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Design of the Feed Liquid System for an Internal Cooling End-milling

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Abstract. In order to weaken the negative effect on environment and human health caused by the overuse of the cutting fluid, the internal cooling cutting is paid more and more attention. An end-milling with an internal cooling lubricant supply is proposed in the paper. The cutting fluid is provided through the internal cooling channels inside the end-milling cutter rather than the traditional external fluid feeding system. With the internal cooling channels feeding system, the cutting fluid can be fed to the cutting zone directly. The design process of the feed liquid system for an internal cooling end-milling is given. And the simulation result about the design is given. And it can meet the expected design goal. In practice, the calculated liquid flow of the internal cooling end-milling cutter is reasonable. The related computation process can serve as reference of domestic design of the feed liquid system for an internal cooling end-milling cutter.

1. Introduction
It is easy to both love and hate of cutting fluid during the cutting process, especially during the hole milling process. It is mainly because that the cutting fluid is beneficial to remove chip and cutting heat, increase the surface finish quality and tool life [1-3], but at the same time, the traditional cutting fluid is unfriendly to the human health and the environment [4-5]. Furthermore, even if the cutting fluid is pressurized, the cutting fluid is difficult to be penetrated into the tool-chip interface [6]. But during some materials machining process, the cutting fluid is indispensable, especially in the machining of difficult to machine metals, such as the machining of titanium alloy, nickel alloy, explosive and flammable materials [7], the use of minimal quality lubrication (MQL) or no coolant result in lots of subsurface damage and short tool service life [8, 9], and so more and more researchers are exploring new cooling systems.

High-speed milling technology has many advantages such as higher efficient, high surface quality machining, and low production cost [10]. Such advantages enable extensive application of high-speed milling technology in more and more metal cutting fields, such as titanium alloys [11]. So it needs more effectively cooling provided in high-speed end-milling of difficult to machine metals.

When cutting with internal cooling end-milling cutter, the internal cooling channels can bring adequate cutting fluid to the tool-chip interface. And therefore the cooling effect is enhanced and the thermal load is effectively reduced. Thus the internal cooling cutting technology is regarded as a promising technology.
Regarding the fluid supply system for the internal cooling cutting can be found only very few literatures. Aurich gave an internal cooling supply for a grinding wheel [12]. So far, there are no literatures that are published to deal with the fluid supply system for an internal cooling end-milling cutter.

The necessary, feasibility, actuality and its research stress of application of the internal cooling feed liquid system in high speed end-milling are all stated. In contrast to the existing end-milling cutters with internal cooling, the flow and pressure of the feed liquid system can be adjusted.

2. Overall design project of the internal cooling feed liquid system

2.1. Internal cooling end-milling

The design of the internal cooling feed liquid system is based on the design of the internal cooling end-milling cutter presented in reference [13]. One of the solid carbide end-milling cutters (shown as Figure 1), with a total length of 90mm, provides two channels with a diameter of 1.4mm, and the distance between the two holes is 6.25mm. The internal channel is double helical channels structure. The channels inner the cutter decrease the stability of the end-milling. For the reason, the diameter of the channel is set to 1.4mm. And an inlet-outlet conveys tool shank is used to convey the cutting fluid to the internal channel of the end-milling cutter.

![End-milling cutter with internal cooling channels.](image)

2.2. Basic requirements of the internal cooling feed liquid system

For the internal cooling feed liquid system to work properly, the cutting fluid supply system should meet the following requirements. (1) The fluid flow provided of the internal cooling feed liquid system should be adjustable. (2) In order to ensure the pressure of the system should not exceed the normal pressure of the oil hydraulic pump, the system should also come with over-load protect. (3) In order to ensure the cooling performance, the used fluid should be collected, filtered, and recycled.

On the basis of the prescribed channel structure and the dimensions of the cooling feed liquid system, the overall design project of the internal cooling feed liquid system is completed and shown as in figure 2. The internal cooling feed liquid system consists mainly of hydraulic oil tank, filter, oil hydraulic pump, relief valve, throttle valve, flow meter, globe valve, and so on. The main function of the throttle valve is to adjust the fluid flow. The relief valve is to limit the maximum pressure of the feed liquid system. At the same time, the relief valve also can provide protection when overload. At the end of the end-milling cutting process, the cutting fluid can be discharged quickly from the globe valve. The accumulated fluid plate is to collect the used cutting fluid. And the hydraulic oil tank and the filter are used to sedimentate and filter the used cutting fluid, so that the cutting fluid can be kept clean.
3. Hydraulic design of the internal cooling feed liquid system

