-flex with accumulate fuel injection system of type Common Rail. The problem, being solved, is maintenance of an effective operation of the specified diesel engines due to perfection work of their fuel equipment.

The results of simulation modeling of the injection process by accumulator fuel delivery system Common Rail of the 50RT-flex engine are presented. On the basis of the functional diagram of system, a calculation model has been compiled that provides a description of the operation of the systems main blocks.

The load characteristic of the fuel equipment is built in the traditional version – the dependence of the fuel delivery parameters from the engine load at a constant speed. For the system under consideration, the control element is the valve assembly connecting the injection control unit (ICU) with injectors. The parameters of the load characteristic in this study are modes with a constant engine speed n=124 rpm and a change in the opening angle of the control valve in the range – φ_v*=6.6–14.4 °CA.*

The parameters of the devices that largely determine the characteristics of the fuel delivery and the quality of the working processes of a diesel engine are considered in more details. Such an element of the system is ICU, the working body of which is the dosing piston. The main parameters of its operation when delivering fuel are the magnitude and speed of the stroke. For the load characteristics in the accepted range of the valve control valve opening angle φ_v *from 6.6 to 14.4 °CA (2.18 times), the piston stroke was* h_p*=4.29–8.61 mm (2.0 more). In this case, the dependence of* h_p *on* φ_v *is linear.*

Area of use of the data received during research, ship crews and the shore services providing operation of vessels are. A material is applied in process of high school and is already used in various educational forms. The given researches are useful to developers and builders of marine diesel engines of a considered class.

Keywords: *common rail system, load characteristics, fuel delivery parameters, control unit, kinematics of elements.*

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1. Introduction

Common rail accumulator systems in recent times are widely used in marine low-speed diesel engines. The range of engines that can be equipped with accumulator systems is quite wide: from diesel engines for agricultural machinery to locomotive and ship installations [1, 2].

Modeling of accumulator fuel delivery systems is mainly devoted to the calculation of processes in electrohydraulic injectors, which are most common in CRS fuel equipment of diesel engines for various purposes [3].

In [4] modeling the hydrodynamics of processes in an electrohydraulic injector with electromagnetic control in the environment of the MATLAB/Simulink package is included. In the proposed mathematical model, the design of an electrohydraulic fuel injector with an electromagnetic valve is used, which provides pressure control in the needle cavity.

The principle of operation of injector is described in [5]. The calculation of fuel movement in the model is based on differential equations [6]. The boundary conditions for each of the sections and volumes are determined based on the corresponding equations of volume balances and acting forces, taking into account the compressibility of the fuel and elasticity of the moving elements.

As follows from the calculations, pressure fluctuations are observed in all sections of the injector fuel path. The largest amplitude is 50 MPa and refers to the needle locking cavity. The pressure at the nozzle inlet is more stable and deviates by 7 MPa by the end of injection.

Experiments on improving combustion using CRS and pilot injection were carried out on the CA6DE engine [7–11].

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The design parameters of the injector and the swirl coefficient of the combustion chamber have been improved and optimized. At the same time, the presence of an electronically controlled CR system and related sensors made it possible to monitor fuel consumption.

The results show, that higher injection pressure as well as lower swirl ratio, correct combustion chamber shape and delayed injection time can improve mixture formation, combustion of the air-fuel mixture, reduce harmful emissions and improve the overall performance. In particular, thanks to the capabilities of the CRS, it is possible to control the injection process.

Comparative studies of the fuel delivery processes by an accumulator system and a direct-acting system for a high-speed diesel engine [12] made it possible to construct a field of parameters for modes of the combined engine characteristic.

It has been established that the maximum pressure in the direct-acting system reaches 1500 bar, which is 200 bar higher than in the accumulator version. This factor relates to the advantages of the direct action system. However, in the long run, an accumulator injection system is preferable, since the fuel pressure is close to a constant value during the entire injection time.

