Research on chip removal mechanism of pulse fluid negative pressure in deep hole machining

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Abstract: The processes of deep hole parts is prone to chip blocking due to its large length-to-diameter-ratios. Aiming at this problem, this paper designs a pulse negative pressure chip removal device based on a negative pressure chip removal system, which realizes the supply of pulsed chip removal fluid, and establishes the pulse fluid mathematical model of the device, and analyzes the effect of pulse supply fluid on the effect of chip removal. The simulation test of its chip removal effect is carried out by the Fluent software, and the results show that the pulsed oil supply device can make the chip produce relaxing combined suction force in the chip drain channel and alleviate the occurrence of chip blocking phenomenon.

1. Introduction

The problem of chip removal is a difficult problem of deep-hole processing technology, and a lot of research has been done by experts and scholars at home and abroad on this problem. ChinJH et al. studied the dynamic pressure of chip removal system and high-pressure cutting fluid by establishing a model of cutting condition monitoring for BTA drills, and designed and developed a simulation calculation method for cutting condition monitoring. Professor KatsubiA studied the form and flow theory of chips, which became the main theory of automatic control of chips. Professor Guan Shixi designed a wedge-shaped jet nozzle structure, which effectively improves the negative pressure chip removal ability.

The above research mainly focuses on the analysis of the negative pressure factor and the structural optimization of the jets, but does not consider the effect of the oil supply method on the effect of negative pressure chip removal. The pulsed oil supply device proposed by the author changes the original oil supply mode, realizes the pulsed supply of chip solution, enhances the chip-removal power, and alleviates the occurrence of chip-blocking phenomenon.

2. Working principle of pulse negative pressure chip removal device

As shown in Figure 1, the device adds a controllable flow regulator to the negative pressure channel compared with the traditional negative pressure chip discharge device, which enables pulsed supply of cutting fluid entering the negative pressure channel. When the flow rate of cutting fluid changes, the
jet velocity will change. The change of jet velocity will lead to the change of negative pressure difference in the chip removal channel and alleviate the phenomenon of chip blocking.

Figure 1 Schematic diagram of pulse negative pressure chip removal device

3. The structure and principle analysis of the regulator

3.1 Flow regulator structure
The structure of the flow regulator is shown in Figure 2. The diameter of the shaft through hole is equal to the diameter of the valve body channel, and the flow regulator is connected with the negative pressure channel. When its working, the servo motor drives the rotating shaft to rotate, the flow regulator and the negative pressure channel realize periodic connectivity, the connected area changes with time, and finally the pulsed supply of cutting fluid is realized.

Figure 2 Structure diagram of flow regulator

1-Lower end cover 2-Seal the ring 3-Adjustment screw 4-Bearing cover 5-Seal the ring. 6-Upper end cover 7-End cover sealing ring 8-Rotary shaft 9-Bearing 10-Valve body

3.2 Principle analysis of flow regulator
The internal structure of the through hole of the flow regulator shaft is shown in Figure 3. The diameter $d$ of the through hole is equal to the chord length $L_0$ of the solid part. The motor drives the rotor to rotate, and the relationship between its speed $n$, pulse frequency $f$ and period $T$ is as follow:

$$f = \frac{1}{T} = \frac{2n}{60} = \frac{n}{30}$$

(1)
Assuming the initial position, the regulator is fully connected to the negative pressure channel, and the cross-section of its connecting portion is shown in Figure 4. In Figure 4, A1A2 and B1B2 are the lengths of the shaft through holes, A1B1 and A2B2 are the lengths of the shaft fixing parts and C1C2 is the length of the negative pressure passage. In Figure 4(a), when the shaft rotation angle $\theta \leq \pi/2$, the chord length of the connecting part of the negative pressure channel and the shaft through hole in the cross section is $AC_2$:

$$AC_2 = \frac{\sqrt{2}D}{2} \sqrt{1 - \cos \left( \frac{\pi}{2} \cdot \theta \right)}$$

In Figure 4(b), when $90^\circ < \theta < 180^\circ$, the channel is gradually opened until complete connection is achieved. At this time, the chord length corresponding to the connected part is $BC_1$:

$$BC_1 = \frac{\sqrt{2}D}{2} \sqrt{1 - \cos \left( \frac{\pi}{2} - \theta \right)}$$

The rotating shaft starts from the initial position and realizes a periodic cycle of the connected area every $180^\circ$. The radial cross-sectional area of the channel is shown in Figure 5. When $\theta \leq \pi/2$, the corresponding chord length $L_1 = A_1C_2$, and the connected area $S$ gradually closes from large to small; when $\pi/2 < \theta \leq \pi$, the corresponding chord length of $L_2 = B_1C_1$, and the connected area $S$ gradually expands from small to large.

$$S = \frac{\pi d^2}{4} - \frac{d^2}{2} \arcsin \left( 1 - \frac{L}{d} \right) - \left( \frac{d - L}{d} \right) \sqrt{\frac{2dL - L^2}{2}}$$

Then the connected area $A$ of the rotating shaft in one cycle is:

$$A = \begin{cases} S_1 \cos \frac{\theta}{2} & \theta \leq \pi/2 \\ S_2 \cos \frac{\pi - \theta}{2} & \pi/2 < \theta < \pi \end{cases}$$

In the above formula, $S_1$ and $S_2$ are the connected areas, when the rotation angle $\theta \leq \pi/2$ and $\pi/2 < \theta \leq \pi$. According to the relationship between the rotation angle $\theta$ and the speed $n$, period $T$, time $t$, and angular velocity $w$:
The area of connectivity between the regulator and the negative pressure channel changes over time, resulting in a change in the flow of traffic through the regulator. When the flow of changing cutting fluid enters the jet gap, a jet velocity of varying sizes is generated, which causes the negative pressure difference in the chip drain channel to change.

4. Simulation test of pulse negative pressure chip removal system

4.1 Simulation model and parameter settings

In this paper, based on the actual mechanical structure of the chip removal system, a three-dimensional model of the dual oil chip removal channel shown in Figure 6(a) is established in UG. In this model, the chip removal channel diameter is 18mm, the jet gap is 1.2mm, and the jet inclination is 15°. Mesh the 3D model in the Fluent software. Figure 6(b) shows the fluid model after meshing.

In the pulsed oil supply system, the flow of cutting fluid belongs to the research category of unsteady turbulent flow. This experiment uses turbulence models, and the internal fluid is sulfurized cutting fluid. The chip removal channel is set to the pressure inlet, and the inlet velocity is set to 0.6m/s, the jet port velocity is set to 1.2m/s, 2.4m/s, 3.0m/s, and the convergence criterion is the continuous equation represented by the difference equation. The calculation error of is subject to less than 0.0001.

4.2 Result analysis

Figure 7 shows the simulation results under three jet velocities. Comparing the pressure and velocity cloud diagram and the pressure velocity distribution table on the central axis in Fig.7, it can be seen that the negative pressure difference and velocity difference generated at different jet velocities are different. In this case, chip liquid will produce fast and slow combination of chip removal effect, to alleviate the occurrence of chip blocking phenomenon.
5. Conclusion

This paper designs a pulsed oil supply device, analyzes its working mechanism, and uses Fluent software to simulate its chip removal effect. The simulation results show that pulsed fuel supply can produce different jet velocities, which in turn changes the negative pressure difference in the chip removal channel. The constantly changing negative pressure difference in the chip removal channel can make the chips have a loose and combined chip removal effect, and alleviate the occurrence of chip blocking in deep hole machining.

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