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ANALYSIS OF REALIZATION OF STEPPED FUEL INJECTION WITHOUT CHANGING DESIGN OF COMMON RAIL INJECTOR

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RESEARCH ARTICLE

ABSTRACT: A calculated-experimental analysis of realization of stepped front edge of injection rate (stepped injection) was carried out. Common rail injectors (CRI) of three most widely used designs took part in the research: CRI No 1 distinguished by its control valve with a locking cone and piston; CRI No 2 with a control valve unloaded from fuel pressure, channel on the piston and enlarged internal volume; CRI No 3 with a control valve having a flat lock and a needle which is not closing the drain channel when staying in the upper position. It is demonstrated that friction in the couple – control valve piston/guiding surface of the CRI No 1 hampers realization of stepped front edge of injection rate due to its smoothening. When using the CRI No 2, it is possible to obtain stepped injection only at low fuel pressure in common rail (pcr ≤ 50 MPa). The CRI No 3 ensure the stepped injection at different pressures up to pcr=200 MPa.

KEY WORDS: common rail injector, common rail fuel system, stepped fuel injection, electric impulse, control valve

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ANALIZA REALIZACIJE STUPNJEVITOG UBRIZGAVANJA GORIVA BEZ PROMENE OBLIKA COMMON RAIL BRIZGAČA

REZIME: Proračunsko eksperimentalna analiza stupnjevite promene brzine ubrizgavanja (stupnjevito ubrizgavanje) je realizovana. Common rail brizgaljke tri najrasprostranjenija oblika su korišćene u ovom istraživanju: CRI No 1 je sa upravljivim ventilom sa konusom i klipom za zaključavanje; CRI No 2 sa upravljivim ventilom neopterećenim pritiskom goriva, kanalom na klipu i povećanom unutrašnjom zapreminom; CRI No 3 sa upravljivim ventilom koji ima ravnu blokiranje i iglu koja ne zatvara odvodni kanal kada nađe u gornjem položaju. Pokazano je da trenje u sprezi - upravljački ventil klip/vođena površina brizgaljke CRI No1 otežava finu realizaciju stupnjevite promene brzine ubrizgavanja. Kada se koristi brizgaljka CRI No 2, moguće je dobiti stupnjevito ubrizgavanje samo pri niskom pritisku goriva u zajedničkoj šini (Common rail) (pcr ≤ 50 MPa). Brizgaljka CRI No3 obezbeđuje stupnjevito ubrizgavanje pri različitim pritiscima do pcr = 200 MPa

KLJUČNE REČI: Common rail brizgač, Sistem za snabdevanje gorivom sa zajedničkom šinom (Common rail), stupnjevito ubrizgavanje goriva, električni impuls, upravljački ventil

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1. INTRODUCTION

Advantages of Common rail (CR) type fuel systems with Common rail injectors (CRI) and electronic control are explained by realization of the principle of sharing two functions: obtaining high fuel pressure and fuel injection process organization. CR fuel systems also enables to carry out multiple injection, flexible control of injection advance angle, injection pressure and amount of injections per cycle. Using CR fuel systems simplifies the tasks of cylinders and cycles shutdown, exhaust gases neutralization system control, as well as sensors and actuators diagnostics.

The further strengthening of ecological rules and standards specifying content of toxic substances in exhaust gases of diesel engines [13-15] accompanied by the requirement for improvement of their fuel efficiency predetermine perfection of CR fuel systems.

Fields of these improvements: raising injection pressure up to 300 MPa [7, 8]; Ensuring the required shape of the injection rate front edge [10, 11] taking into account wave propagation effects originating during fuel injection [12]; control of fuel distribution by the combustion chamber [9].

A boot-shaped front edge of the injection rate enables to decrease the pressure rise rate and maximal pressure in the cylinder at many operating modes which makes it possible to decrease tailpipe toxic emissions and noise level.

2. RESEARCH OBJECTS

The research objects were three modern Common Rail injectors (CRIs) having different designs which are distinguished by the following specific features.

Specific design feature of the CRI No 1 shown in Figure 1 – design of its control valve 2 including its locking cone 13 having internal diameter 2 mm and valve piston 12 having diameter 12 mm [3]. This CRI design is used by the Delphi company and the Altai Factory of Precision Articles (AZPI).

