

## Ways of Speed Increase for Internal Combustion Engine Fuel Injectors

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**Abstract:** The study describes the schematic solutions which may improve the injector performance. The advantages and disadvantages of these solutions are described. These solutions are the criterial prerequisites for the creation of new design injectors and fuel systems. In accordance with the fuel system requirements, these solutions will improve the ICE characteristics at various speeds and conditions. Besides the main schematic offers the ways for further development for the improvement of fuel injection systems are specified. These studies were conducted on the equipment of CAM technology common use center.

**Key words:** Fuel systems, nozzle, spring, needle, locking element, injection

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### INTRODUCTION

One of the most important ways to improve the injection systems in internal combustion engines is the nozzle speed increase during the moments of their opening and closing for which the low quality of fuel dispersion is typical. At that the design of nozzles must meet the economic reasonability of its mass production. The injectors containing a poppet with a spray, body, the valve located in its working cavity, the electromagnetic, hydraulic or electro-hydraulic drive as well as the return valve spring pressing the valve directly to the poppet or included in the drive composition are used most commonly.

### SOLUTION OPTIONS

The researchers consider possible solutions to improve the injectors: A single-needle injector with an equipped electric motor, the pressure control spool-type valve in the cavity over a needle which is the hydraulic control cavity (Grekhov *et al.*, 2004). The electric motor rotates at a constant speed equal to the ICE crankshaft rotation speed. At the moment, prior to the injection commencement of injection the spool valve disconnects the hydraulic control cavity from the working chamber. When the fuel is supplied to the working chamber from the plunger pump the needle opens. At that the fuel exits through the orifice from the hydraulic control chamber, providing a needle opening damping. At the moment prior to the plunger pump fuel supply cutoff, the spool valve connects the needle hydraulic control with a working cavity and the needle is rapidly locked at the maximum pressure. At that a strong pressure increase and pump loading is prevented by fuel leak via a nozzle. Since, the

poppet area is large and the cylinder pressure may prevent the needle closing, then it is necessary to maintain a relatively high pressure in the system. The hydraulic control cavity remains connected to a working chamber during the operation cycles of other nozzles.

The multi-needle injector (RU 2507410 patent), similar to the described above but different by the fact that some of the same needles are controlled by multiple electric motors. The setting of the operational needles number from the ECU controller. The assumed modes of electric motors:

- The sequential switching for a few minutes. At that the order of a needle triggering is an occasional one
- Some closing positions, the constant rotation with speeds at which the change in the composition of triggered needles occurs at the random order of triggering (RU 2411391 patent)

The inclusion of described solutions in a needle assembly provides the advantages as the implementation possibility:

- Concerning the multiphase injection where in the cyclic dose is given by several portions which is achieved with a high speed of jets which are usually electrically controlled
- Concerning the step injection with a variable number of fuel spray cones that may be achieved using a multi-needle assemblies

### SOLUTION DISADVANTAGES

The general short comings of these nozzles, conditioned by the presence of needle assemblies are

the large size and an increased weight of needles, thus failing to achieve the performance sufficient to take full advantage of the multi-phase injection in one-needle nozzles and to combine the number of needles in the multi-needle assembly units sufficient for the full advantage of step injection implementation (Rosseev *et al.*, 2001). The disadvantages also include:

- The application of the closing forces for the needles only on their ends removed from the poppet. Thus, the stability provision concerning the needles compressed along the entire length requires the increase of their radial dimensions
- The dynamic nature of the loads acting on the needle also require the needle and poppet contact area increase besides the radial dimensions increase to ensure their durability
- The large cross-sectional areas of needles and the large areas of their contact with the poppets heated to high temperatures which give rise to a significant amount of heat flows transmitted through, the needle body in the direction from the poppet to the precision guides that requires special measures to protect the nozzles from needle hanging and jamming, the measures related mainly to the removal of precision guides from the poppets with a corresponding increase of needle weights and dimensions

Besides, the absence of the return spring as part of the loading units leaks, injectors with the engine off which limits their use in fuel systems.

Nozzles with a spring unit loading that retain the described above advantages, associated with the presence of the needle assemblies, provide a seal with the turned off engine. At that their constituent return springs also perform the needle elastic loading function that provides the additional advantages for injectors.

The properties of self-opening and self-closing of a spring-loaded needle during the pressure changes in the nozzle operational chamber which provides the ability to manage its work as a part of the fuel supply system with plunger pumps. The characteristics of these properties are the values of needle pressure opening and closing counterbalancing the force generated by the return spring on the needle, respectively in fully closed and fully open positions (Belousov *et al.*, 2007). Defined under the terms of injector operation the values of these characteristics within the given values of the needle section areas and its differential site are achieved by the selection of the return spring stiffness and tightening.

