SIMULATION OF INJECTION PROCESS
IN PROTOTYPE DISTRIBUTOR
INJECTION PUMP OF PR4 TYPE

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Summary. The article presents numerical simulation results of injection process in prototype injection pump of PR4 type. It is distributor pump destined for high speed compression-ignition engines with capacity of cylinder up to 1.3 [dm³]. New injection pump has made in cooperation of Fuel Injection Equipment "PZL-MIELEC" Ltd and Faculty of Automotive Vehicles and Internal Combustion Engines in Rzeszow University of Technology. The worked out construction of distributor pump of PR4 type is Polish counterpart of technically advanced pumps VE of Bosch firm and DP200 of Lucas firm. It is provided that its commercial price will not exceed 50% of quoted foreign pumps price, at simultaneously remained functional values and durability and reliability levels. Besides, in consequence of application of series innovatory solutions assuring injection pressures order of 90 [MPa], one could be influence more effectively on the level of toxic components in exhaust gas. The results of injection process simulation contain the main quantities describing course of hydrodynamic phenomena in pump, in particular: expression pressure in piston-distributor cell, pressures at the beginning and the end of pipe, needle lifts of sprayer, instantaneous fuel doses injected to the cylinder etc. These quantities are calculated in function of pump rotary speed and working stroke of the piston.

1. Introduction

Present automotive vehicles, which possess multi-cylinder compression-ignition engines, in majority have multi-section or distributor pumps. In the lorries and buses most often uses direct injection and multi-section pumps. Rotational speeds of these engines don’t exceed 3000 [r.p.m.] and injection systems with multi-section pumps sufficiently realized functions respecting to uniformity of dose. American factories (a.o. Cummins, Detroit Diesel) for this group of engines preferably used systems with injection units, which are characterized with definite exploitation advantages.

In the compression-ignition engines of the passenger cars and delivery trucks dominates distributor pumps and direct injection to turbulence chamber type Ricardo-Comet. Desirable dosage uniformity of engine rotational speeds of 5000-6000 [r.p.m.] isn’t ensuring by multi-section pumps. Besides direct injection assure more profitable run of the combustion process by creation conditions to rise qualitatively better mixtures in short time.

Last years of development high-speed compression-ignition engines created constructions with direct injection to combustion chamber and high-pressure systems type Common Rail. Participation in market of sale these engines are significant not yet, but considering on expectation benefits, it will be distinct increase in nearest years. This is characteristic in countries of European Union and USA where participation of passenger cars with compression-ignition engines increases in markets about 15% all new cars disposed. Assess of this participation in markets with this group of cars will still increase to about 22% in 2005 year [1, 2, 7].

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Proper operating of the injection apparatus principally influence on effectively of work parameters and toxicity of exhaust gases in compression-ignition engine. Here decides preparation quality of air-fuel mixture and run of combustion process. Both, quality of mixture and combustion process are immediately depend from kind of injection system and its technical parameters.

Injection systems with the distributor pumps are characterized with many advantages in relation to multi-section systems. Doubtless basics are possibilities of use to high-speed engines and assure of dose proper stability, what we can’t obtain in line pumps. The one pressure section measures doses of fuel and passes them to distributor, which is periodically united with suitable flow pipes and injectors. This manner of selection quantity of fuel, in dependence from temporary work conditions of engine, gives possibility of periodicity dose both in succeeding cylinders, as well as in following cycles of expression to these cylinders.

Foundation of project realizers is elaboration and initiate to production of distributor pump to compression-ignition engines with cylinder capacities to 1,3 [dm³]. Computational results of computer simulation confirm that pump PR4 will realise these expectations. In first foresees application of pump to home-grown engines 4C90 and 4CT90 and to engines of delivery trucks type Ford Transit and VW Transporter. In home-grown produced engines is in-line pump type PP4M of MOTORPAL firm, while this delivery trucks engines have pump VE of Bosch firm. In second stage plans elaboration on the base of pump PR4 modified construction of distributor pump, which will replace existing in-line pumps in middle-speed direct injection compression-ignition engines. There are already initial conception and computational works at this version of pump in use to engine 4CT107 type.