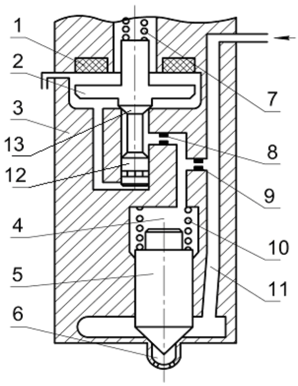

Figure 1. A construction diagram of the CRI No 1 distinguished by its control valve with a locking cone and valve piston:

1 – electromagnet; 2 – control valve; 3 – body; 4 – control chamber; 5 – nozzle needle valve; 6 – sack volume; 7 – valve spring; 8 – outlet fuel jet; 9 – inlet fuel jet; 10 – needle valve spring; 11 – internal volume; 12 – control valve piston; 13 – control valve locking cone

The basic specific feature of the design of the CRI No 2 (Figure 2) – fuel pressure balanced control valve 2 (in its closed position). In addition, the CRI No 2 is distinguished by the presence of the channel 14 in the piston 5 and increased internal volume 6 [2, 6]. This construction diagram corresponds to the model CRI 2.6 of the Bosch company.

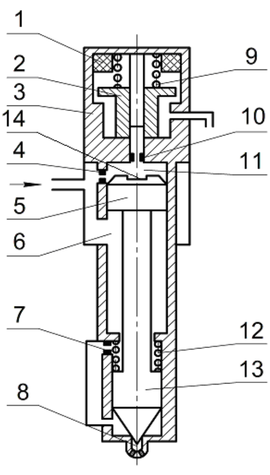

Figure 2. A construction diagram of the CRI No 2 with fuel pressure balanced control valve, valve channel and increased internal volume:

1 – electromagnet; 2 – control valve; 3 – body; 4 – inlet fuel jet; 5 – multiplier piston; 6 – internal volume; 7 – nozzle fuel jet; 8 – suck volume; 9 – valve spring; 10 – outlet fuel jet; 11 – control chamber; 12 – needle valve spring; 13 – needle valve; 14 – multiplier piston

channel

Figure 3 shows the construction diagram of the CRI No 3 which is distinguished by the design of its control valve 3 with a flat latch and also by the fact that the end surface of the needle valve 8 does not cover the fuel drain hole when the needle valve is in the upper point (in contrast, for example, to the diagram of the CRI No 4 that will be mentioned below) [1].

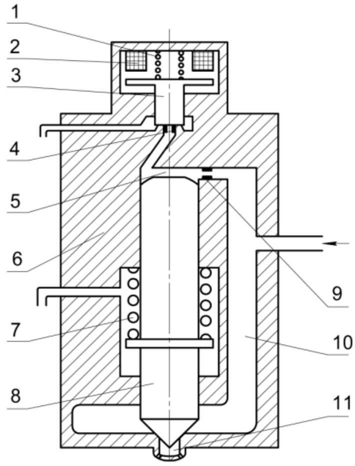

Figure 3. A construction diagram of the CRI No 3 which is distinguished by the control valve with a flat latch and a needle valve which does not cover the fuel drain hole when it is in the upper position:

1 – control valve spring; 2 – electromagnet; 3 – control valve; 4 – outlet fuel jet; 5 – control chamber; 6 – CRI body; 7 – needle valve spring; 8 – nozzle needle valve; 9 – inlet fuel jet; 10 – CRI internal volume; 11 – sack volume

The construction diagram of the CRI No 3 was realized in the injector PLTD.387442.20.00 of the MADI Problem Laboratory of Transport Engines (PLTD) jointly with the Noginsk Fuel Equipment Factory (NZTA).

3. SIMULATION RESULTS

Mathematical models of the Common Rail fuel systems with CRIs of the designs presented above were published in a number of papers [1, 3-5].

Calculated analysis of the CRI No 1 (Figure 1) was carried out using the dependence of the electromagnet force F_{em} versus time τ, as shown in Table 1. Parameters of the CRIs manufactured by the NZTA were used as input data.

Table 1. **Durations of control impulses and intervals between them depending on time for the CRI No 1**

Parameter	Value							
τ (ms)	0	0.10	0.20	0.30	0.38	0.48	0.90	0.95
F_{em} (N)	0	200	200	0	0	200	200	0

Figure 5 and Figure 6 show the results of calculation at pressure in the common rail p_{cr} = 100 MPa and fuel injected mass Q_c = 258,2 mg, where q_{cv} – control fuel flow through the valve; q_{ir} – injection rate; h_{cv} – control valve displacement; h_{nv} – needle valve displacement; k_{fr} – friction coefficient.