3.1. Computation of the feed liquid system flow

The number of channels was set to 2 (shown in Figure 1) because of limited space within the end-milling cutter. Larger numbers of channels result in that the strength of the end-milling tool is reduced and even it is difficult to process. The cutting fluid discharges at the tip of the end-milling cutter. So for the reason, only 1/2 of the total coolant is provided through one channel. So the total flow of the system is double that of every channel flow. It can be expressed with Eq. (1). And one channel flow contains two parts, including the flow produced by centrifugal force ($q_1$) and the flow caused by pressure difference of the internal cooling holes inlet and outlet ($q_2$). And it can be represents with Eq. (2).

$$Q = 2q$$  \hspace{1cm} (1)

$$q = q_1 + q_2$$  \hspace{1cm} (2)

Where, $Q$-total flow of the system, $q$-one channel flow, $q_1$- the flow produced by centrifugal force, $q_2$- the flow caused by pressure difference of the internal cooling holes inlet and outlet.

3.2. The flow produced by centrifugal force

It is assumed that the cutting fluid flow is under centrifugal force, and the flow is presumed steady flow. So the flow produced by centrifugal force can use approximate formula Eq. (4) to integrate.

$$a = \frac{du}{dt} = \frac{du}{dr} \frac{dr}{u} = r\omega^2$$  \hspace{1cm} (4)

Figure 2. Schematic diagram of internal cooling feed liquid system.
\[ r = \frac{H}{2} \]  

(5)

Where, \( u \)-the velocity of the internal cooling hole center, \( r \)-the distance between the internal cooling hole center and the end-milling center, \( H \)-the distance between the two internal holes, \( \omega \) - rotational angular velocity.

### 3.3. The flow caused by pressure difference

The flow caused by pressure difference of the internal cooling holes inlet and outlet, heedless of centrifugal force consequence, can be expressed with EQ. (6).

\[ q = \frac{\pi d^4}{128\mu L} \Delta p \]  

(6)

Where, \( d \)-the diameter of the internal cooling hole, \( \mu \)-the dynamic viscosity, \( L \)-length of the end-milling cutter, \( \Delta p \) - differential pressure.

On account of the specified internal cooling channel, the hydraulic design is finished. The minimum flow comes from the flow produced by centrifugal force.

If \( Q < 2q_1 \), the squirted cutting fluid shows frosted appearance. And furthermore, the smaller the flow of the feed supply system provided, the greater the atomization.

If \( Q > 2q_1 \), the cutting fluid is ejected continuously. And with the increase of the cutting fluid of the feed supply system, the pressure of the internal cooling channel inlet also increases.

Of course, so in order to reach good cooling effect, the total flow of the system should be greater than the flow produced by centrifugal force.

### 4. Computational fluid dynamics simulation

To determine the feed liquid system, the flow of the fluid is known as average value. And one of the computational fluid dynamics (CFD) software Fluent is used to get more detail about the cutting fluid from the outflow of the internal cooling channel.

Resemble the preceding result [12], only the cutting fluid discharge of the inlet is changed. The less leakage, and the better performance of the feed liquid system. And the leakage of the components is neglected in the simulation. The result of the feed liquid system flow is displayed in Figure.3. Because the diameter is especially small, the flow difference of the feed liquid system under different inlet velocities. The velocity of the inlet is increased from 17.3 m/s to 37.4 m/s, the flow only add about 3 L/min.

The CFD simulation is based on N-S-equation and the same boundary conditions, velocity and pressure under different inlet parameters are given in figure.4 and figure.5, respectively. Figure 4 shows the simulation of the velocity field with different inlet velocity. And the simulation is assumed under a single phase flow (only cutting fluid). With the increase of inlet velocity, the cutting fluid outlet axial velocity is gradually increased. And the cutting fluid close to the hole-wall flows faster.
The simulation result of the pressure field is shown in Figure 5. With the increase of inlet velocity, the low pressure area shows an accelerating expansive trend, but the pressure close to the hole-wall is relatively higher. So the liquidity of cutting fluid is good.

5. Conclusion
A high-speed end-milling cutter with an internal cooling lubricant feed system which affords a direct cutting fluid into the tool-chip interface zone was preferred in the paper. As using the feed liquid system for the internal cooling end-milling cutter, the overall contact area is continually offered with cutting
fluid. And the simulation result about the design is given. And it is consistent with the expected design goal.

In the feed liquid system for the internal cooling end-milling cutter, in addition to the adjustable flow of the cutting fluid, the feed liquid pressure and the cleanness of the cutting fluid should all be considered. Designing reasonable feed liquid system can not only improve the adaption in the actual production of the internal cooling end-milling, but also can enhance the reliability of the supply liquid system. Thus every components of the system can maximum play role, and it is also helpful to lower cost.

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