NUMERICAL ANALYSIS OF EFFECT OF GEOMETRIC PARAMETERS ON HYBRID PRESSURE DISTRIBUTION IN INTERNAL GEAR MOTOR AND PUMP

Pham Trong Hoa[1], Nguyen Thiet Lap[1], Ngo Ich Long[2], Nguyen Van Kuu[3]

Abstract: *The paper analyzes the effect of geometric parameters on proportion of hydrodynamic and hydrostatic pressure in the oil lubrication film of internal gear motor and pump. The Reynolds equation with appropriate boundary condition is solved to obtain 2D hydrodynamic pressure distribution by using the finite difference method (FDM). The resistance network model (RNM) is used to predict the hydrostatic pressure profile. Numerical calculations point out that the radial clearance has much effect on both static and dynamic pressure. The axial clearance has effect only on hydrostatic pressure profile. Meanwhile, the L/D ratio has slightly effect on pressure distribution*

Keywords: Pressure distribution, internal gear motor and pump (IGMaP), hydrodynamic, hydrostatic.

1. INTRODUCTION

Oil lubrication film is very important in the field of tribology science. With the help of oil lubrication during operation, the friction between the relative rotating surfaces is reduced and the vibration is absorbed, and therefore, it protects the rotating surfaces (Hamrock et al, 2004). Oil film pressure is one of the most important parameter of the oil film characteristics.

There are two classical categories of lubrication regimes, e.g., hydrostatic and hydrodynamic. The operating principle of hydrodynamic lubrication regime is based on the high rotating speed to produce the hydrodynamic pressure distribution which is balanced to the external applied forces. It means that the hydrodynamic pressure is dependent on the values of rotating speed. This lubrication mode is suitable for those machines that operate normally at high rotating speed. Meanwhile, hydrostatic lubrication regime operates based on the high external supplied pressure into film thickness to produce hydrostatic pressure which is balanced to the external applied force. In some cases, it exists simultaneously both of those pressure components. This is known as the hybrid regime of lubrication. According (Pham, 2019), for IGMaP the oil film runs at hybrid mode of lubrication.

Some studies relating to the issue of hybrid lubrication regime has been performed so far. The oil film temperature distribution for hybrid journal bearing was investigated by Xiu in study (Xiu et al, 2009). He pointed out that if the oil temperature in the film thickness exceeds over 75°C, it can cause the bearing failure. Hybrid pressure profile has been calculated by using FDM in study (Vijay et al, 2013) for journal bearing. The maximum pressure and the minimum fluid film thickness for hybrid journal bearing under micro-polar lubrication has been studied by (Rana et al, 2016). In study (Helene et al, 2003), Helene investigated the pressure distribution for journal bearing under the effect of flow in the feeding recess.

Due to lots of phenomenon happening inside, such as friction development, pressure and speed dependent on each other, it makes the hybrid pressure in IGMaP is complex (Pham et al, 2018). Until now, the issue of hybrid pressure in the oil lubrication film in IGMaP has been not released. This paper analyzes the effect of some geometric parameters on the simultaneously existence issue of

[1] *Faculty of Mechanical Engineering, University of Transport and Communications*

[2] *School of Transportation Engineering, Hanoi University of Science and Technology*

[3] *Faculty of Mechanical Engineering, Thuyloi University*

both hydrodynamic and hydrostatic pressure components by using finite difference method and hydraulic resistance.

2. GEOMETRIC CHARACTERISTICS OF THE RING GEAR AND FORMATION OF THE EQUATION

Three main elements of an internal gear motor and pump are depected in **Fig.1**, e.g., a ring gear which is consider as rotor, a fixed-pinion gear which connected to shaft, and the housing (stator). The diameter of outer ring gear has a slightly smaller than that of the inner housing. The space between the outer ring gear and the inner housing is called the thin gap which is filled by oil lubrication. Unlikely to other rotating machines, the oil lubrication is supplied from an external system. For IGMaP, the oil lubrication is taken directly from high pressure chamber. This means that the oil lubrication is also the working oil.

