ANALYSIS OF FLOW CHARACTERISTICS OF ROTATIONALLY SYMMETRIC SEAL GAP WITH SLIP BOUNDARY CONDITIONS

Zhaomiao Liu [a)], Guobin Wang
College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, Beijing, 100124, China

Summary Both theoretical analysis and numerical simulation method are adopted to understand the flow and bearing performance with the slip boundary conditions in the rotating disk with symmetrical seal gap. And further comparative analysis is taken on the role of non-linear movement of slip along the rotating disk gap wall. Results will provide references to the applications of rotating disc gap flow under high-pressure and high-shear special conditions.

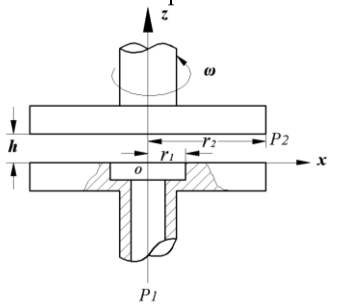
INTRODUCTION

The disc gap flow is wildly used in slip clutch, hydraulic pump and fluid thrust bearing system etc. Studies of gap flow mainly include analysis of rotationally symmetric disc flow gap [1] and analysis of extrusion flow in two parallel discs [2]. However, there is a little investigation of boundary slip in the rotationally symmetric seal gap. Using a system with radius of 60mm and end-gap thickness of 53μm disc rheometer experimental Chang [3] found the slip coefficient that is 2~ 50μm. Navier proposed the Navier slip model in which the wall slip velocity is proportional to the local velocity gradient [4]. The non-linear slip model under high shear rate conditions and the limit shear slip model for viscoplastic fluid are also proposed in the boundary slip investigations. This paper derived the mass flow and bearing capacity of rotationally symmetric gap flow under the action of the Navier slip model and numerically analyze the wall slip velocity magnitude along the radius and circumferential under different slip model and slip length.

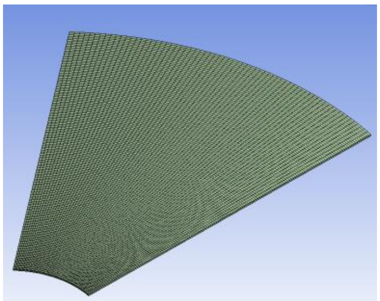
FLOW EQUATIONS AND WALL SLIP BOUNDARY CONDITIONS

Rotary shear seal gap geometry and numerical analysis parameters

The ideal model of rotational symmetric gap flow is simplified from static pressure hydraulic components of the sealing hydrostatic thrust bearings and slip rings (Fig.1(a)). The upper disc rotates at ω but the lower is static so the liquid flow driven by pressure and rotating shear in sealing gap. As shown in Fig.1(a), r_1=0.02m, r_2=0.08m, h is 0.05 mm~0.3 mm, P_1=0.34MPa, P_2=0, the rotation speed of upper disc is n=700r/min, and the viscosity of fluid liquid is μ=0.0721Pa.s. The cylindrical coordinates and periodic boundary condition are used in the numerical analysis as shown in Fig.1(b), which is able to improve the efficiency of numerical simulation.



a. Sketch of rotational symmetry gap flow



b. Sketch of refined grid for simulation

Fig.1 Sketches of model and refined simulation grid

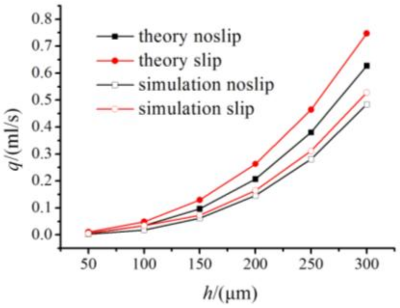


Fig.2 Comparison of simulation and theory of mass flow rate in rotational seal gap flow

Theory derivation of rotation sealing gap flow with slip condition

The sealing gap flow under pressure is the full development laminar flow and can be simplified to 2D Poiseuille flow. Using the Navier slip boundary condition, the mass flow of sealing gap caused by pressure can be derived as

$$q_1 = \frac{\pi h^2 (b+h)\Delta p}{6\mu \ln(r_2 / r_1)} \tag{1}$$

where b is slip length, $\Delta p = P_1 - P_2$. The mass flow of sealing gap caused by rotating shearing is derived as

$$q_2 = \frac{\rho \pi h^3 \omega^2}{18\mu}\left(\frac{h+2b}{2(h+b)} - \frac{h}{5}\right)(r_2^3 - r_1^3) \tag{2}$$