The feature of a spring-loaded needle as hydro mechanical oscillatory system is to convert a continuous

fuel supply in the work space in a favorable intermittent “crushing injection” according the fuel spray quality criterion which is an analogue of the multi-phase uncontrolled injection. The needle fluctuations are peculiar for “crushing injection” which are accompanied by the changes in the working chamber volume (pumping effect) and the changes of fuel flow through the outlet nozzles (throttling along the sealed section). The amplitude and the position of the extreme points of these oscillations depend on the accumulator properties of the fuel supply line to the working chamber, the total cross section flow of the nozzle outlets, the mass, the size and quantities of the movable element speeds, the stiffness of return springs, the fuel supply amount in the plunger pump working chamber (Falaleev *et al.*, 2014). The characteristics of this relation for each of the variants for a particular implementation of such fuel supply systems with such injectors are the critical supply, the excess of which makes the nozzle perform a continuous injection and the minimum flow at which the needle oscillation amplitude provides the minimum acceptable quality of fuel spray (Chegodaev and Falaleev, 1985). The reduction of the minimum and the increase of the critical feeds favorable by fuel spray quality criterion are achieved with a consistent increase of the total cross section flow of the exhaust nozzles of the poppet nozzle assembly and the natural oscillation frequency of the spring-loaded needle (improved performance) as well as with its diameter decrease (pumping effect reduction).

The possibilities of “crushing” injection are additionally limited by the fact that at the large relative areas of the differential needle areas as well as at the significant thermal deformation of the injector elements it is necessary to ensure the set values of pressure opening and closing, eliminating the possibility of the stiffness increase concerning the return springs to increase the frequency of the spring-loaded needle oscillations. Besides, the constant opening and closing pressure values of a needle in a multi-needle sprayer eliminates the possibility of their triggering order change for the periodic cleaning of nozzles which creates the possibility of rapid coking within the light feed modes.

#### **INJECTOR LOCKING ELEMENT OPTIMIZATION**

One of the solutions concerning the nozzle Locking Element (LE) optimization is its implementation in the form of a flat spring, the peripheral part of which is associated with the an electromagnet housing and the central part of it has the possibility of axial shifts in the gap between the electric magnet poppet and core due to elastic

deformations of the middle part of the spring. This LE, retaining the anchor, valve and shock damping element functions inherent to disk LE acquires the stabilizer functions of its own position as well as the return spring functions. The high stiffness of flat springs provides the opportunity of the counteracting force values optimization in the extreme positions of LE according to performance criteria and the impact energy reduction.

The flat springs allow not only to reduce the LE impact energy and even break the LE at the approach to the electromagnet core, providing its “freeze” near the core when you set certain characteristics of the spring deformation. In this case, the effect of “sticking” is excluded and the time of LE duration after the electric power shut off almost tends to zero as the central part of LE immediately starts to return to the poppet from the “hang-up” position (Belousov *et al.*, 2009).

The characteristic of LE deformation may be accorded with the characteristic of forces conditioned by the presence of hydraulic pressure in the nozzle cavity, so that their combined characteristic will be an increasing one throughout, the working stroke of the central LE part (Belousov and Falaleev, 1989). With the proper management of the electric current in the electromagnet coil demonstrates the possibility to “freeze” the LE central part at any point of the stroke and, consequently, the possibility of LE braking when it lands on the poppet and then the possibility of control appears. The reduction of this effect influence on fuel consumption due to the embedded network voltage fluctuations is achieved by using the magnetic conductor elements saturation, including LE. According to the researchers opinion the magnetic conductor saturation should be achieved at the minimum operating conditions concerning the current level at the time of separation of the LE central part from the poppet (Vinogradov, 2014; Falaleev and Zhizhkin, 1996).

The flat springs of a plate type may provide an effective braking of the LE central part at the end of opening and closing working strokes due to damping processes of the liquid squeeze from the gaps between the surfaces of both central and peripheral elements of the spring and the adjacent elements of the injector.