Calculation results presented in Figure 5 were obtained in case when there was no friction (k_{fr}=0 Ns/m) in the joints of the CRI. A similar result was obtained at p_{cr}=160 MPa, at that, the same dependence F_{em}=f(τ) was used (see Table 1).

For calculation of the influence of friction forces F_{fr} during the control valve piston movement, data indicated in paper [16] obtained for the nozzle needle valve was used. The calculation results demonstrated that the boot-shaped front edge of the injection rate was smoothed completely at k_{fr}=60 Ns/m (p_{cr}=100 MPa) and at k_{fr}=50 Ns/m (p_{cr}=160 MPa). Figure 6 shows the results of calculation at the same mode that in Figure 5, but with k_{fr}=60 Ns/m ($F_{fr\ max}$=84 N).

Calculated analysis of the CRI No 2 (Figure 2) was carried out using parameters corresponding to the CRI 2.6 model of the Bosch company for estimation of the opportunity of realization of the boot-shaped fuel injection rate. It was shown that at p_{cr} = 100 MPa, this may be realized only using the impulses differing by 1 ms (Table 2) which was out of the limit of accuracy of modern Common Rail systems control. At the present operation mode of the CRI No 2, the fuel injected mass Q_c was 43.86 mg, and control fuel consumption Q_{con} = 37.28 mg.

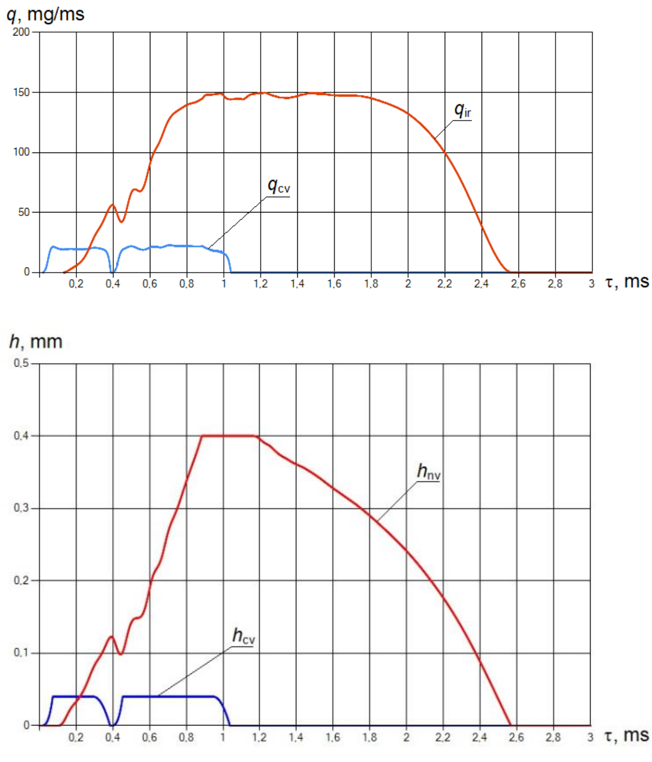

Figure 5. Calculation results of fuel injection process parameters of the CRI No 1 using input data of the injector produced by the NZTA at p_{cr} = 100 MPa, Q_c = 258,2 mg, k_{fr}=0

