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# Flow Criterion Research on Fluid in Hydrostatic Bearing from Laminar to Turbulent Transition

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***Abstract***

*The multi- pad circular guide hydrostatic bearing of heavy-duty CNC machine is taken as the research object. Based on the lubrication properties of the heavy hydrostatic bearing, viscosity-temperature equation of interstitial fluid is established in various viscosities. In accordance with factory actual production, the fluid critical from laminar to turbulent is calculated by finite volume method. The inner flow field of hydrostatic bearing is simulated, when the rotating speed of workbench is 6r/min at different flow. The simulation results reveal flow distribution low and verify the reliability of the calculation. The results show that, the transition critical inlet fluid flow from laminar to turbulent of fluid in hydrostatic bearing is 22L/min. Through the above analysis and research, reveals the flow rule of the hydrostatic bearing oil film bearing gap, provides a theoretical basis for actual hydrostatic bearing for engineering structural optimization design.*

***Keywords:*** *hydrostatic bearing, flow field, finite volume method, flow criterion*

## 1. Introduction

Now, with the development of modern industry, rotating machinery tends to be more efficient, high-speed, high-precision and high-power, and the need precision, low power consumption, high stability of the bearing as a system support. Accordingly, following the study of the hydrodynamic lubricating bearing, shows that the hydrostatic bearing lubrication performance has a great impact on the bearings service life and reliability. Its lubricating performance will directly affect the entire machine reliability, longevity and economic indicator

Currently, scholars have studied on film lubrication performance to a certain degree. Scholars Sharma, Satish C. using the finite element method theoretically studied the performance of four containers hydrostatic tapered bearing system. Establish the bearing clearance space control flow lubrication Reynolds equation. Calculate the numerical values of different external load bearing static and dynamic performance. The simulation results show that the oil flow is also a greater impact on the capacity of the tapered bearing [1] .In 2012, Maher, Bilal M. A.studied on the Stokes movement of viscous fluid oil in the fluid hydrostatic bearing, which is elliptical outer boundary, and concentric circle inner boundary. Through analysis in the form of graphics, given a two-dimensional pressure distribution, and calculate the total thrust approximate estimates, derived the result consistent with the aforementioned theoretical results [2]. De Pellegrin, Dennis V.and Hargreaves, Douglas J. pointed out that it is that the bearing

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with constant external turbocharged prolonged the service life of the bearing and decreased the friction and wear ,and simulated the influence the size and shape of the groove have on the bearing performance [3]. Nicodemus, E. Rajasekharand Sharma, Satish C. studied the theoretical influence micro polar lubricants have on wear properties of hydrostatic bearing with 4-vessel and compensation of capillary resistor, simplified the lubricants with additive into micro polar fluid, and solved the flow equation and the Reynolds equation using the finite element method [4]. In 2001, M. Wen-qi, J. ji-hai, Z. Ke-ding, has numerically analyzed the characteristics of fluid flow in annular hydrostatic bearing considering variable viscosity and different working condition by the finite element method, obtained viscosity field distribution, and compared with in constant viscosity. The result proved that the influence which the changing oil viscosity have on the pressure distribution of hydrostatic bearing in a high relative rotating speed between friction pairs cannot be neglected [5,6].

The paper summarizes the vertical lathe workbench at home and abroad and the performance of hydrostatic guide-ways [7-16], study for vertical lathe hydrostatic bearing, establish hydrostatic bearing fluid model. Calculate the numerical values of gap fluid flow field under different inlet flow, and get the flow state distribution of the gap fluid. Explore the inlet flow rule of the flow state distribution of this vertical lathe hydrostatic bearing. Determine the hydrostatic bearing fluid transition flow from laminar to turbulent, thereby improving the entire machine's precision.

## 2. Hydrostatic bearing gap fluid model and control equation

### 2.1. Gap Fluid Model

A three-dimensional geometric solid model of the intermediate film in many oil pad circular guide hydrostatic bearing is generated by UG, which is the specialized three-dimensional CAD software, as is shown in Figure 1.

