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Modeling of Injection Parameters for Diesel Engine Injector Nozzles with the Additional Precision Guiding Interface

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Abstract

Perfection of output parameters of diesel engines is considered as a result of the rail-pressure increase and modernization of nozzle tribosystems represented at high (up to 300 MPa) values of the fuel pressure. The nozzle with the modified design and additional (bottom) precision guiding interface is used and hydrodynamic parameters of injection are analyzed. The computational fluid-dynamic (CFD) modeling for estimation of hydrodynamic parameters of the fuel flow and force distribution in the "needle – nozzle body" system is used. The results of the injection modeling and contact parameters for the modified design of nozzle precision interfaces are established and discussed. The ways of increasing the stability of needle position in the nozzle body with perfection of parameters of fuel injection are presented.

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Keywords: nozzle of fuel's injector; precision interfaces; thermal and mechanical parameters of nozzle; nozzle's design

1. Introduction

Modern diesel engines motor-building is developing with increasing the specific capacity at decreasing the fuel consumption and toxicity of exhaust gases [1-8]. These results are achieved by means of complex measures, which include the perfection of engine's mechanic components and different systems as well as parameters of operation cycle. Perfection of operation cycle parameters is provided by relevant actions connected with injection process, because deviations of fuel's injection parameters lead to deviations of combustion process with negative influence to engine's output parameters. One of the ways of controlling the injection process is perfection of injector's nozzle

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design. This is especially actual for modern Common Rail (CR) -injectors with high (up to 300 MPa) values of rail-pressures [2, 4-11].

Perfection of nozzle's design is provided by the following ways:

- creation of the additional (bottom) guiding precision interface (fig. 1);
- reducing the height of top (guiding/sealing) precision interface;
- creation of the circle groove with special profile on the sealing part of the needle.

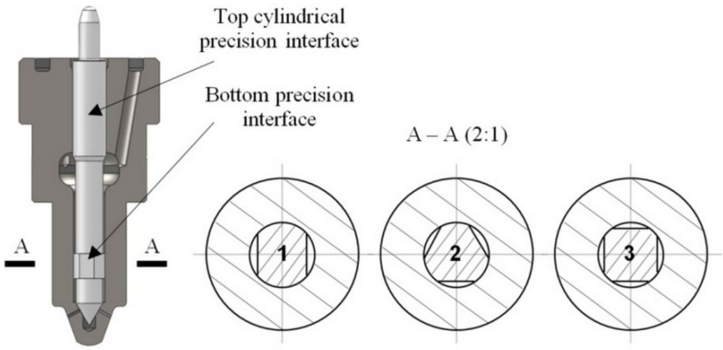

Fig. 1. Different variants of profile for additional (bottom) guiding precision interface

Variant 2 (which design is fully or partially proved by Ganser's patent, Germany) with the so-called "triangle" profile looks as most suitable and balanced from technological and hydrodynamic points of view. The positive effect from implementation of additional (bottom) precision interface can be considered with estimation of deviation (ΔX) of the needle's axe from axe of the nozzle's body (fig. 2).

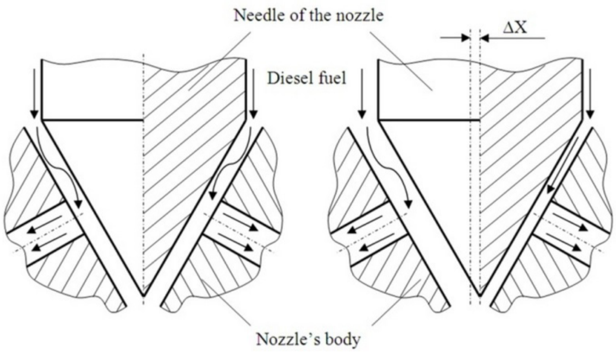

Fig. 2. Different positions of the needle in the nozzle's body: (a) with additional precision interface (left), (b) without additional precision interface (right)

The influence of additional (bottom) precision interface could be verified with CFD-modeling of hydrodynamic parameters [12, 13, 17-22] for fuel's flow at different positions of the needle.