Ns/m

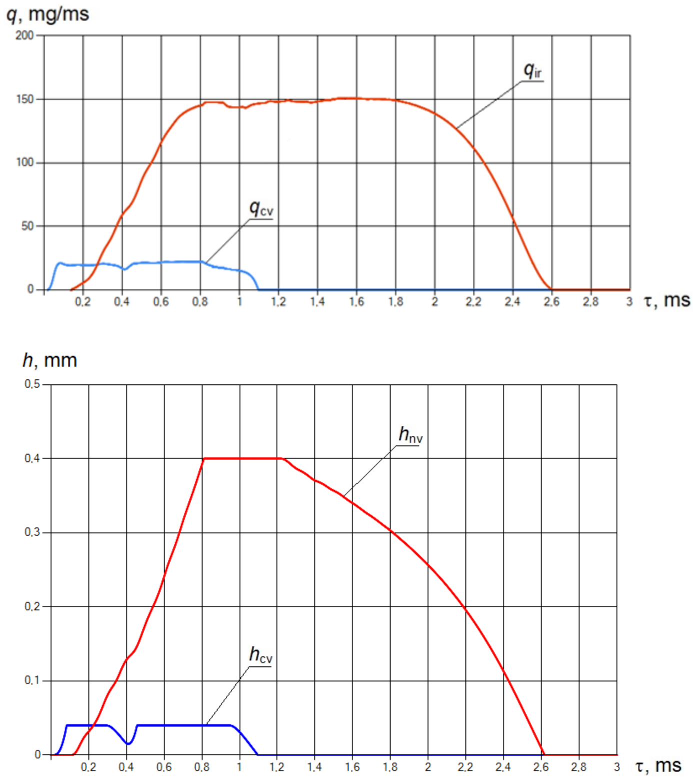

Figure 6. Calculation results of fuel injection process parameters of the CRI No 1 using input data of the injector produced by the NZTA at p_{cr} = 100 MPa, Q_c = 273,8 mg, k_{fr}=60 Ns/m

Table 2. Durations of control impulses and intervals between them depending on time for the CRI No 2 at pcr = 100 MPa

Parameter	Value							
τ (ms)	0	0.006	0.007	0.008	0.19	0.20	2.0	2.1
F_{em} (N)	0	200	200	0	0	200	200	0

To get the boot-shape injection rate at p_{cr} = 200 MPa, one had to increase the tightening force of the valve spring from 47 to 94 N. At these conditions, for organization of the boot-shaped injection, impulses differing by 0.01 ms were required.

Table 3 presents the dependence of the electromagnet force F_{em} on time τ at p_{cr} = 50 MPa. At this operating mode of the CRI No 2, the calculated fuel injection mass Q_c was 31.1 mg, and control fuel consumption Q_{con} = 26.54 mg.

Table 3. Durations of control impulses and intervals between them depending on time for the CRI No 2 at pcr = 50 MPa

Parameter	Value							
τ (ms)	0	0.005	0.015	0.020	0.19	0.20	2.0	2.1
F_{em} (N)	0	200	200	0	0	200	200	0

The results presented in Tables 2 и 3 show that it is possible to obtain the boot-shaped injection rate at a modern accuracy of the control system signals (± 1 ms) only at $p_{cr} \leq 50$ MPa due to particular design of the control valve of the CRI No 2 (Figure 2). One should also mention that the boot-shaped injection is used as a rule at close to maximal loads [8] when a high fuel injection pressure is required.

For design of the CRI No 3 (Figure 3), a calculated analysis of the opportunity of getting a boot-shaped injection rate in case of supply of one (Table 4) and two (Table 5) primary impulses was carried out. Parameters of the CRI PLTD.387442.20.00. were used as input data.

Table 4. Durations of control impulses and intervals between them depending on time for the CRI No 3 at pcr = 200 MPa (one primary impulse)

Parameter	Value							
τ (ms)	0	0.1	0.12	0.14	0.35	0.37	2.0	2.1
F_{em} (N)	0	200	200	0	0	200	200	0

Table 5. Durations of control impulses and intervals between them depending on time for the CRI No 3 at p_{cr} = 200 MPa (two primary impulses)

Parameter	Value											
τ (ms)	0	0.1	0.2	0.25	0.38	0.43	0.435	0.445	0.63	0.68	2	2.1
F_{em} (N)	0	200	200	0	0	200	200	0	0	200	200	0

Figure 7 and Figure 8 show the results of the CRI No 3 injection process calculation when one and two primary impulses were supplied correspondingly.

In this way, the calculations proved the opportunity of realization of the boot-shaped fuel injection rate using the CRI No 3 both by forming one primary impulse (Figure 7), as well as two primary impulses (Figure 8).

4. CONCLUSIONS

1. The authors carried out a calculated-experimental analysis of the opportunity of organization of boot-shaped injection using Common Rail injectors (CRI) of three main designs that are used: CRI No 1 (Delphy and AZPI design) distinguished by their control valve with a locking cone and valve piston; CRI No 2 (Bosch design, CRI 2.6 model) with fuel pressure balanced control valve, channel in the piston and

increased internal volume; CRI No 3 (MADI-NZTA design, PLTD.387442.20.00 model) distinguished by its control valve with a flat latch and needle valve not closing the drain hole when staying in the upper position.

2. The boot-shape front edge of the CRI No 1 may be partially smoothed when attaining the friction coefficient more than 60 Ns/m in the joint: control valve piston – CRI body.
3. Authors demonstrated that it was possible to obtain the boot-shaped injection rate of the CRI No 2 only at low pressures in the common rail ($p_{cr} \leq 50$ MPa), which may be explained by specific features of the design of its control valve.
4. The CRI No 3 ensure the opportunity of getting boot-shaped injection of fuel at various pressures in the common rail.