Noteworthy is the suggestion of the authors of [13] to use a set of indicators in the form of a sum of relative values parameters as an objective function when optimizing fuel delivery in diesel engines. These include: specific fuel consumption, the content of nitrogen oxides, the amount of solid particles in the exhaust gas, the noise level.

Thus, *the aim of research* is to develop system parameters that sufficiently reflect the quality of processes in fuel equipment and their impact on the performance of diesel engines. As a result of simulation modeling, it was supposed to obtain the values of the accepted parameters and make recommendations on the use of fuel injection systems of the type under consideration when diesel engines are operating in load characteristic modes.

2. Materials and Methods

The object of study is hydrodynamic processes in the elements of Common Rail fuel injection systems of RT-flex type low-speed marine diesel engines, which are widely used on marine ships. The features of the fuel equipment of this type are, along with the accumulator, the presence of a separate metering device – an injection control unit (ICU).

Values used in the study:

ICU – injection control unit (ICU);
QP – dosing piston ICU (QP – Quantity Piston);
CR (CRS) – common rail system;
°CA – degrees of crankshaft rotation;
WC – working cavity ICU;
BC – buffer cavity ICU;
$\varphi_{p.a}$ – general angle of movement of QP;
φ_p – QP feed angle;
φ_v – control valve opening angle;
φ_{cs} – angle of crankshaft rotation;
φ_{inj} – injection angle;
z_n – stroke of the nozzle needle;
x_p – QP coordinate;
h_p – motion of QP;
$\varphi_{p.\max}$ – angle of QP maximum motion;
φ_p – QP feed angle;
v_p – QP speed;
$p_{w.c}$ – pressure in the ICU working cavity;
$p_{b.c}$ – pressure in the buffer cavity of ICU;
g_f – injection intensity;
q_c – cyclic feed;
$\varphi_{i.a}$ – total injection angle.

3. Results and Discussion

One of the basic indicators of the diesel fuel injection system is the load characteristic. Traditionally, it is provided as a dependence of the fuel delivery parameters on the position of the injection pump control at a constant camshaft speed. For direct-acting systems, such elements are the rack of injection pump bushing and the mechanism for turning the valves eccentrics of the injection pump in valve type. In the expected common rail fuel injection system (Fig. 1) of the RT-flex engine, the duration in cylinder injection is set by the opening time of the control valves – Injection control valves.

The simulation was performed in the GT-Power environment.

A simulation study with the aim of constructing load characteristics of fuel injection system was carried out for modes with a constant engine speed $n=124$ rpm and changes in the opening angle of control valve in the range $\varphi_v=6.6–14.4$ °CA.

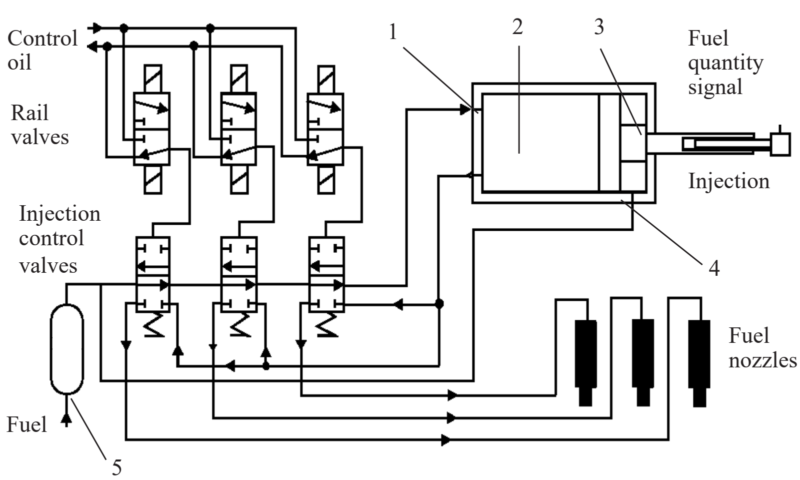

Fig. 1. Accumulator fuel injection system CRS of RT-flex engines:
1 – injection control unit – ICU; 2 – working cavity of ICU; 3 – buffer cavity of ICU; 4 – quantity piston; 5 – fuel rail accumulator

The fuel injection process starts from the moment the control valve opens. In this case, the metering piston moves, delivering fuel to injector. The combined oscillograms of piston stroke are shown in Fig. 2.