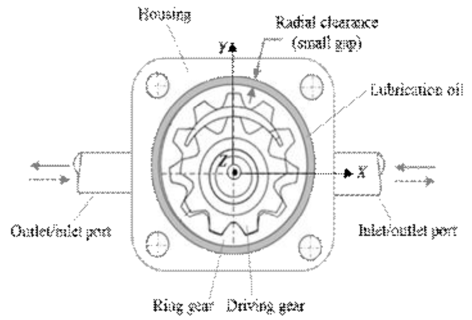


Fig.1. Internal gear motor and pump

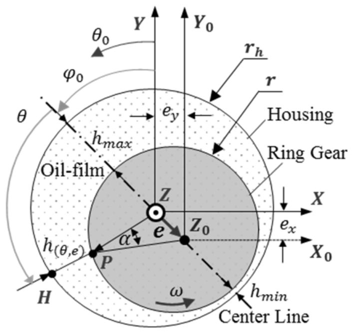


Fig.2. Oil film thickness

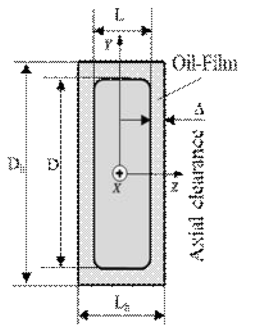


Fig.3.Radial clearance

Nominal radial clearance is the distance between the outer ring gear to inner housing surface when the ring gear and housing is centered in radial direction. The nominal radial clearance is presented in **Fig.1**. Nominal axial clearance is the distance in axial direction between the ring gear side to housing side in case of the ring gear and housing is centered. The nominal axial clearance is described in **Fig.3**. During operation, the oil film thickness is a function of eccentricity and position angle of the ring gear center. Based on the geometry of IGMaP in **Fig.2**, the oil film equation is formed as follows (Xiu et al, 2009):

$$h_{(\theta,e)} = c\left(1+\varepsilon\cos\theta\right) \quad (1)$$

Where: ε is the eccentricity ratio; i.e., the ratio of eccentricity to radial clearance (e/c); θ is the angle from the centre line (ZZo) to the measured point (H) along with the circumferential direction; c is the radial clearance; i.e., the difference between the radius of the housing (r_h) and the ring gear (r).

$$c = r_h - r \quad (2)$$

Hydrodynamic pressure distribution: The well-known Reynold's equation in its non-dimensional for incompressible liquid is described as follows (Hamrock et al, 2004):

$$\frac{\partial}{\partial\bar{\theta}}\left(\bar{h}^3\frac{\partial\bar{p}}{\partial\bar{\theta}}\right)+\left(\frac{D}{L}\right)^2\frac{\partial}{\partial\bar{z}}\left(\bar{h}^3\frac{\partial\bar{p}}{\partial\bar{z}}\right)=12\frac{\partial\bar{h}}{\partial\bar{\theta}} \quad (3)$$

Where: h is the film thickness [m]; c is the radial clearance [m]; r is the ring gear radius [m]; L is the length of ring gear [m]; D is the diameter of the ring gear [m]; μ is the dynamic viscosity [Pas]; p is the pressure [Pa]; θ, z are hydrodynamic film co-ordinates [m]. By the use of the finite different method (FDM) combining with appropriate boundary condition, the Reynolds equation has been solved to obtain 2D hydrodynamic pressure distribution.

Hydrostatic pressure distribution: The hydraulic resistance is defined according to Ohm's law in the same way as the electric one (Helene et al, 2003). The capillary in the supply line may be considered as a constant flow resistance. The flow in film thickness is also considered as flow resistance. This resistance depends upon the value of the film thickness and it is computed as follows,

$$R_t = \frac{1}{\left[c\left(1+\varepsilon\cos\theta\right)\right]^3} \quad (4)$$

The flow through the axial clearance is considered as the hydraulic resistance of a rectangular cross section. It is calculated as,

$$R_r = \frac{12\mu L}{\left(D\Delta^3(1-0.63\frac{D}{\Delta}\right)} \quad (5)$$

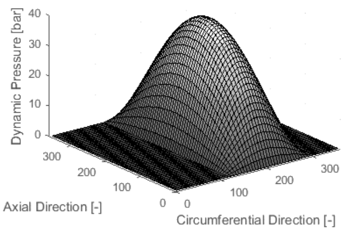
Based on the electrical diagram, it allows us to apply the formulas and symbols for the calculation of flow and pressure. The resistance network model (RNM) for calculation of hydrostatic pressure profile is governed based on the resistance flow equation. The hydrostatic pressure for each position of circumferential position is supposed the same over the axial direction. Thus, the hydrostatic pressure distribution in this paper will be presented in 1D.

