Analysis on Oil Film of Hydrostatic Bearing in Gear Pump Operating at High Pressures and High Speeds

Lupeng WU[1], Baoyu SONG[*1], Yang ZHOU[1] and Minghui HAO[1]
[1.] *Department of Mechanical Engineering*, Harbin Institute of Technology, Harbin, Heilongjiang 150001, China

***Abstract* — The model of oil film in hydrostatic bearing used in gear pump operating at high pressures and high speeds was established with CFD method. Under certain eccentric ratio, the pressure distribution of oil film, the flow velocity of hydraulic oil and the leakage at different rotation speed were respectively calculated. Force conditions and motion of the oil film in the hydrostatic bearing were studied when gear pump operated at high pressures and high speeds. The results show that under certain eccentric ratio, the oil film in relief groove generates pressure drop and vortex. And the phenomenon of vortex becomes more obvious with increasing rotation speed. Also the mass flow rate of the outlet is reduced with increasing rotation speed.**

Keywords* - *Hydrostatic bearing*; *CFD*; *High speeds*; *High pressures*; *Oil film pressure

Ⅰ. INTRODUCTION

Hydrostatic bearings are widely applied in gear pumps, and the oil film of hydrostatic bearing plays an very important role in supporting rotor, cooling down rotor and lubricating rotor.[1-3]When gear pumps operate, rotor stability is directly affected by the working state of oil film. Currently, most scholars use to study the characteristics of oil film with the method of solving Reynolds equation.[4]But we can already use CFD technology to replace the fluid flow experiments with the rapid development of it. The pressure distribution of oil film in journal bearings at different rotation speed and eccentric ratio were calculated by Guo.[5]And the model of hydrostatic bearings used in gear pumps at high pressures and high speeds was presented by Zhou.[6]This paper integrate the analysis of hydrostatic bearings using CFD method by scholars to calculate the oil film of hydrostatic bearings applied in the gear pumps operating at high pressures and high speeds. On the basic of the results, the reasonableness of the design in hydrostatic bearings is verified.

Ⅱ. MODEL OF HYDROSTATIC BEARING

The study object in this paper is hydrostatic bearing used in the gear pump operating at high pressures and high speeds. There is a pressure drop of 25Mpa between the inlet chamber and the outlet chamber in gear pump, therefore a radial force of 2068.5N is generated on hydrostatic bearing where supports the rotor. In order to balance the radial force, inlet groove, relief groove and oil guide is designed. The 3D model of the hydrostatic bearing is shown in Fig.1.

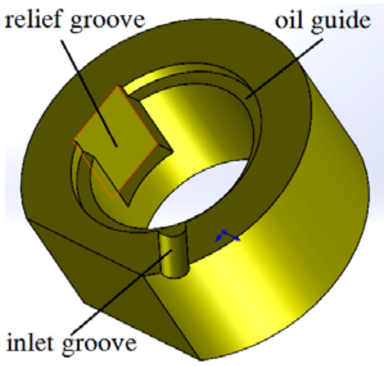


Fig. 1 3D model of hydrostatic bearing.

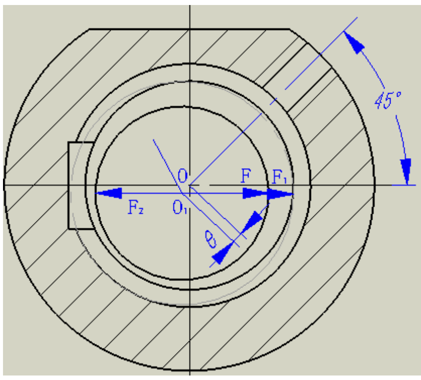


Fig. 2 Structure diagram of hydrostatic bearing.

Fig.2 depicts the structure of hydrostatic bearing. Where is the pressure generated in outlet chamber, is the pressure generated in inlet chamber, is the pressure generated by relief groove, and e is the eccentric distance.

III. MATHEMATICAL MODEL OF OIL FILM

Mathematical model of oil film in hydrostatic bearing is depicted in Fig.3.Where r is radius of rotor, R is radius of hydrostatic bearing, α is angle of inlet groove, e is eccentric distance which direction is along the axis of inlet groove. Rotor rotates clockwise around the center.