Nomenclature

ΔX	deviation of the needle's axe from axe of the nozzle's body
R_1, R_2	radii of the sealing precision interface
a	distance from top of the needle to middle of the guiding/sealing precision interface
b	distance from top of the needle to middle of the additional guiding precision interface
F_N	radial force

2. Hydrodynamic models of fuel's flow

For investigation of hydrodynamic parameters for fuel's flow at different positions of the needle the CFD-models with account of needle's deviations were prepared (fig. 3) and the following research tasks were outlined:

- to estimate the distribution of pressure and fuel's flow velocities close and in holes of injection with and without the needle's deviation;
- to find the solution for stabilization of fuel's flow near holes of injection and minimizing the areas of "zero"-pressures;
- to prove the most suitable nozzle's design for conditions of high values of rail-pressure with minimal non-regular injection parameters.

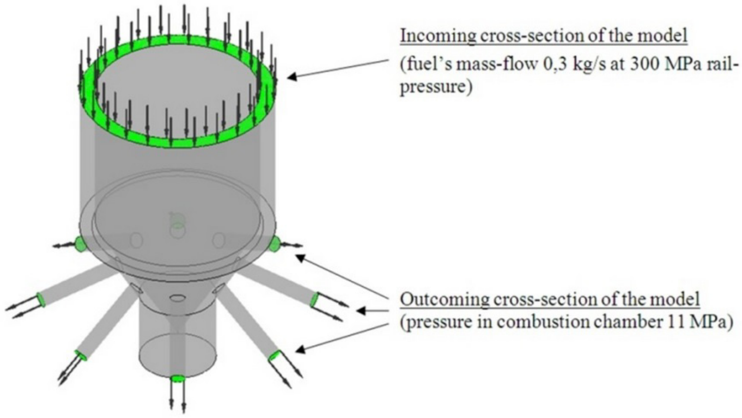

Fig. 3. CFD-model for investigation of hydrodynamic parameters for fuel's flow with account of the needle's deviation

For selected models the following boundaries were assumed:

- incoming cross-section – fuel's mass flow;
- outcoming cross-sections – counter-pressure into combustion chamber.

The calculations were done for different values of the needle's deviation starting from 16 μm to 64 μm with step 16 μm. For the comparison of the hydrodynamic parameters of injection fuel's flow the results of numerical simulations for models with deviation of needle and model without the needle's deviation are presented and analyzed.

3. Results of hydrodynamic parameters simulation and discussion on the perfection of nozzle's design

According to the results which were achieved in course of modeling, the non-regularity of fuel's velocity in different holes of injection increases with increasing the deviation of the needle (fig. 4).

This situation leads to irregularity of fuel's mass-flow in different parts of combustion chamber and, as a result, leads to different values of air-ratios, deviation of injection and combustion parameters from the requested and deterioration of the diesel engine's output and ecology parameters. Additional (bottom) precision interface will promote the decrease of the needle's deviation with positive effect [14-16, 23].

The received results of modeling have satisfied correlation with experimental tests results from High Pressure Chamber (fig. 5). The data were received in laboratory of Institute for Internal Combustion Engines (LVK) of Faculty for Mechanical Engineering of Technische Universität München (TUM, Munich, Germany) [24].

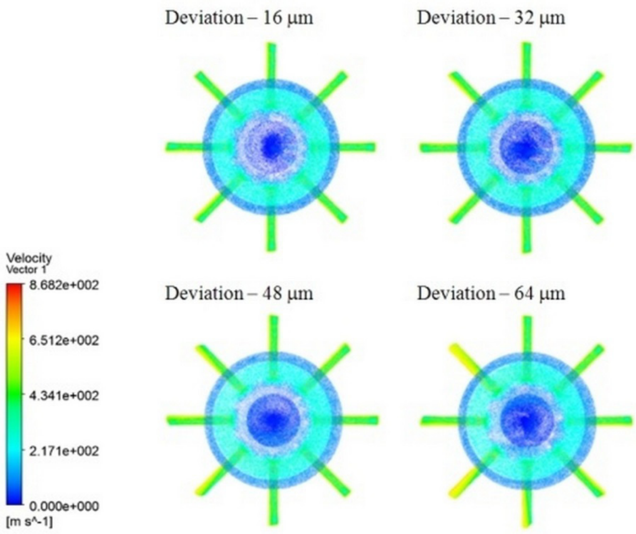

Fig. 4. Velocity of fuel's flow into holes of injection at different deviation of the nozzle's needle