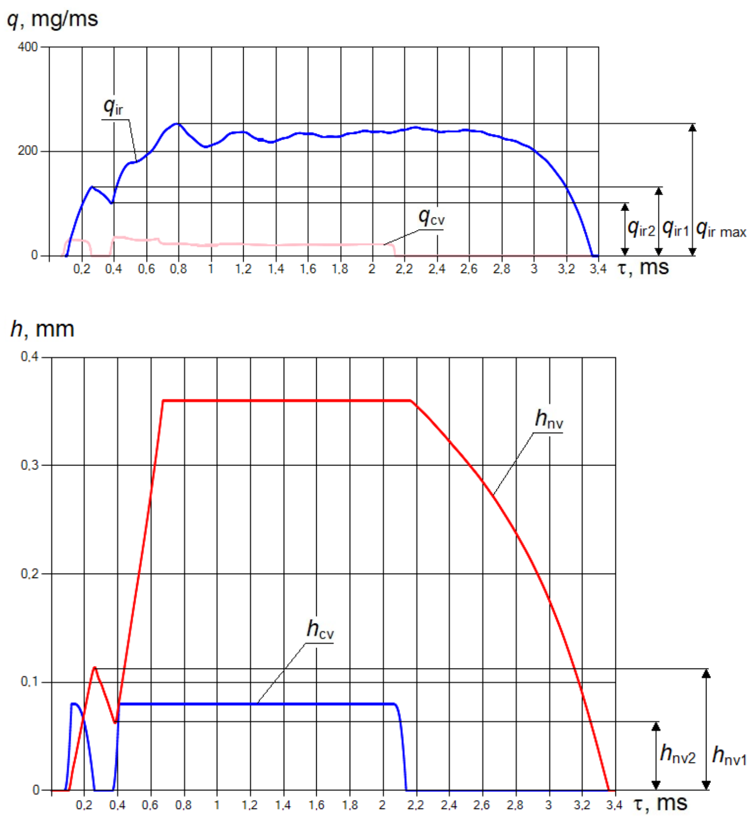

Figure 7. Calculation results of fuel injection process parameters of the CRI No 3 using input data of the injector PLTD.387442.20.00 at p_{cr} = 200 MPa, Q_c = 662,5 mg

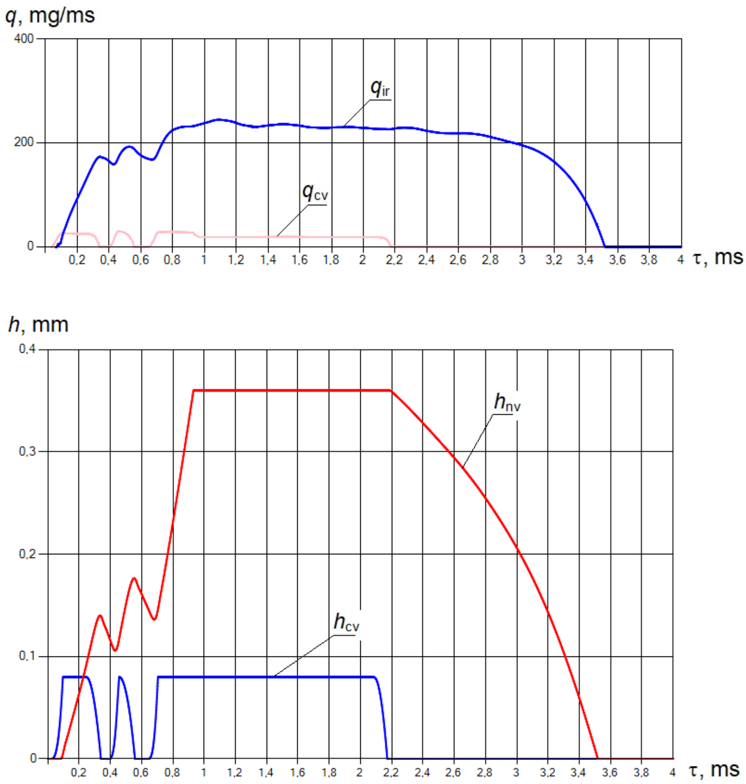

Figure 8. Calculation results of fuel injection process parameters of the CRI No 3 with two primary impulses using input data of the injector PLTD.387442.20.00 at p_{cr} = 200 MPa, Q_c = 675,24 mg

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