

MODELING OF COOLANT FLOWS FOR IN-PROCESS OPTICAL MEASUREMENT

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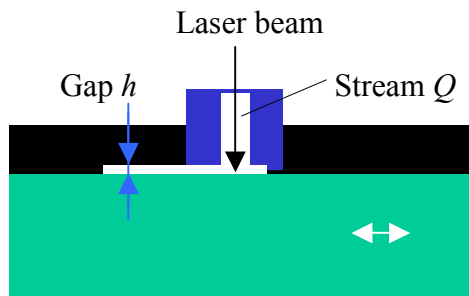
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Abstract: Mathematical models to describe the fluid flows are presented. The models are derived based on fluid dynamics principles. The purpose of the work is to provide a theoretical basis for parameter adjustment for a newly developed method for in-process optical measurement under coolant conditions. In this method, the coolant fluids are removed using a fluid stream to build a transparent window for measurement. It shows that the size of the transparent window is a function of the flow, the velocity, the gap, and the viscosity of the coolant. In the experimental testing, images of the coolant flows were obtained and results were compared with those of the theoretical models. The comparison shows good agreement between them.

Keywords: in-process measurement, surface profile, fluid flow, coolant

Introduction

In general, the coolant fluids must be applied at the grinding zone during grinding operation. However, the coolant fluids are opaque and cover the surface of the workpiece. This causes in-process optical measurement of the surface profiles impossible. In order to realize in-process optical measurement, a device is designed [1], in which, as shown in Fig. 1, the optically transparent fluid is used to remove the coolant fluids, then, a transparent window is generated. The laser beam can go through the transparent window and reach the surface of workpiece for the measurement.



The transparent window is a hyperbolic curve opening along the coolant movement direction and governed by many factors. Q , h , V_w are three main parameters. The parameter Q is the flow rate of the transparent fluid with the unit ml/s, h is the gap between measurement device and the test surface, and V_w is the velocity of

test surface, which is the same as the velocity of coolant fluid flow. The relationships between the transparent window parameters and the transparent fluid flow rate Q , the machine table movement speed V_w , and the gap between the transparent window device and workpiece surface h are to be examined.

Mathematical Models of the Coolant Flows

According to the basic analysis [2-5], the transparent fluid flow Q is a point source. In the real system, the gap h is quite small, so we can admit it to be as a line source. The complex potential for a line source located at the position $z=z_0$ is

$$F = \frac{m}{2\pi} \ln(z - z_0) \quad (1)$$

On the other hand, the coolant flow can be simplified to a uniform flow at V_w velocity and along the direction of workpiece movement. This flow and the line source are combined to a flow potential field as described in Fig. 2.

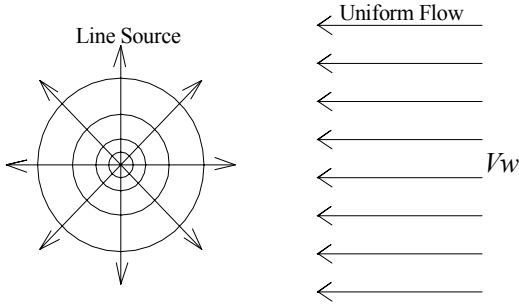


Fig. 2 Flow potential field

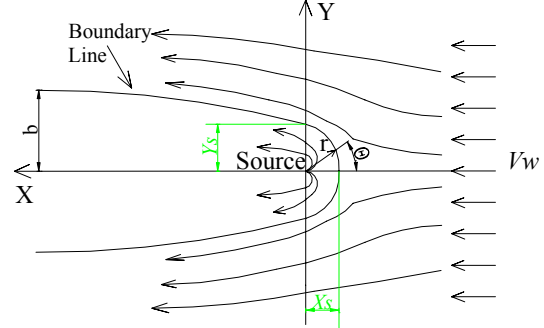


Fig. 3 Stream lines and boundary line

The stream function [2, 4-5] is

$$\psi = V_w y + \frac{Q}{2\pi h} (\pi - \theta) + C \quad (2)$$

The interface boundary of the two fluids includes the stagnation point. So the boundary line, as shown in Fig. 3, can be computed from $\psi=0$. Therefore,

$$y = \frac{Q}{2\pi h V_w} \theta \quad (3)$$

where $\theta \rightarrow \pi$, $y = b = \frac{Q}{2hV_w}$. $\theta=0$, $y_0=0$, $x_0 = \frac{Q}{2\pi h V_w}$. $\theta=\pi/2$, $y_1 = \frac{Q}{4hV_w}$, $x_1=0$. The parameters

$X_s=x_0$ and $Y_s=y_1$ will be used to describe the transparent window form in the future.

For the above basic models, the flow potential field is supposed as an ideal flow field. In fact, this flow field is in a narrow region between two plates, which is quite small from workpiece surface to the bottom of transparent window device. Owing to the viscosity, boundary layer effect should be one of main factors for transparent window. In the gap between the two plates, the coolant fluid flow is a plane Couette flow because of viscosity; its velocity is variable at different laminar layer. The velocity profile is plotted in Fig. 4. According to the no-slip boundary condition, it is a linear relationship. Therefore,

$$V_x = \frac{V_w}{h} z \quad (4)$$

Specially, $v_x(z=0)=V_w$ and $v_x(z=h)=0$.