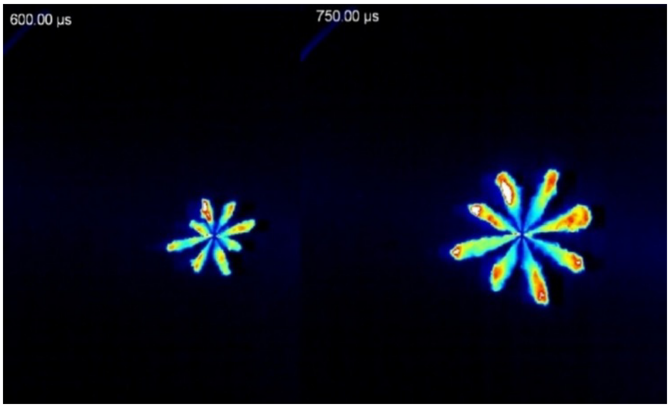

Fig. 5. Spray pattern of series nozzle at beginning of spray process at 300 MPa injection pressure

Different lengths of sprays are the result of different fuel's velocities in and close to holes of injections. This situation was provoked by the radial deviation of needle's position in the nozzle's body.

The distribution of pressure and fuel's flow velocities close and in holes of injection with maximal (64 μm) needle's deviation is presented (fig. 6).

The results of numerical simulations demonstrate different hydrodynamic parameters (fuel's pressures and velocities) for different holes of injection at maximal (64 μm) deviation of the needle. This situation can be explained by irregular geometry parameters for hydraulic tract in the sealing precision interface. As a result of the needle's deviation the mass flow of fuel decreases with decreasing of hydraulic cross-section, which finally leads to decreasing of pressure and velocity of injecting fuel and, subsequently, leads to deviation of injection parameters from the requested.

Due to the sharp turn of fuel's flow in the sealing precision interface there appear some areas with the so-called "zero"-pressures (blue-color areas on fig. 6). The appearance of "zero"-pressures areas is very undesirable, because it leads to cavitation and erosion processes, which is most actual at these (up to 300 MPa rail-pressures and up to 900 m/s velocities) parameters of fuel.

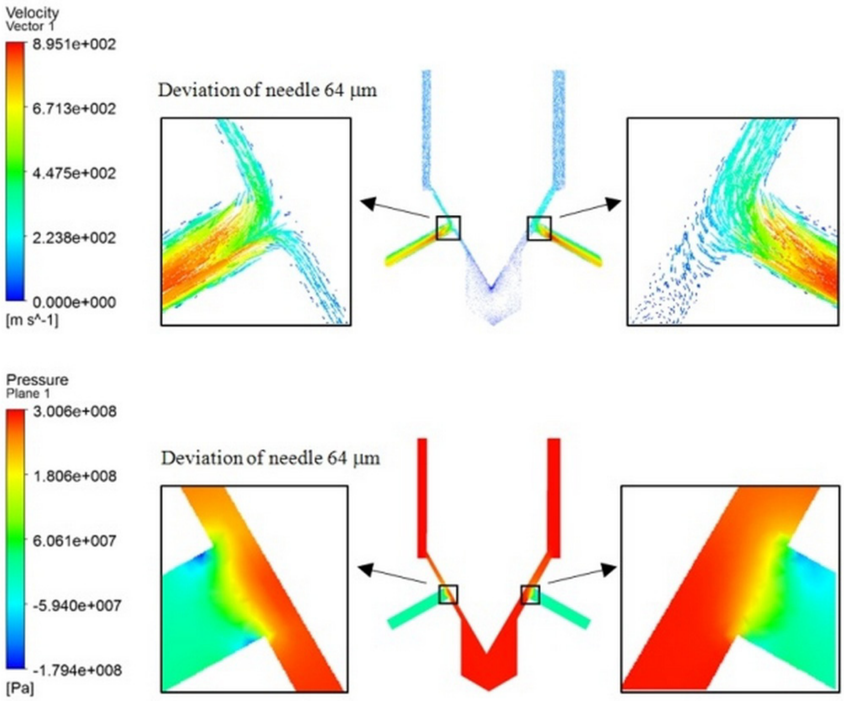

Fig. 6. The distribution of fuel's flow velocities (up) and pressure (down) and close and in holes of injection with maximal (64 µm) needle's deviation

As one of possible ways of stabilization of fuel's stream in the sealing precision interface and in holes of injection is creation of the circle groove with special profile on the sealing part of the needle. This action allows to rotate the fuel with maximal possible radii and without undesirable sharp turns. The design of the sealing part of the needle and results of modeling the hydrodynamic parameters of fuel's flow (without deviation of the needle) are presented (fig. 7 and 8).