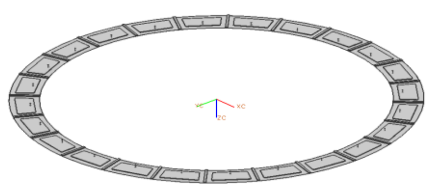

**Figure 1. Gap fluid mode of hydrostatic bearing**

### 2.2. Control Equation

The basic equation is mostly set on the control volume in the discussion of fluid dynamics. The basic equation has two forms of integral and differential [18-19]. The integral relationship of fluid physical quantities was gained through quadrate the control volume and the control plane. The differential relationship of fluid physical quantities was obtained from any space point by mapping the equation of the micro-control element or the system directly. The general performance relation such as the resultant force between objects and the main energy exchange can be obtained through solving the basic equation in integral form. The flow details and the fluid physical quantities from any space point can be gained by solving the basic equation in differential form or the integral relationship of the micro-control element. The main differential equations are the mass conservation equation, the momentum conservation equation and the energy conservation equation.

 

The influence of centrifugal force should be taken into consideration due to the rotating motion droved by the rotating worktable. When the fluid rotates at a constant angular velocity of ! in the rotating frame, the new kinetic energy should take the influence of the coriolis force and the centrifugal force into account .The relevant formulas are shown as follows:

$$
\begin{aligned}
S_{cor} &= -2\rho\omega \times U \\
S_{cfg} &= -\rho\omega \times (\omega \times r) \\
S_{M,rot} &= S_{Cor} + S_{cfg}
\end{aligned}
\tag{1}
$$

Where $S_{Cor}$ is the coriolis force, $S_{cfg}$ is centrifugal force, $r$ is the position vector of the micro-control element under rotational coordinate, $U$ is the velocity, $\omega$ is the rotational angle-velocity.

In the energy equation, the equation of total enthalpy is:

$$I = h_{stat} + \frac{1}{2}U^2 - \frac{1}{2}\omega^2 R^2 \tag{2}$$

Where $h_{stat}$ is the static enthalpy.

The mass conservation equation, the momentum conservation equation and the energy conservation equation can be listed out considering the centrifugal force through the above equation.

The mass conservation equation is:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0 \tag{3}$$

Where $\rho$ is the density, $t$ is the time. The density is a constant value for that the research fluid is incompressible fluid, i.e. $\frac{\partial \rho}{\partial t} = 0$ , $\nabla$ is the divergence. That is:

$$\nabla \cdot (\rho U) = \mathrm{div}(\rho U) = \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{4}$$

Where $u$ . $v$ . $w$ is the components in x, y and z directions of velocity vector $U$ .

The momentum conservation equation is:

$$\frac{\partial(\rho U)}{\partial t} + \nabla(\rho U \otimes U_{abs}) = \nabla(-p\delta + \mu(\nabla U + (\nabla U)^{T})) - \rho\omega \times U - \rho\omega \times (\omega \times r) \tag{5}$$

Where $p$ is the stress on the fluid micro-element, $U_{abs}$ is the velocity vector on the absolute coordinate, $\mu$ is the viscosity , $\rho$ is the density.

The energy conservation equation is:

$$\frac{\partial(\rho h_{tot})}{\partial t} - \frac{\partial p}{\partial t} + \nabla \cdot (\rho U h_{tot}) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (U \cdot \tau) + U \cdot S_M + S_E \tag{6}$$

Where $h_{tot}$ is the total enthalpy, $T$ is the temperature (℃), $\lambda$ is the fluid heat transfer coefficient of the fluid, $S_M$ is the momentum source, $S_E$ is the inner heat source and the part that the mechanical energy caused by the viscosity is converted into the heat energy.

In the article, it is necessary to point out that the energy conservation can be ignored for the incompressible flow and without considering the heat transfer.

 

# 3. Theoretical Calculations and Numerical Simulation Analysis

## 3.1. Theoretical calculations

There are two flow state in pipe flowing: laminar flow and turbulent flow. Laminar flow means that when the liquid flow, no lateral movement of fluid particles, no mixing, no interfering, linearly or laminar flowing. Turbulent flow means that when the liquid flow, fluid particles has a lateral movement, strong mixing, particle colliding, doing the flow in mixed and disordered state. The state of the hydrostatic bearing fluid flow can be calculated by calculating the Reynolds number. Reynolds number is calculated as follows:

$$Re = 0.001 \upsilon \rho h / \mu \le 1000 \tag{7}$$

In the formula, $\rho$ is the fluid density; $\upsilon$ is average velocity of the fluid; $\mu$ is the kinematic viscosity of the fluid; $h$ is the bearing gap.

The research object in this paper is the large size hydrostatic bearing, the oil cavity depth is much greater than the oil pad, so even in the case of high speed. Oil flow in oil cushion remains the state of laminar flow. And the flow state in the oil chamber only needs computational analysis to get. This research object uses quantitative oil, the load range of the workbench is 61.2t ~ 165.2t, the corresponding inlet flow range is 3L/min ~ 12L/min.