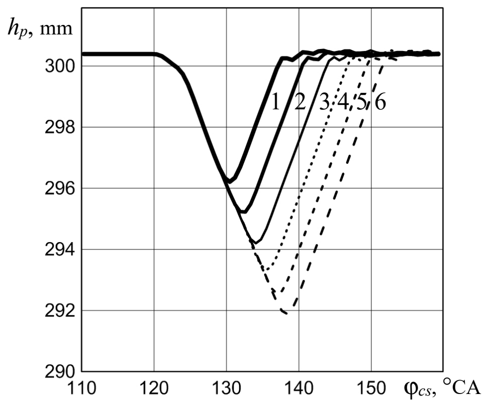

Fig. 2. Dependence of the stroke metering piston on the angle of rotation the crankshaft: 1 – φ_v=6.6 °CA; 2 – φ_v=8.4 °CA; 3 – φ_v=10.2 °CA; 4 – φ_v=12 °CA; 5 – φ_v=13.2 °CA; 6 – φ_v=14.4 °CA

Numerical parameters are given in Table 1.

A graphical representation of the dependence piston stroke on the load characteristic mode is given in the corresponding insert h_p (Fig. 3).

Additional information about the movement of the piston is its position along the x_p coordinate, referred to the initial state x_p=300 mm.

When analyzing the motion of the metering piston, attention is drawn to the linear nature of its movement hp and the same type of oscillograms (Fig. 2, 3). The numerical values of the process parameters are presented accordingly.

So, with an increase in the duration of the opening of the control valve φ_v from 6.6 to 14.4 °CA (2.18 times), the piston stroke was h_p=4.29–8.61 mm (2.0 more).

Essential for the fuel delivery process are the phase parameters of the individual components. This also applies to the movement of the QP. Starting from the initial position is observed at the same angle of rotation of the crankshaft, equal to 120 °CA in all modes. In the cycle of operations performed by the QP, its working stroke ends at the angle $\varphi_{p.\max}$=130.45–138.8 °CA, and the entire cycle with reverse movement is $\varphi_{p.a}$=23.42–37.84 °CA.

It is possible to pay attention to the nature of the dependence $\varphi_p=f(\varphi_v)$ – a straight line representing a linear relationship.