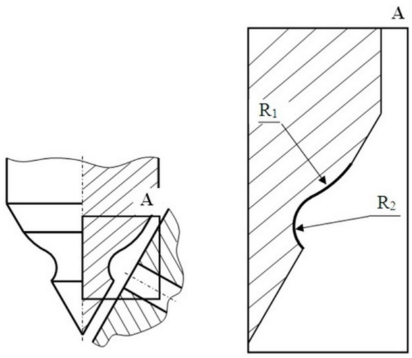

Fig. 7. The design of the sealing part of the needle with circle groove and special profile

For this design of the sealing part of the needle the conic part is shaped by two radii which create more smooth part of fuel's flow and promote the stabilization of the stream's parameters.

According to the received results, the distribution of pressures and velocities in nozzle's holes of injection is more stable and regular. The features of the mentioned radii, which are shaped by the circle groove should be discussed and estimated in detail, but it can be considered as independent investigations.

The next step of investigations which is directed to perfection of nozzle's design is reducing the height of top (guiding/sealing) precision interface. This measure should provide the decrease of radial force in the guiding/sealing interface with increasing the nozzle's durability and service life.

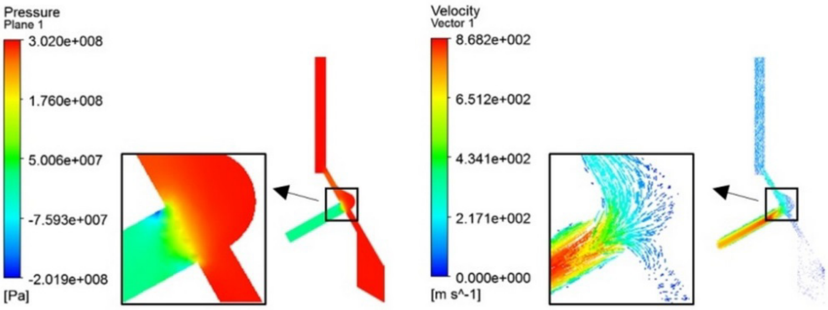

Fig. 8. Hydrodynamic parameters of fuel's flow for the needle with special design of sealing precision interface

At reducing the height of top (guiding/sealing) precision interface the parallel effect of increasing of leakage which leads to increasing the fuel-pump capacity is expected. Numerical estimation of the fuel's leakage mass-flow is performed with series of CFD-models of the top cylindrical guiding precision interface. The models have different lengths starting from 10 mm and finishing with 5 mm.

For all the investigated CFD-models the same types of boundaries (incoming leakage mass-flow and outcoming fuel's pressure) were used. It should be noted, that for achieving the incoming rail-pressure 300 MPa the incoming fuel's leakage mass-flow should be increased with decreasing the height of the top cylindrical guiding precision interface. The results of numerical simulation of distribution of fuel's velocities are presented and analyzed (fig. 9).

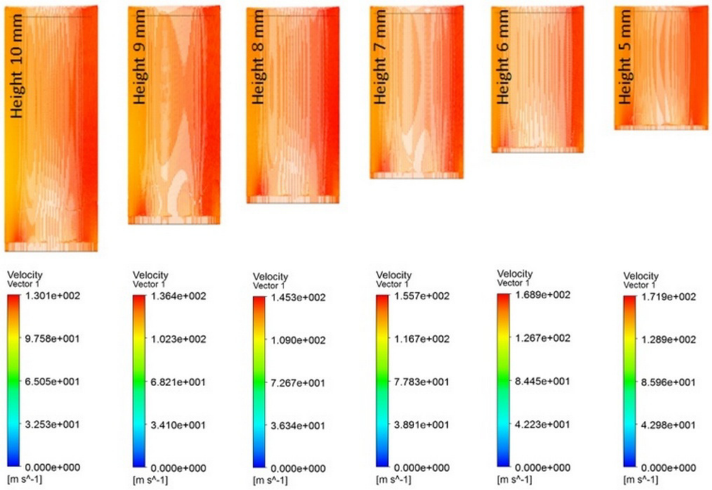

Fig. 9. Distribution of fuel's leakage velocity at different heights of top guiding/sealing precision interface