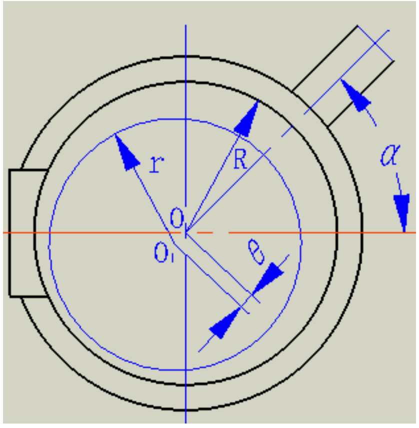


Fig. 3 Mathematical model of oil film.

In the FLUENT software, the oil film of hydrostatic bearing in the gear pump operating at high pressures and high speeds is calculated with the non-compressible equations called N-S, and the equations as follows.

$$\rho(\frac{\partial \upsilon_x}{\partial t}+\upsilon_x\frac{\partial \upsilon_x}{\partial x}+\upsilon_y\frac{\partial \upsilon_x}{\partial y}+\upsilon_z\frac{\partial \upsilon_x}{\partial z})=\rho X-\frac{\partial p}{\partial x}+ \frac{\partial}{y}[\mu(\frac{\partial \upsilon_y}{\partial x}+\frac{\partial \upsilon_x}{\partial y})]+\frac{\partial}{z}[\mu(\frac{\partial \upsilon_x}{\partial z}+\frac{\partial \upsilon_z}{\partial x})] \quad (1)$$

$$\rho(\frac{\partial \upsilon_y}{\partial t}+\upsilon_x\frac{\partial \upsilon_y}{\partial x}+\upsilon_y\frac{\partial \upsilon_y}{\partial y}+\upsilon_z\frac{\partial \upsilon_y}{\partial z})=\rho Y-\frac{\partial p}{\partial y}+ \frac{\partial}{x}[\mu(\frac{\partial \upsilon_y}{\partial x}+\frac{\partial \upsilon_x}{\partial y})]+\frac{\partial}{z}[\mu(\frac{\partial \upsilon_y}{\partial z}+\frac{\partial \upsilon_z}{\partial y})] \quad (2)$$

$$\rho(\frac{\partial \upsilon_z}{\partial t}+\upsilon_x\frac{\partial \upsilon_z}{\partial x}+\upsilon_y\frac{\partial \upsilon_z}{\partial y}+\upsilon_z\frac{\partial \upsilon_z}{\partial z})=\rho Z-\frac{\partial p}{\partial z}+ \frac{\partial}{x}[\mu(\frac{\partial \upsilon_x}{\partial z}+\frac{\partial \upsilon_z}{\partial x})]+\frac{\partial}{y}[\mu(\frac{\partial \upsilon_y}{\partial z}+\frac{\partial \upsilon_z}{\partial y})] \quad (3)$$

$$\frac{\partial \upsilon_x}{\partial x}+\frac{\partial \upsilon_y}{\partial y}+\frac{\partial \upsilon_z}{\partial z}=0 \quad (4)$$

where,

ρ ---the density of the hydraulic oil, Kg/m^3 ;

t ---the time , s ;

$\upsilon_x,\upsilon_y,\upsilon_z$ ---the flow velocity of hydraulic oil in the direction of x, y, z , m/s ;

X,Y,Z ---the tangential force in the direction of x, y, z , N ;

p ---the pressure, N ;

μ ---the dynamic viscosity of hydraulic oil, $Pa \bullet s$.

TABLE I shows that the dimension of oil film.

TABLE I. DIMENSION OF OIL FIL

parameters	value
radius of hydrostatic bearing ***R***	12mm
radius of rotor ***r***	11.8mm
Bearing width ***B***	20mm
angle of inlet groove α	45°
eccentric distance ***e***	0.06mm
eccentric ratio ε	0.6

The oil film is meshed by Workbench16.0 software, in which mesh type is tetra/mixed, max element is 0.001 and min size limit is 3e-7.Finally, the number of cells generated is around 3626458,as shown in Fig.4.