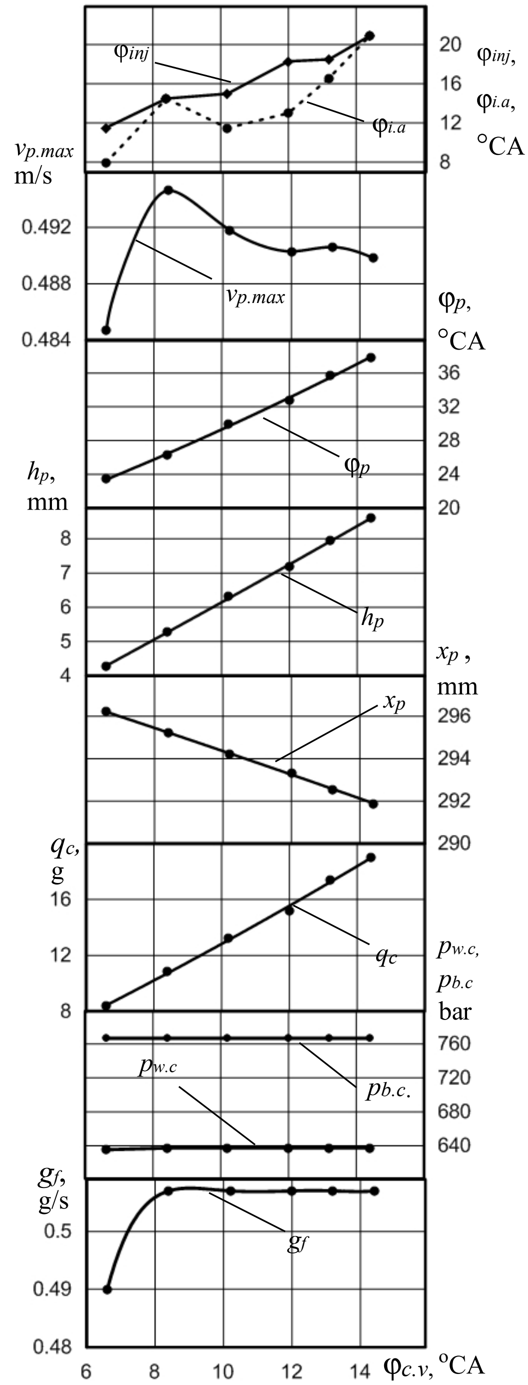

Fig. 3. Load characteristics of the 50RT-flex common rail fuel supply system

Table 1

Parameters of the fuel injection system load characteristic

No. regime	φ_v, °CA	h_p, mm	x_P, mm	$\varphi_{p.a}$, °CA	φ_p, °CA	$v_{p.\max}$, m/s	g_f, kg/s	$p_{b.c}$, bar	$p_{w.c}$, bar	q_c, g
1	6.6	4.29	296.21	23.42	9.73	0.4847	0.49	766.7	634.5	8.375
2	8.4	5.27	295.22	26.31	11.4	0.4946	0.507	766.7	636.5	10.82
3	10.2	6.31	294.2	29.91	13.26	0.4918	0.507	766.7	636.5	13.27
4	12	7.18	293.33	32.79	14.66	0.4903	0.507	766.7	636.5	15.17
5	13.2	7.94	292.55	35.68	16.52	0.4906	0.507	766.7	636.5	17.37
6	14.4	8.61	291.89	37.84	18.03	0.4898	0.507	766.7	636.5	18.99

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Along with the parameters of the QP motion, shown in the oscillogram in Fig. 2, its velocity v_p is of significant interest. The change v_p in the working cycle of the QP is shown in the graph of Fig. 4, and the maximum values for the extreme modes of the load characteristic are included in Table 1. Their maximum values are used as the main speed parameters. For all six modes, this indicator does not go beyond $v_{p.\max}=0.4847–0.4946$ m/s. The shape of the v_p curves (Fig. 4) is quite complex. The initial section corresponds to a set of speed and passes into a period of little changing value. This is followed by a sharp rise in the graph with a change in the direction of movement of the QP and again a segment of the constant v_p. The final phase contains an active decrease in speed, and the cycle ends with a long section of damped oscillations.

Returning to the QP motion oscillograms (Fig. 2), it can be noted that with a graphic representation of the QP movement, the velocity pulsations have practically no effect on the shape of the h_p curves.