3. SIMULATION RESULTS AND DISCUSSION

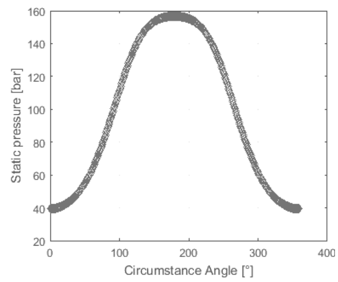
An in-house calculation tool has been established to optimal the calculation time. The typical working oil, HLP 46, is used in this study. This is also the oil lubrication. The dynamic viscosity of this oil is 0.042 Pa.s at the oil temperature of 40°C. The maximum working pressure is at value of 200 bar and the maximum rotating speed is at value of 2000 rpm. In study (Pham, 2018) pointed out that among geometric parameters of internal gear motor and pump, radial clearance, axial clearance and L/D ratio are the important parameters which have greatly effect on dynamic behaviour of IGMaP.

3.1. Effect of radial clearance

The pressure distribution for different values of radial clearance is described in **Fig. 4**, **Fig.5** and **Fig. 6**.

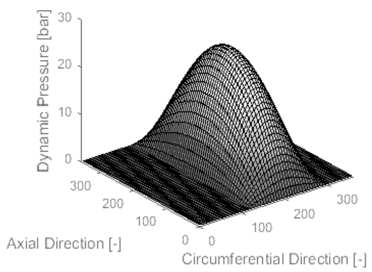


a) 2D hydrodynamic pressure distribution

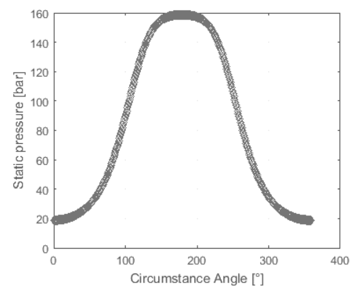


b) Hydrostatic pressure profile

Fig.4. Calculation for radial clearance at value of 50 μm

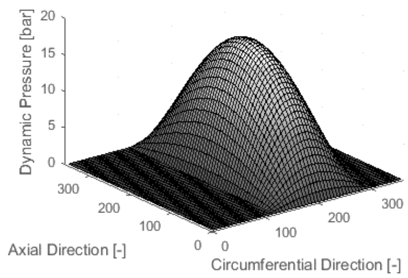


a) 2D hydrodynamic pressure distribution

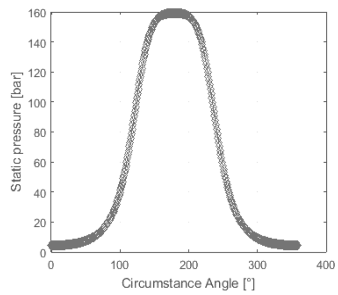


b) Hydrostatic pressure profile

Fig.5. Calculation for radial clearance at value of 75 μm



a) 2D hydrodynamic pressure distribution



b) Hydrostatic pressure profile

Fig.6. Calculation for radial clearance at value of 100 μm

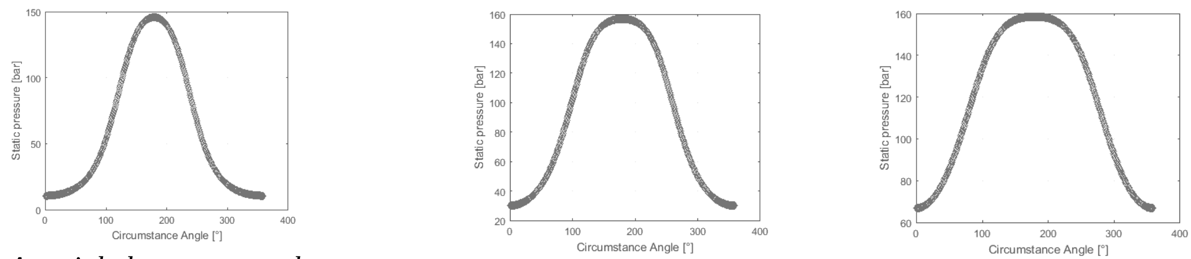
From these figures one can see that for low value of radial clearance, the maximum hydrodynamic pressure is better than that of large value of radial clearance, meanwhile, the maximum hydrostatic pressure is almost the same for both cases. However, for large value of radial clearance, the hydrostatic pressure profile has larger area. The proportion of hydrodynamic and hydrostatic pressure components is almost the same, i.e., 23% of static and 77% of dynamic for radial clearance at value of 50 μm; 21% of static and 79% of dynamic for radial clearance at value of 100 μm. The details of calculation results are presented in **Table 1**. The reason for high dependence of hydrodynamic pressure on the value of radial clearance can be explained by using the Reynolds equation. According to equation (3) one can see that the hydrodynamic pressure is inverse proportional with the film thickness. In other words, it is inversely proportional with the radial clearance.