In the case of the workbench rotational speed constant, which use the working commonly speed of 6r/min. The critical Reynolds number is Re=1000, then the inlet flow is 22L/min. For comparison, also calculate the inlet flow correspondence rates of 12L/min, 22L/min, 24L/min, 36L/min, 48L/min Reynolds number as shown in Table 1.

**Table 1. Reynolds Number in Different Inlet Flow**

| Flow (L/min) | 12 | 22 | 24 | 36 | 48 |
|---|---|---|---|---|---|
| Reynolds number | 733 | 1000 | 1065 | 1384 | 1729 |

## 3.2. Numerical simulation analysis

When considering changed viscosity conditions, other boundary conditions constant, set the workbench rotational speed of 6r/min constant. The inlet flow rates of 12L/min, 22L/min, 48L/min, and obtain the flow chart were shown in Figure 2, Figure 3 and Figure 4 in CFX.

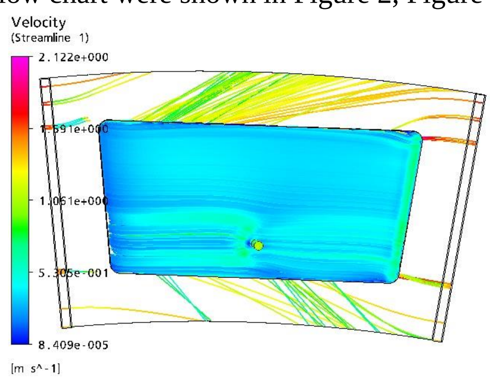


**Figure 2. Streamlines of 12L/min inlet flow**

 

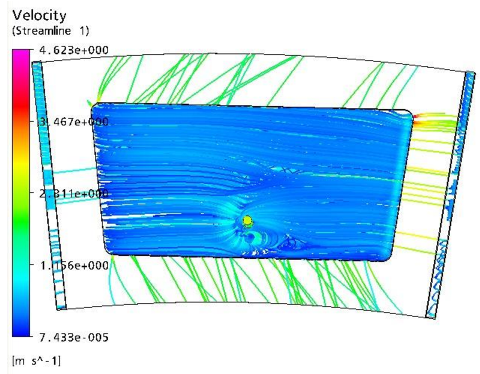


**Figure 3. Streamlines of 20L/min inlet flow**

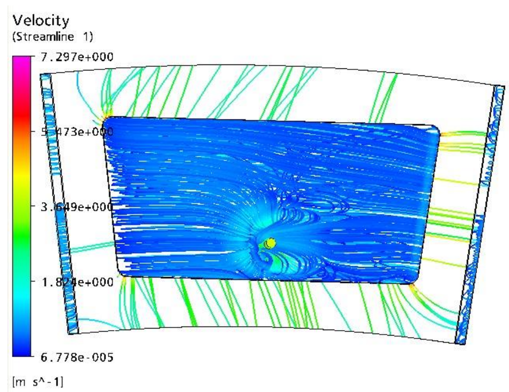


**Figure 4. Streamlines of 36L/min inlet flow**

It can be seen from Figure 2, when the inlet flow is 12L/min, that the flowing lines in oil chamber is very smooth, no flow lines, lines cross and no any swirl. It can be seen that the flow is a laminar flow. In Figure 3, when the inlet flow is the critical inlet flow whose velocity is 22L/min, there are some swirls near the flow line of the oil chamber inlet. The rest flow lines are very smooth. It can be seen that the flow is critical state of laminar and turbulent flow. Figure 4 shows that when the inlet flow-rate of oil chamber is 36L/min, there are lots of significant flow lines and lines cross in oil chamber and a large number of swirls. Its flow state is a typical turbulent flow.

## 4. Conclusion

Gap fluid in large size hydrostatic bearing is numerical analyzed by finite volume method. The result reveals gap fluid flow state in different flow. Based on the flow simulation by CFX, the critical inlet flow is 22L/min when the worktable speed is 6r/min. Compared the simulation and calculation datum in Table 1, the simulation is agree with the calculation values and simulation is practical and reliable.

Divergence phenomenon did not appear during numerical simulation. It indicates that it is stable to solve equation by finite volume method. At the same time, the flow distribution of interstitial fluid on hydrostatic guide is accord with the practical. It testifies that the research method is credible.

 

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