Passed analysis of market in Poland provide that one year application for distributor pumps to engines with cylinder capacity to 1,3 [dm³] carries according to transportation analysts about 6-8 thousand units by year. This refers mostly so-called secondary market, because at present in our country exploits (outside agriculture) about 500 thousand vehicles with compression-ignition engines equipped in distributor pumps. Lack of competition on Polish market causes, that injection pumps offered by Bosch and Lucas firms are very expensive. As foresees, commercial price of the distributor pumps produced in WAW "PZL-MIELEC" will not exceed 50% price of foreign pumps, at maintenance of functional values and comparable levels of durability and reliability. Topicality realized of project in replaced facts is so indisputable, all the more, that construction of PR4 pump is first Polish elaboration of distributor pump.

2. Short description of construction and operation of prototype injection pump

Distributor injection pump PR4 is construction about the piston-distribution system and is equipped in mechanical centrifugal governor. In one-piece frame are following main functional units (Fig. 1):
- propeller shaft of cam disk and speed governor 2,
- cam disk 3,
- piston-distributor 6,
- batcher 15,
- sliding-vane force pump 12,
- gear transmission of speed governor 10,
- roll ring 4,
- centrifugal speed governor 7,
- hydraulic timing unit 11.
Fig. 1. Distributor injection pump PR4 type: 1 – pump frame, 2 – driving shaft, 3 – cam disc, 4 – roll ring, 5 – distributor cap, 6 – piston-distributor, 7 – mechanical governor, 8 – governor head, 9 – governor cover, 10 – gear transmission of speed governor, 11 – timing unit, 12 – sliding-vane force pump, 13 – regulating valve, 14 – solenoid valve, 15 – batcher, 16 – connector pipe

Fuel received from the fuel tank by external feeding pump flows through fine filter to sliding-vane force pump 12. Regulating valve 13 assures constant value of pressure fuel 0.3–0.4 [Pa]. With channels inside of casing pump and distributor cap 5 fuel is brought to force chamber over piston-distributor. Volume of force chamber is appointed with position piston-distributor 6 and batcher 15.

Piston-distributor is started by propeller shaft of pump 2. Across cam disk (stroke) 3 and rollers placed in roll ring 4, piston-distributor obtains, besides rotary motion, also to-and-fro motion. In upper parts the piston-distributor works as high-pressure section in consequence of also to-and-fro motion, instead in lower part determines controller with filling fuels device. Filling begins with moment start so-called jump of power supply (isn’t here initial jump, as in multi-section pumps), instead finishes together with exposure of overflow holes by steering edge of batcher. Position of batcher qualifies therefore quantity of fuel dose. Result of rotary motion of piston-distributor is doses distribution across distributive groove in
piston on each outlet and by connector pipes bringing fuel to high-pressure pipes. Piston-distributor executes during one turn so much of jumps (strokes of pressing), how much is connector pipes 16.

Mechanical regulator 7 steers with move of the batcher by lever transferring motion of muff, which is forced with power of governor weights 8. Rotational speed of engine is transferred by toothed gear 10 from propeller shaft of pump on governor weights, which deflect in consequence of centrifugal forces. Greater rotational speed evokes greater deviation of governor weights and in consequence longer move of muff regulator. If engine doesn’t work, starter spring holds starter lever in such position, that with starting moment is automatically given full dose.

Timing unit 11 is controlled in dependence from pressing pressures of sliding-vane force pump. Fuel pressure influences on piston of timing unit, which conquering tension of spring turns roll ring. In this way are changes angle of injection advance. Displacement angle, which assures timing unit of PR4 pump is to 12° turn of driving shaft.

Represented description of construction and activity of new distributor pump doesn’t scoop certainly all aspects of its working. With moment obtained of construction will presented details of steering with dose of fuel, speed governor work, steering with beginning and finish of injection, activities of dose corrector and smoke limiter, cooperation of pump with EGR system of engine etc.

3. Preliminary results of simulation for select pump parameters

Computational experiment of the distributor pump PR4 was passed basing oneself on the computer programs with enable analysis of injection process. Automobiles and Internal Combustion Engines Department PR2 possesses elaborated and verified programs to numerical simulation of hydrodynamic occurrences in different injections installation systems [3, 4, 5]. On stage of new construction creation of pump or its modification, as also designs of other fuel apparatus part, computational models permit on generating data about reaction of the system in definite structure of experiment. This manner we get information to prognosis maintenance of injection pump for different work conditions.