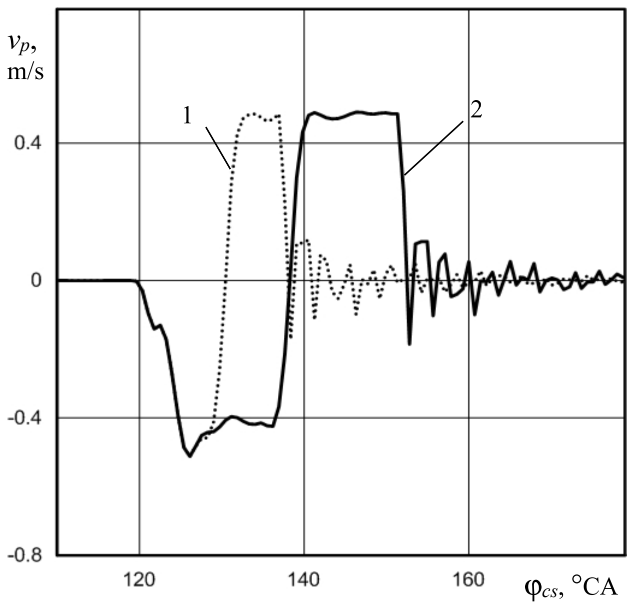

Fig. 4. Graphs of DP speeds for extreme values φ_v:
1 – 6.6 °CA; 2 – 14.4 °CA

The final result of the injection system operation is the delivery of fuel to the engine cylinder during open of nozzle. This information is contained in the oscillograms Fig. 5. For the two extreme modes of the load characteristic with the opening angles of the control valve $\varphi_v=14.4$ °CA and $\varphi_v=6.6$ °CA – the following are shown: z_n – stroke of the needle nozzle and $p_{w.c}$ – fuel pressure in the working cavity of the ICU.

A fundamentally important fact, judging by the oscillograms, is the method of regulating the fuel delivery in Common Rail accumulator systems. Graphs of the needle lift z_n and show almost the same injection start angle $\varphi_b=122.5$ °CA for extreme modes of the load characteristic.

Thus, the principle of regulation is established – at the end of delivery.

Curves z_n are very informative for estimating the delivery law. A feature of process in this regard is a relatively small delay in the landing of the needle in the nominal mode and a clear subinjection at low loads (Fig. 6).

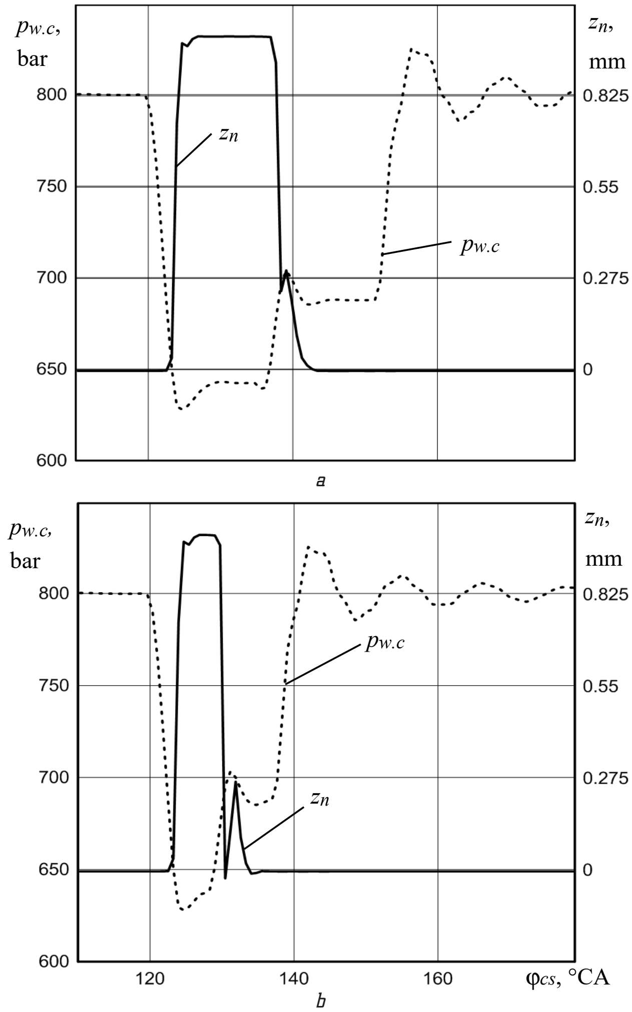

Fig. 5. Oscillograms of injector operation at:
a – $\varphi_v=14.4$ °CA; *b* – $\varphi_v=6.6$ °CA; z_n – stroke of the nozzle needle;
$p_{w.c}$ – pressure in the working cavity of the ICU