Table 1. Effect of radial clearance

Parameter	Radial clearance		
	c = 50 μm	c = 75 μm	c = 100 μm
Hydrodynamic component (%)	23	22	21
Hydrostatic component (%)	77	78	79
Maximum dynamic pressure (bar)	39.98	24.71	17.54
Maximum static pressure (bar)	156.68	158.11	159.29

3.2. Effect of axial clearance

The numerical calculation points out that the axial clearance has almost no effect on the hydrodynamic pressure distribution. This is because the axial clearance is not a component in Reynolds equation (3). In contrary, the axial clearance has great effect on hydrostatic pressure profile, consequently, it has much effect on the proportion of hydrodynamic and hydrostatic components. The calculation results for two cases of axial clearance are presented in **Fig. 7**.



a) As axial clearance at value of 30 um

b) As axial clearance at value of 50 um

c) As axial clearance at value of 65 um

Fig.7. Hydrostatic pressure profile

For large values of axial clearance, the proportion of hydrostatic pressure is better than that of low values of axial clearance e.g., as axial clearance at value of 30 μm the proportion of hydrostatic is 63%, however, as axial clearance increasing up to value of 65 μm the proportion of hydrostatic pressure increases up to 76%. Details of calculation results is presented in **Table 2**.

Table 2. Effect of axial clearance

Parameter	Axial clearance		
	Δ = 30 μm	Δ = 50 μm	Δ = 65 μm
Hydrostatic component (%)	63	71	76
Maximum static pressure (bar)	145.74	153.68	158.47

3.3. Effect of L/D ratio

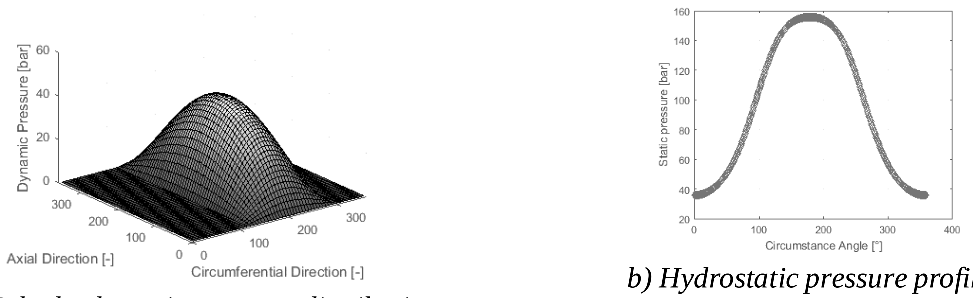
Effect of different values of L/D ratio on hydrodynamic and hydrostatic pressure are presented in **Fig.8**, **Fig.9** and **Fig.10**.

a) 2D hydrodynamic pressure distribution *b) Hydrostatic pressure profile*

Fig.8. Calculation for L/D ratio at value of 0.5 (L = 0.034m and D = 0.07m)

a) 2D hydrodynamic pressure distribution *b) Hydrostatic pressure profile*

Fig.9. Calculation for L/D ratio at value of 0.375 (L = 0.034m and D = 0.0906m)



a) 2D hydrodynamic pressure distribution *b) Hydrostatic pressure profile*

Fig.10. Calculation result for L/D ratio at value of 0.25 (L = 0.034m and D = 0.114m)

The details of calculation results are presented in **Table 3**. The maximum hydrodynamic and hydrostatic pressure are almost the same for both cases of L/D ratio. This means that L/D ratio has slightly effect on maximum pressure. However, from **Fig.8b, Fig.9b** and **Fig.10b** one can see that L/D ratio has significant effect on minimum hydrostatic. Consequently, the proportion of hydrostatic pressure increases with the decrease of L/D ratio, meanwhile, the proportion of hydrodynamic pressure decreases with the decrease of L/D ratio.