Computer simulation has been executed by used computational program worked basing oneself on modified model introduced e.g. in works [3,4]. Range of calculations included identification all of possible parameters of injection process for different configuration of geometrical values of basic composition elements, as also of variable conditions of load and rotational speed [6]. In this article are presented preliminary results of simulation for select pump parameters in function of rotational speed n and jump working plunger h. Represented following parameters of injection process:

- distribution of maximum pressure in expression chamber of piston-distributor \( p_{\text{max}} \) (Fig. 2),
- distribution of maximum pressure at the beginning of injection pipe \( p_{\text{1}}^{\text{max}} \) (Fig. 3),
- distribution of maximum pressure in pipe before injector \( p_{\text{2}}^{\text{max}} \) (Fig. 4),
- distribution of average speed for growth of pressure in expression chamber of piston-distributor \( V_{\text{spf}} \) (Fig. 5),
- distribution of expression period of fuel by piston-distributor \( t_{\text{pt}} \) (Fig. 6),
- distribution of opening period of sprayer needle \( t_{\text{b}} \) (Fig. 7),
- distribution of flowing out dose from sprayer \( Q_{\text{h}} \) (Fig. 8),
- distribution of average speed of fuel outflow from sprayer \( C_{\text{sr}} \) (Fig. 9).
Fig. 2. Distribution of maximum pressure in expression chamber of piston-distributor $p_{\text{max}}$.

Fig. 3. Distribution of maximum pressure at the beginning of injection pipe $p_{1\text{max}}$. 
Fig. 4. Distribution of maximum pressure in pipe before injector $p_{2\text{max}}$

Fig. 5. Distribution of average speed for growth of pressure in expression chamber of piston-distributor $V_{krPt}$
Fig. 6. Distribution of expression period of fuel by piston-distributor $t_{pl}$

Fig. 7. Distribution of opening period of sprayer needle $t_{hi}$
Fig. 8. Distribution of flowing out dose from sprayer $Q_n$.

Fig. 9. Distribution of average speed of fuel outflow from sprayer $C_{Sr}$. 
Selection of above parameters of the injection process assures sufficiently analysis of hydrodynamic occurrences occurring on pressing side of pump. We can to investigate distribution of fuel pressures in most important sections of injection system, activity of sprayer needle and course of injection to combustion chamber. On stage of create of the new construction injection pump simulation of occurring physical occurrences accelerates process for obtainment of optimum solution.

4. Recapitulation

Distributor injection pump type PR4 is new generation pump. This kind of pump assures obtainment increase of injection pressures. It characterizes with modern technical and technological execution, which are unique in relation to produced at present pumps of firms Bosch (models VE, RP44) and Lucas (model DP200). In comparison with these executions to most important differences we can include:

- separation of steering pressure from pressure which there is in pump (in hitherto existing pumps with parallel piston to driving shaft axis, steering pressure fills all volume of frame and regulator cover, what considerably enlarges danger of fuel leakages both in motion and not-motion connections),
- driving shaft is built on roller and ball bearings (in hitherto existing pumps are slide bearings), what eliminates propensity to seizing and reduce quantity of emanated warm inside pump in consequence of friction forces,
- geometrical dimensions of forcing, driving and regulating pump elements are chosen on enlarged static and dynamic loads; it assures permanent and reliable work at injection pressures of 100 MPa and doses of fuel to 150 mm³/injection, with pressing speed to 25 mm³/1°OWK (in relation to above pumps of foreign firms diameter dimensions and length are slightly greater than pump type VE, but clearly smaller than pumps type DP200 and RP44).

Executed comparisons by realizers of project in relation to application distributor pump type PR4 shows, that with success it will be able to replace not only above mention distributor pumps firms Bosch and Lucas, but also following models of line pumps:

- P2, P7, PWM in versions 2-, 3-, 4-, 6-sections (produced by WAW” PZL-MIELEC”)
- A, MW in versions 2-, 3-, 4-, 6-sections (produced by firm Bosch),
- My, Mf, M3 in versions 2-, 3-, 4-, 5-, 6-sections (produced by firm MOTORPAL).

Analyzing represented preliminary results of computer simulation for new distributor pump PR4 type we can ascertain that it shows correctness of activity and correctness of injection process reactions on extortions. Both curves of fuel pressures (expression and before injector) as of needle lift and temporary dose in function of crank angle shows similarity in character of runs to well-known pumps with piston-distributor system of work (e.g. VE firm Bosch, DP firm Lucas). Further improvement works on construction of pump and on analysis of injection process with used many-parameters optimizations method will permit certainly to finish up pump to its foreseen of applications.
Bibliography


SYMULACJA PROCESU WTRYSKU W PROTOTYPOWEJ ROZDZIELACZOWEJ POMPIE WTRYSKOWEJ TYPU PR4