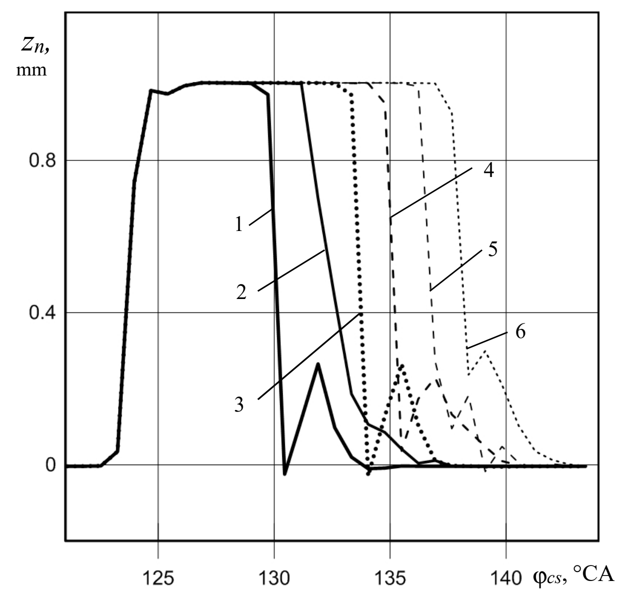

Fig. 6. Movement of the nozzle needle at different angles of opening the control valve: 1 – $\varphi_v=6.6$ °CA; 2 – $\varphi_v=8.4$ °CA; 3 – $\varphi_v=10.2$ °CA; 4 – $\varphi_v=12$ °CA; 5 – $\varphi_v=13.2$ °CA; 6 – $\varphi_v=14.4$ °CA

Equally important information is provided by the fuel pressure curves.

At the moment the needle is lifted, there is a quite expected drop in pressure $p_{w.c}$: from the initial value of 800 bar to the level of 636 bar. The latter is maintained throughout the entire fuel injection.

There is a common thing in the final phase of injection – pressure fluctuations during needle landing. The difference relates to the timing of needle seating. The delay in pressure growth at the level of 700 bar for the mode φ_v=14.4 °CA leads to a short-term stop of the needle landing. There is even a slight upward shift. In another case (Fig. 5, *b*, φ_v=6.6 °CA) a similar change in $p_{w.c}$ causes postinjection.

Area of use of the data received during research, ship crews and the shore services providing operation of vessels are. A material is applied in process of high school and is already used in various educational forms. The given researches are useful to developers and builders of marine diesel engines of a considered class.

The main limitation for using the results of the study is the type of engine control system (the material of article refers to systems of WECS type). The transition to other options of control systems will require clarification of the quantitative dependencies presented in the work.

Conditions of the martial law on carrying out of researches the influence have not rendered. Work is executed before introduction in Ukraine of the martial law.

The further researches proceed in a direction of development speed characteristics of the class of considered in article fuel delivery systems of marine low speed diesel engines.

4. Conclusions

1. A simulation study of the fuel delivery processes by the Common Rail accumulator system, which is widely used on low-speed marine engines of the RT-flex type, has been carried out.

2. The load characteristic is built in the form of dependence the parameters fuel delivery from duration of the opening the control valve.

3. An analysis of the operation the quantity piston of injection control unit, which sets the processes in the remaining elements of the system, is presented.

4. The linear nature of the dependence the stroke of QP from duration of opening the control valve has been established. An increase in φ_v by 2.18 times leads to a doubling of h_p.

5. The method of regulating the cyclic feed by the Common Rail system has been established. This system uses end-of-feed control. The potential for optimizing the fuel delivery phases in the system has not been realized.

6. The features of the injection process associated with the stroke of the nozzle needle are revealed. The pressure fluctuation in the final phase of injection leads in some modes to post-injection, in others to stepwise movement during landing.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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