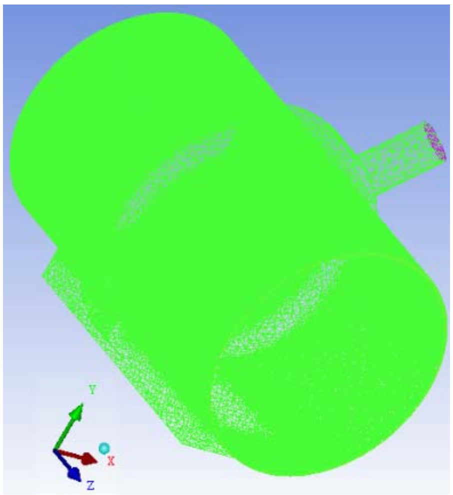


Fig. 4 Mesh of oil film.

The oil film is analyzed with FLUENT software. Conditions are supposed that hydraulic oil is incompressible, inertial force is ignored and viscosity is equivalent in all points of oil. The density of oil is $960Kg/m^3$, and the viscosity is $0.048Pa \bullet s$.

Boundary conditions are set that the inlet pressure is 25 MPa and the outlet pressure is 0.1Mpa and laminar is

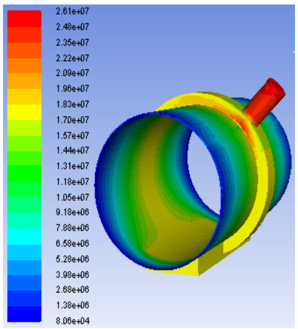
DOI 10.5013/IJSSST.a.17.43.25

ISSN: 1473-804x online, 1473-8031 print

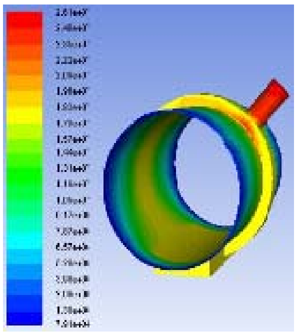
selected in FLUENT software. In addition, the continuity is set 2.5e-5.

Ⅳ. RESULTS OF THE SIMULATIONS

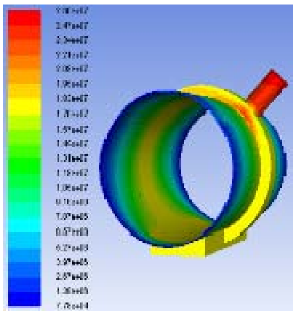
The pressure distribution of oil film, the flow velocity of hydraulic oil and the mass flow rate at different rotation speed were respectively calculated when parameters of oil film, eccentric ratio, mesh and boundary conditions are unchanged. Fig.5 shows the results of calculation at 6000, 7000, 8000, 9000, 10000r/min.



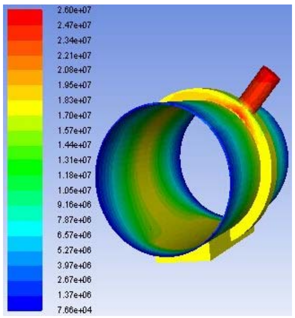
(a) $\omega = 6000r/\min$



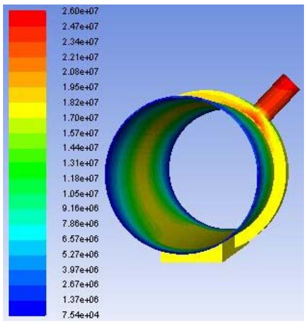
(b) $\omega = 7000r/\min$



(c) $\omega = 8000r/\min$



(d) $\omega = 9000r/\min$

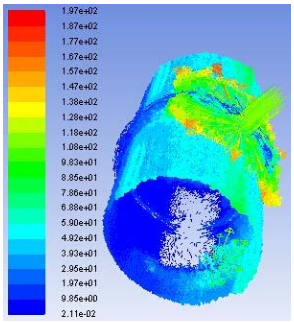


(e) $\omega = 10000r/\min$

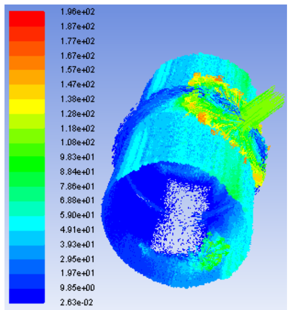
Fig.5 Pressure distribution of oil film.