Figure 1 shows the example of the constructive scheme for a flat leaf spring of an electromagnetic injector. The central part of the spring performs the anchor and valve functions and the coil blades of the peripheral part perform the magnetic conductor spring functions and the valve guide. This solution besides its high technology ensures the certainty of all contact point positions of the sealed valve and poppet surfaces thus, reducing the necessary conditions for the tightness, the contact

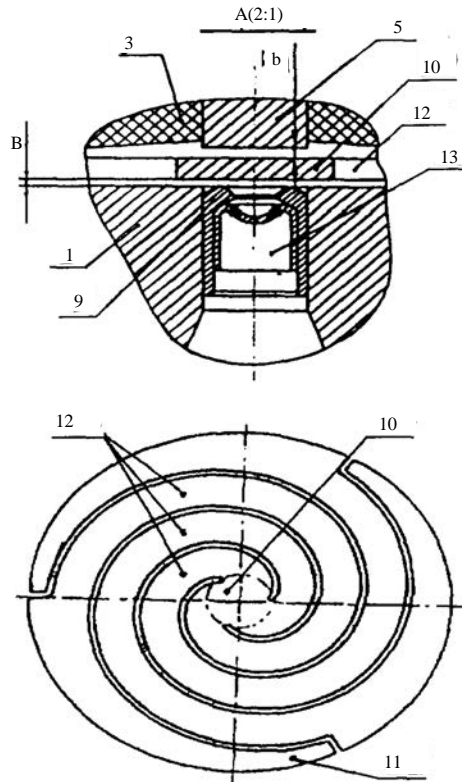


Fig. 1: The structural layout of the flat leaf spring of an electromagnetic injector: 1) the case made of non-magnetic material; 3) the electromagnet coil; 5) the core; 9) the support poppet; 10) the central part of the locking element; 11) the peripheral part of the locking element; 12) the elastic elements; 13) the spraying device

pressure provided by a spring. The achieved total force of the valve pressure to the poppet, combined with a small mass of moving elements united in one piece and the high stiffness of the spring allowed the use of an electromagnetic drive with a small driving force and respectively, a high speed.

Currently, analyzed and modeled different valve spring structures, including the options of a helical and slotted springs, the performance of transverse cuts on a needle, etc.

Figure 2 illustrates an electromagnetic injector (RU 2411391 patent) elastically sensitive hydraulic drive of a poppet shift, the position of which determines the magnitude of the composite spring impact on the valve contacting with this poppet which is called tension. By increasing the pressure in the injector operational cavity the hydraulic force is increased pressing the valve to the poppet. This force protects from the pressure drop in the

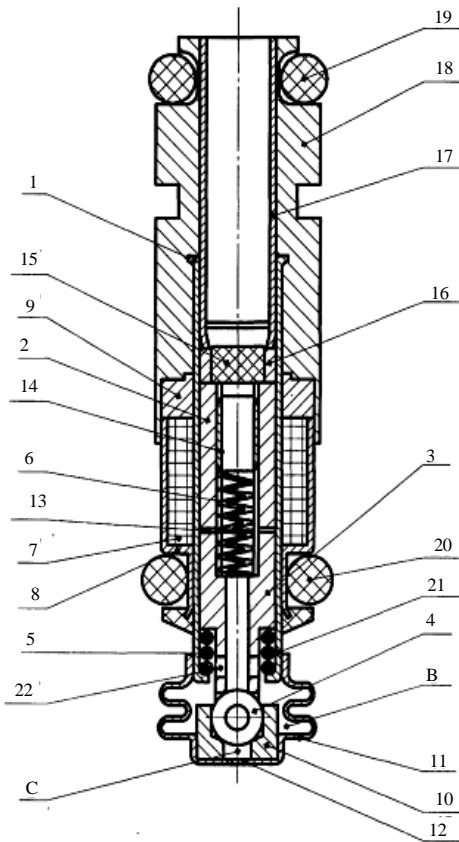


Fig. 2: The nozzle with an additional drive, reducing the effort of the electromagnetic nozzle valve opening for the main drive

operational and sub valve cavities. Simultaneously, the bellows of the elastic sensitive drive shifts the poppet towards the injection cavity and the contacting valve by changing the tension of the composite spring by magnitude and direction. Thus, the reduction necessary for force valve opening is achieved. This measure allows the use of high-speed electromagnetic actuators with low driving force within the high pressure systems.

The nozzle design allows the use of an electromagnetic actuator as a switch-gear device in the injection systems with a single plunger pump supplying alternately several nozzles. In the absence of a control signal for an electromagnetic drive the pressure change cycle in the cavity is accompanied by the joint displacements of the poppet and the valve in the direction of an injection cavity and back without opening the nozzle. When the control signal is supplied to the actuator the nozzle is triggered similarly to the injectors with a movable poppet.

## CONCLUSION

Based on the foregoing, researchers consider it reasonable to continue the operation for the nozzle performance improvement in the following areas:

- The coordination of force characteristics, the transition to lightweight needles, the return springs rigidity increase in the nozzles containing the sprays with needles
- The nozzles with LE, pressed by the fuel pressure to the poppets need the promising improvement of controls based on the use of continuously rotating control devices, including a variable within the angular velocity cycle and the use of controlled effect for a sharp transition from the "open" to "closed" position (sustainable extreme LE positions control by changing the characteristics)

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