Table 3. Effect of L/D ratio

Parameter	**L/D ratio**		
	L/D = 0.5	L/D = 0.375	L/D = 0.25
Hydrodynamic component (%)	33	30.8	29
Hydrostatic component (%)	67	68.5	71
Maximum dynamic pressure (bar)	42.21	41.74	41.12
Maximum static pressure (bar)	152.42	153.91	155.78

The reason for changing of proportion of hydrodynamic and, therefore, hydrostatic pressure according to the L/D ratio can be explained by the appearance of the L/D ratio in Reynolds equation.

4. CONCLUSION

Based on the numerical results in this study, some conclusions can be drawn as follows,

- By solving the Reynolds equation, the 2D hydrodynamic pressure distribution in the oil lubrication film can be obtained while the hydrostatic pressure profile can be calculated through the resistance network model.
- Radial clearance has great effect on both hydrostatic and hydrodynamic pressure distribution.
- Axial clearance has no effect on hydrodynamic pressure, however, it has strong effect on hydrostatic pressure component.
- L/D ratio has effect on both hydrodynamic as well as hydrostatic pressure.

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REFERENCES

B. J. Hamrock and S. R. Schmid (2004), *Fundamental of Fluid Film Lubrication Second Edition*, Marcel Dekker Inc, New York, USA.

Trong Hoa Pham (2019), "*Hybrid method to analysis the dynamic behavior of the ring gear for the internal gear motors and pumps*", Journal of Mechanical Science and Technology, 33, p602-612.

Xiu, S.C., Xiu, P.B., and Gao, S.Q. (2009), "*Simulation of Temperature Field of Oil Film in Super-high Speed Hybrid Journal Bearing Based on FLUENT*", Advanced Materials Research, p296-300.

Vijay, K.D., Satish, C., Pandey, K.N. (2013), "*Analysis of Hybrid (Hydrodynamic/ Hydrostatic) Journal Bearing*", Advanced Materials Research, 650, p385-390.

Rana, N.K., Gautam, S.S. (2016), "*Performance characteristics of constant flow valve compensated conical multirecess hybrid journal bearing under micropolar lubrication*" Int. J. Design Engineering.

Helene, M., Arghir, M., Frene, J. (2003), "*Numerical Three-Dimensional Pressure Patterns in a Recess of a Turbulent and Compressible Hybrid Journal Bearing*", Journal of Tribology, 125, p301-308.

Pham, T.H., Müller, L., Weber, J. (2018), "*Dynamically loaded the ring gear in the internal gear motor/pump: Mobility of solution*", Journal of Mechanical Science and Technology.

Tóm tắt:

MÔ PHỎNG SỐ ẢNH HƯỞNG CỦA THÔNG SỐ KẾT CẤU ĐẾN PHÂN BỐ ÁP SUẤT THỦY TĨNH VÀ ÁP SUẤT THỦY ĐỘNG CỦA MÀNG DẦU BÔI TRƠN TRONG BƠM BÁNH RĂNG ĂN KHỚP TRONG

Bài báo phân tích ảnh hưởng của các thông số kết cấu đến phân bố áp suất thủy tĩnh và áp suất thủy động của màng dầu bôi trơn trong bơm bánh răng ăn khớp trong. Áp suất thủy động được tính toán thông qua việc giải phương trình dòng chảy Reynold. Mô hình sức cản thủy lực được sử dụng để tính toán áp suất thủy tĩnh. Các kết quả tính toán số chỉ ra rằng, khe hở hướng tâm có ảnh hưởng rất lớn đến phân bố của áp suất thủy tĩnh và áp suất thủy động, khe hở hướng chỉ ảnh hưởng đến áp suất thủy tĩnh trong khi đó tỷ số kết cấu L/D có ảnh hưởng ít đến cả hai thành phần áp suất thủy tĩnh và thủy động.

Từ khóa: Phân bố áp suất, bơm và mô tơ bánh răng ăn khớp trong, áp suất thủy tĩnh, áp suất thủy động.

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