The maximal velocity of fuel in the cylindrical top guiding precision interface changes from 130 m/s at 10 mm height to 172 m/s at 5 mm height of the interface. The increasing of fuel's velocity is evidence of increasing the fuel's leakage mass-flow because the geometry parameter for cylindrical gap was not changed.

The fuel's leakage mass-flow at different heights of top guiding/sealing precision interface is presented on figure 10. According to the received results the fuel's leakage mass-flow is changing from 0,43 kg/h at 10 mm height to

0,6 kg/h at 5 mm height of top precision interface. This situation could be explained by decreasing the hydraulic resistance of the interface with decreasing the interface's height.

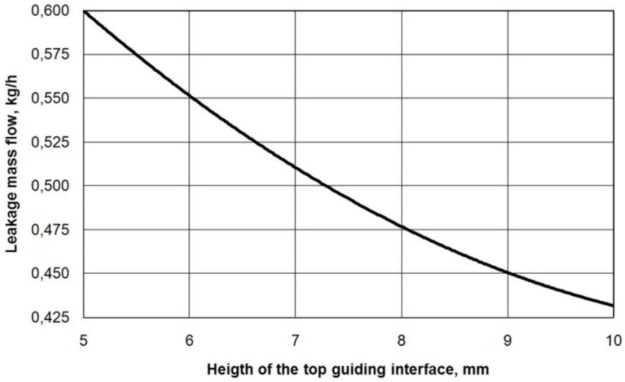

Fig. 10. Fuel's leakage mass-flow at different heights of top guiding/sealing precision interface

Along with increasing the leakage mass-flow there is change of the situation with radial force for investigating interfaces. The estimation of the difference of fuel's pressure in the top cylindrical guiding interface (fig. 11) makes it possible to estimate the radial force and, subsequently, nominal pressure for additional bottom guiding interface.

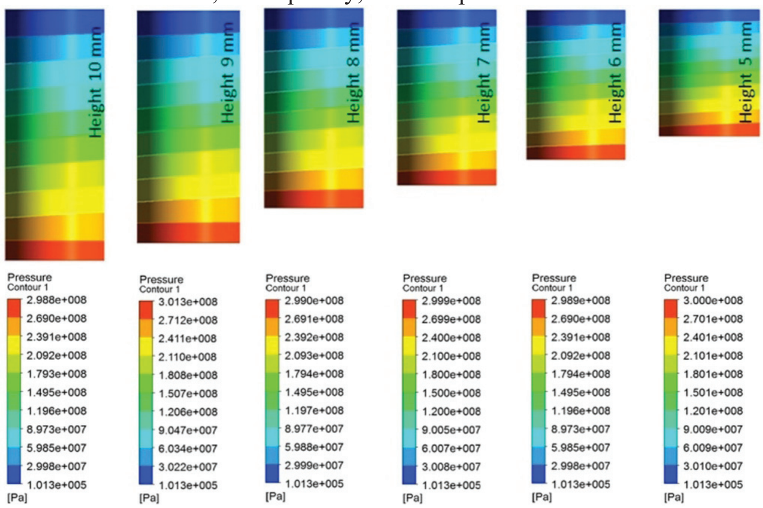

Fig. 11. Distribution of fuel's pressure at different heights of top guiding/sealing precision interface

The differences of fuel's pressure and geometry parameters for top cylindrical precision interface allow to calculate the radial force and nominal contact pressure for the investigated interface. The radial force from top cylindrical interface is transferred to bottom additional interface with relevant geometry coefficient at assumption of scheme of forces which is represented on figure 12. Finally, the radial force and nominal contact pressure for bottom precision interface in function of the height of top interface were estimated and analyzed.

The analysis of nominal contact pressures for the investigated interfaces shows opposite dynamics of changes of these parameters in function of height of top cylindrical interface.