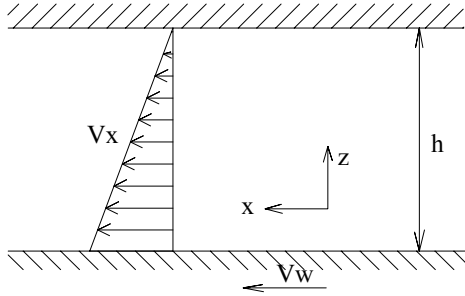


Fig. 4 Coolant fluid flow velocity

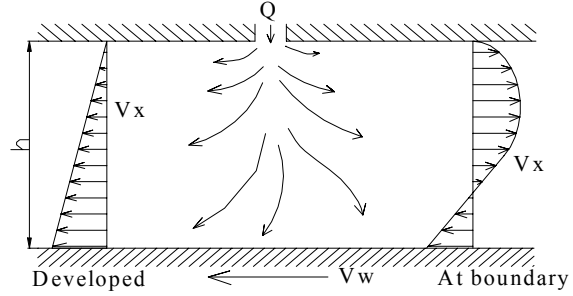


Fig. 5 Transparent fluid flow velocity

Similar to coolant fluid flow, transparent fluid flow is affected by two plates too. As a line source, transparent fluid flow is complex around jet point and at a narrow region between a moving plate and a steadying one. The flow is a composite flow, which consist of a Couette flow and a line source flow. Let the Couette flow velocity be v_{x1} and the line source velocity be v_{x2} , then the sum represents the flow $v_x = v_{x1} + v_{x2}$, as shown in Fig. 5. The Couette flow is a shear flow, which is governed by shear stress from viscosity. In this case, shear stress $\tau_{zx} = \mu dv_x / dz$. Thus, the velocity will be governed by fluid viscosity μ and velocity V_w of the moving plate.

According to the above analysis, the boundary line of transparent window is the function of parameters Q , h , V_w . Furthermore, owing to the effect of boundary layer, the viscosity of fluid affects the velocity profile. So, the transparent window will be governed of Q , h , V_w and μ . It can be described as:

$$x_s = \frac{Q}{2\pi h V_w} \cdot C_x \quad (5)$$

$$y_s = \frac{Q}{4h V_w} \cdot C_y \quad (6)$$

where C_x and C_y are the coefficients that depend on the fluid viscosity μ and the plate materials.

Experimental Results and Discussion

An experimental system has been set up to investigate the flow fields. The flow field images under different conditions covering parameters Q , h , V_w have been measured [3]. Let parameters h and V_w be constant and change the Q , we get the different transparent window regions. Fig.6 to Fig. 9 are the sample images of flow field when $h=0.3\text{mm}$ and $V_w = 111\text{mm/s}$. Similar to the Q experiments, let Q and V_w be constant, a serial of X_s and Y_s under different h can be measured.

Let Q and h be constant, another X_s and Y_s under different V_w are measured and shown in Fig.10 and Fig.11, where X_{sv} and Y_{sv} are the curve of real data; X_{so} and Y_{so} are the theoretically line depending on the model equation.

It can be seen that within the effective region that are 4mm and 5mm at x and y axis, respectively, in this experiment, the actual data are suitable with the models.



Fig. 6 $Q=2.25\text{ml/s}$

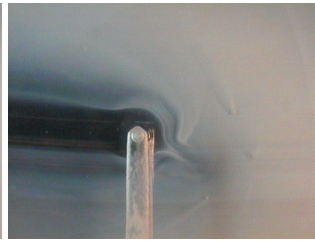


Fig. 7 $Q=1.305\text{ml/s}$



Fig. 8 $Q=0.562\text{ml/s}$

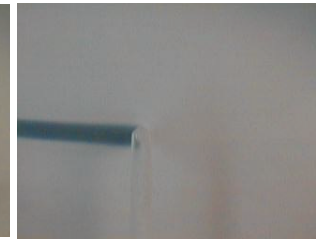


Fig. 9 $Q=0.250\text{ml/s}$

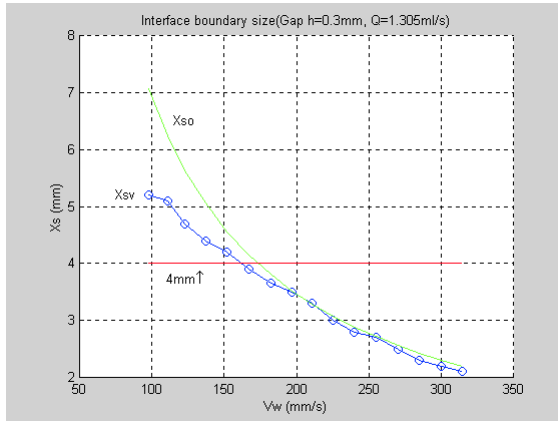


Fig. 10 X_s and X_{s0}

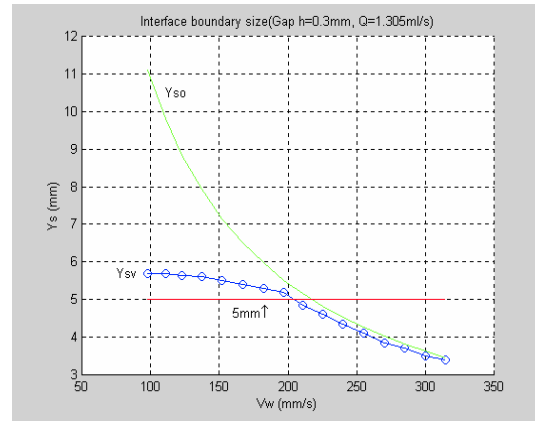


Fig. 11 Y_s and Y_{s0}

Conclusions

The coolant fluid field has been analyzed. The models are developed based on the fluid dynamics principles. The models can be used to calculate the size of the transparent window, if the one is within the effective region. The research work should be useful to design a suitable system based on the parameters Q , h , and v_w to create a required transparent window.

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