The mass flow of pressure driven and shear-driven make up the overall mass flow of rotationally symmetric flow in disc gap, that is

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[a)] Corresponding author. Email: lzm@bjut.edu.cn.

$$q = q_1 + q_2 = \frac{\pi h^2 (b+h)\Delta p}{6\mu \ln(r_2 / r_1)} + \frac{\rho \pi h^3 \omega^2}{18\mu}\left(\frac{h+2b}{2(h+b)} - \frac{h}{5}\right)(r_2^3 - r_1^3) \tag{3}$$

RESULTS AND ANASYSIS

Comparison of theory and simulation of flow characteristic with wall slip

Fig.2 shows the comparative analysis of the effect of slip on the flow characteristics of sealing gap between theory and numerical results. It shows that the change trend of the flow mass rate with seal gap thickness for theoretical are almost the same as that for simulation, but the numerical results are less than that of theoretical case. The slip boundary condition improves the mass flow rate at the same gap thickness.

Table 1 shows the bearing capacity results of disc seal gap flow at different gap thickness, when the slip parameter is b=1.0μm and seal gap thickness is 50μm~300μm. The bearing capacity is increasing while the thickness of gap flow is reducing. For the same thickness cases, the bearing capacity of slip cases is less than that of no-slip cases. When the gap thickness is smaller, slip will lead to even lower bearing capacity than no-slip cases. That is, wall slip boundary condition reduces the bearing capacity of seal gap flow.

Table1 The capacity of disc gap flow at different gap thickness

h (μm)	No-slip case	Slip case
50μm	37659.3	37656.3
100μm	37646.8	37645.8
150μm	37616.86	37615.8
200μm	37525.4	37498.6
250μm	37315.3	37265.2
300μm	36932.0	36847.7

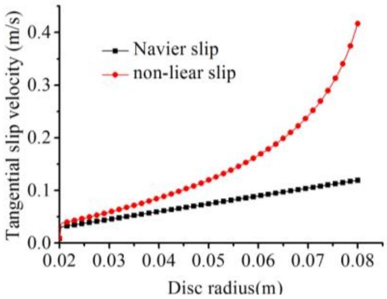

Fig.3 Tangential slip velocity along radius

Non-linear effect of wall slip in the rotating symmetric gap flow

Thompson 错误！未找到引用源。 described that the slip depends on the shear rate and presented the non-linear slip model by molecular dynamics simulation method, and it is expressed as

$$u_s = b_0 \dot{\gamma} / (1 - \dot{\gamma} / \dot{\gamma}_C)^{-1/2} \tag{4}$$

where b_0 is the initial slip length parameter, $\dot{\gamma}_C$ is the critical shear rate and b is non-liner slip length. When $\dot{\gamma}_C \to \infty$, $b \to b_0$, then non-linear slip model becomes the linear Navier slip model. When b_0 is very small, the non-linear slip model becomes the limit shear stress model.

Fig.3 shows that tangential slip velocity along radius with the non-linear slip condition. In the simulation, the gap thickness h=200μm, rotation speed is of 3000r/min, the slip coefficient is b_0=1.0μm and the limit shear rate is 1.5e5Pa. The tangential slip velocity increases linearly with radius of Navier slip, which is similar to results of literature [15] but non-linearly of Non-linear slip condition. When r =0.02m, the tangential slip velocity are same. With the radius increasing, that is, the shear rate increasing, difference of slip velocity appears gradually.

CONCLUSIONS

From the simplified N-S equations, theoretical derivation of the rotating disc gap flow control equation with wall slip condition is obtained. The results are consistent with that of numerical simulation. It is shown that the slip effect will increase the mass rate, and reduce the bearing capacity of gap flow. Non-linear slip boundary condition is introduced into rotational symmetry seal disc gap flow, and comparative analysis has done with the Navier slip model at high shear rate condition.

ACKNOWLEDGEMENT

The authors do thank the support of National Natural Science Foundation of China (Grant No.11072011 and No. 11002007)

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