The investigated conditions are as follows: the height of top cylindrical precision interface is changing from 5 mm to 10 mm at permanent height of additional bottom precision interface equal to 3 mm.

According to the received results the nominal contact pressure for top cylindrical interface increases with decreasing the height of interface, but nominal contact pressure for additional bottom interface decreases with decreasing the height of interface.

This situation is explained by the changing of the (a/b)-relation and confirms strong interdependence between interface's parameters.

Thus, the nozzle's design should be created with account of actual loads of the top and bottom precision interfaces because the force and nominal contact pressure from top cylindrical interface influence the same parameters in the bottom additional interface.

4. Dissemination of results

The proposed nozzle's design and central ideas about the separation of functions of precision interfaces should be interesting for other types of equipment (high-pressure pumps, plungers controlling devices, high-precision bearings etc). Thus, the received results can be disseminated for different types of precision tribosystems requiring of the technical solutions which must be considered specially for precision interfaces.

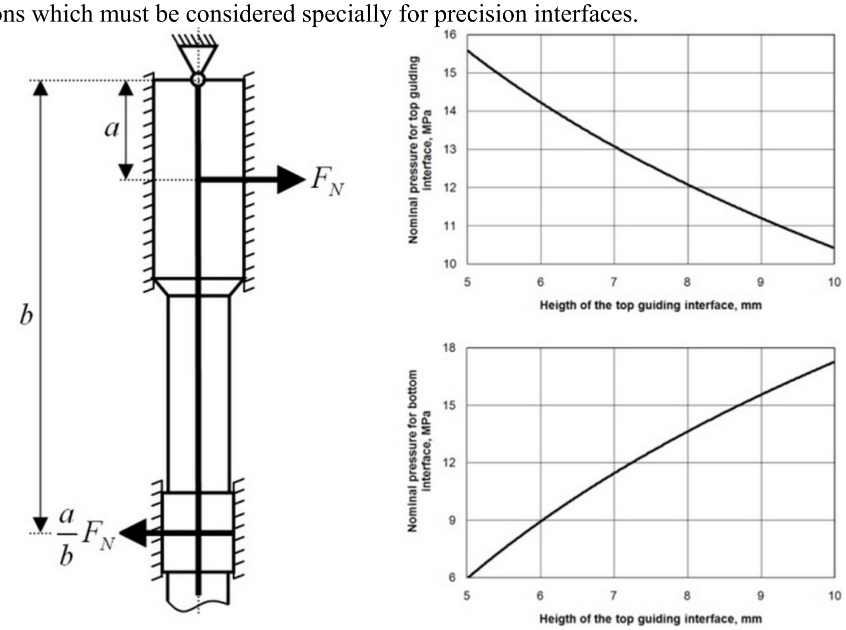

Fig. 12. The distributions of radial forces and nominal contact pressures for top (up) and bottom (down) precision interfaces

5. Conclusions

Analysis of hydrodynamic parameters and characteristics of injection for nozzle with changed design and with high (up to 300 MPa) rail-pressure operation conditions lead to the following conclusions.

- the nozzle's design with conic part of the needle which is shaped by two radii create more smooth distribution of fuel's flow velocities and promote the stabilization of fuel's stream parameters;
- decreasing the height of top cylindrical precision interface from 10 mm to 5 mm leads to increasing the mass-flow rate of the leakage from 0,43 kg/h to 0,6 kg/h;
- the height of bottom additional precision interface equal to 3 mm and the height of top cylindrical precision interface equal to 10 mm provide the nominal contact pressure close to 17 MPa for additional bottom precision interface and close to 10,6 MPa for top cylindrical precision interface;

- the height of bottom additional precision interface should be coordinated with the height of top cylindrical precision interface due to inter-influence of radial forces and, subsequently, the nominal contact pressures in the interfaces.

6. Outlook

The perspective directions for future investigations should be focused on:

- investigation of the complex CFD-model with different nozzle's geometry for estimation of pressures and forces specially for additional bottom precision interface for searching the ways of needle's stabilization;
- investigation of micro-mechanical situation for additional bottom and sealing precision interfaces with taking into account the roughness parameters in the "needle - nozzle's body" sealing contact area;
- searching the most effective nozzle's design with best possible durability and maximal service life.

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