Numerical Study on Abrasive Flow of the Fuel Spray Nozzle Based on RNG k - ε Model

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Abstract: In view of the current problems that it is difficult to polish small size and complex curved surface, a processing method based on solid-liquid two-phase abrasive flow is proposed. In order to verify the rationality and practicability of the processing method, the numerical simulation is carried out for the processing of solid-liquid two-phase abrasive flow. By using the RNG k-ε turbulence model and the Mixture model, the fuel spray nozzle is taken as the research object. The dynamic pressure, the turbulent dissipation rate and turbulent kinetic energy at the nozzle hole are analyzed and compared. The simulation results show that with the increase of inlet velocity, dynamic pressure, fluid velocity and turbulent kinetic energy at nozzle orifice increase at some extent, which tells that the effect of solid-liquid two-phase flow on the pore wall is stronger, the more intense the friction between the fluid and the wall, the better the polishing effect, thus the effectiveness of the abrasive flow processing was concluded and providing theoretical support for the fluid processing of complex components.

1. Introduction

Manufacturing industry is a precision ultra-precision machining and intelligent field, the processing of parts and components of the surface quality requirements continue to improve, especially in aerospace, military, medical and other fields, which are greatly challenged by the difficulty of processing. The process will encounter a variety of complex parts and irregular surfaces, such as some tiny holes, narrow ditch, cross hole rounding deburring, etc. The traditional processing methods seem that cannot be effectively used, and the advent of abrasive flow processing technology has brought a ray of hope for precision ultra-precision machining [1,2].

Abrasive flow processing technology developed in recent decades, a new technology, which is based on liquid as a carrier and the hard particles (diamond, silicon carbide, silicon carbide) as a grinding tool, by giving a certain speed or pressure to its flow through the surface to be processed, so as to achieve the purpose of precision machining [3-5]. Li Junye [6] and other scholars take the common rail tube as the research object, and studied the process of abrasive flow polishing common rail tube, and explored the influence of each process parameter on the abrasive jet polishing. The results showed that the control silicon carbide volume fraction can change the viscosity-temperature characteristics of the abrasive flow polishing process, which can control the abrasive flow of polishing quality. M Sprating [7] attempt to improve the external morphology of freeform surfaces, especially
knee joint, by abrasive flow finishing process. Experimentally, effects of abrasive flow finishing process parameters are investigated to develop “know how” of the process on the freeform surfaces. Abrasive flow finishing process has given 76.56% reduction in finishing time as compared to the time required by “ball end” type tool used for finishing knee joint. HS Mali and A Manna [8] analyzed the influences of AFM(Abrasive Flow Machining) process parameters on surface finish and material removal, Taguchi experimental design concept, L 18 (6 1 65×653 7 ) mixed orthogonal array is used to determine the S/N ratio and optimize the AFM process parameters. Analysis of variance and F test values also indicates the significant AFM parameters affecting the finishing performance.

2. Physical model and meshing
The nozzle parts selected in this paper are the parts of a diesel engine where there are six small holes. The large hole diameter of the runner is 4 mm and the small is 0.16mm. The three-dimensional solid model is shown in Figure 1. In order to facilitate the simulation analysis, the three-dimensional solid figure of the drawn nozzle is simplified, the solid part is hidden, the internal channel part is abstracted, only the main nozzle and the six nozzle holes are reserved, and the three-dimensional solid simplifies the result as shown in Figure 2.

![Figure 1 Three-dimensional solid model](image1)

![Figure 2 The runner model](image2)

There is a extremely important step before simulating the injector, which is the meshing. It can be said that the quality of the grid directly determines the final simulation results are reliable or not, and this step is the longest step consuming time in the entire simulation process. In the meshing process, the tetrahedron mesh can be used for any geometry, and it can be quickly and automatically generated, and is suitable for complex geometry, easy to use the curvature and approximate size features in the key area to automatically refine the mesh, which in line with the characteristics of the complex geometric structure of the nozzle. After meshing, 230,845 nodes are formed, and the quality of the grid is tested. The quality of the grid is found to be good, and the divided grid model is shown in Figure 3.

![Figure 3 Meshing model](image3)

3. Simulation conditions
In the abrasive flow polishing process, there are many factors that affect the processing effect, and the speed is one of the most important one. In this paper, the nozzle was selected to simulate and analyze with the speed of 25m/s, 30m/s, 35m/s and 40m/s respectively to discuss the precision machining effect of the abrasive flow under different inlet velocities to create the theoretical basis for the actual machining. Phase-Coupled SIMPLEC with pressure-velocity coupling was used to solve. The velocity-inlet for inlet and outflow for outlet were taken. The liquid phase of the solid-liquid
two-phase flow was hydraulic oil and dispersant, the solid phase was silicon carbide particles whose volume fraction was 20%.

4. Simulation results analysis

Using the self-developed abrasive flow machine tool, the numerical simulation of nozzle under different inlet velocities was carried out to study the effect of speed on the nozzle. The dynamic pressure distribution under different speeds are shown in Figure 4.

As can be seen from Fig.4 that with the inlet speed increases, the dynamic pressure is also increasing, especially to the top of the nozzle, the dynamic pressure changes more pronounced. When the abrasive flow just flow into the nozzle, the section has not changed, the speed is almost constant forward speed, so the dynamic pressure is close to a constant value, the change is not obvious; when the fluid into the variable cross section, there is a significant gradient in dynamic pressure, especially when it comes to the top orifice of a nozzle. The dynamic pressure of the orifice is even greater because the fluid encounters resistance in the direction of travel as it enters the variable section. And the impact to the wall produced, but the impact is not particularly apparent. However, the dynamic pressure is better demonstrated, with the smaller cross-sectional size, the more obvious dynamic pressure, especially into the small holes, the pressure is greater. Therefore, it can be inferred that with the increase of velocity, the pressure between the fluid and the wall is also larger, the effect of squeezing and friction generated by the abrasive flow and the wall is greater, and the grinding effect of the abrasive flow on the wall is stronger. The higher the removal rate, the better the polishing effect, indicating that the abrasive flow processing can achieve better processing results. In order to further verify the polishing effect of the abrasive flow, the turbulent dissipation rate and turbulent kinetic energy of the flow field are respectively analyzed. The simulation results are shown in Figure 5 and Figure 6.
The turbulent dissipation rate plays a major role in polishing the wall surface by the abrasive flow. The greater turbulent dissipation rate, the better the effect on the wall. Turbulent kinetic energy represents the strength of the turbulent state, which is an indicator of the development or decline of turbulence. The larger the turbulent kinetic energy, the more thorough the turbulent flow develops. The more homogeneous the mixed, the better the consistency of the polishing. It can be seen from Fig. 5 and Fig. 6 that turbulent dissipation rate and turbulent kinetic energy both increase with different inlet velocity, and are most obvious at the orifice of the nozzle. It is consistent with the dynamic pressure distribution, the reliability of abrasive flow polishing is confirmed.

5. Conclusion
Aiming at the difficulty of polishing complex parts such as micro-holes, a method of solid-liquid two-phase abrasive is proposed. By analyzing and comparing the dynamic pressure, turbulent dissipation rate and turbulent kinetic energy at different inlet velocities, the dynamic pressure, turbulent dissipation rate and turbulent kinetic energy have varying degrees of increase in the nozzle top, which shows that the more intense the collision and friction, the better the polishing performance.

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