In the figure, it can be seen that the pressure varies in oil film where the inlet groove owns the maximum pressure labeled 2.60e+07Pa, which is higher than the inlet pressure 2.50e+07Pa.Obviously, the pressure in relief groove generates a pressure drop, in which the pressure is only 18.11e+07Pa.In addition, figure 5 shows that rotation speeds have a little influence on the maximum pressure of the oil film at high pressures and high speeds.

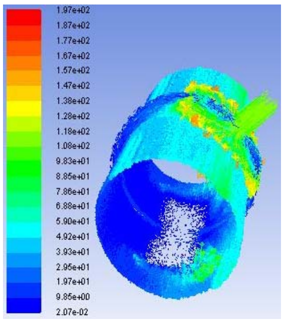
The flow velocity of oil film at different rotation speed is depicted in Fig.6.



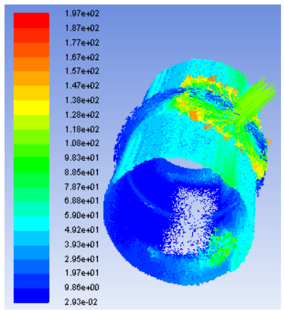
(a) $\omega = 6000r/\min$



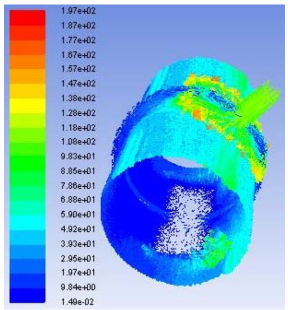
(b) $\omega = 7000r/\min$



(c) $\omega = 8000r/\min$



(d) $\omega = 9000r/\min$



(e) $\omega = 10000r/\min$

Fig. 6 The flow velocity of oil film.

It can be seen in the figure above that the maximum flow velocity of hydraulic oil in hydrostatic bearing is at the inner ring bearing and the inlet groove. In addition phenomenon of vortex is observed in relief groove and it becomes more obvious with increasing rotation speed. Figure.6 also shows that rotation speeds have a little influence on the maximum flow velocity of hydraulic oil in the oil film at high pressures and high speeds.

The relations between rotation speeds and mass flow rates in outlet are outlined in Fig.7. It shows that the mass

DOI 10.5013/IJSSST.a.17.43.25

ISSN: 1473-804x online, 1473-8031 print

flow rates decrease when rotation speeds increase with around linear relation.

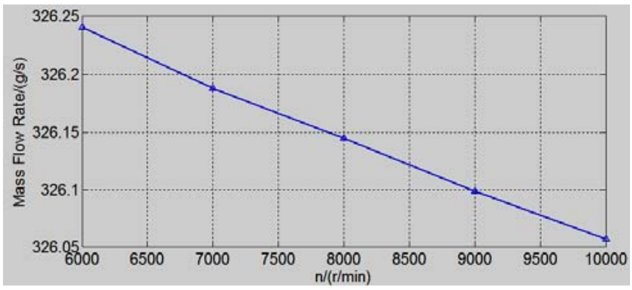


Fig. 7. The mass flow rates of oil film.

Ⅴ. CONCLUSIONS

This paper presents the model of oil film in hydrostatic bearing at high pressures and high speeds. Force conditions and motion of the oil film in the hydrostatic bearing were analyzed with FLUENT software at different rotation speed. The main results obtained in the study are as follow.

1. The pressure in relief groove generates a pressure drop, in which the pressure is only 18.11e+07Pa that not high enough to balance the pressure difference between the inlet chamber and the outlet chamber in gear pump.

2. Vortex is observed in relief groove and it becomes more obvious with increasing rotation speed, which demonstrates effects on stability of rotor increase with the increasing rotation speeds

3. The mass flow rates decrease when rotation speeds increase with around linear relation.

ACKNOWLEDGMENT

We wish to thank Professor Mohamed Hafez, Mechanical and Aerospace Engineering, University of California Davis, for his technical assistance and helpful discussion.

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