

Boundary element method of hydrodynamic characteristics of lubricant in three-leaf dislocated floating-ring bearing

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Abstract: The problem of hydrodynamics of the three-leaf dislocated floating-ring bearing was studied by means of boundary element method. The law including the distribution of pressure on boundary surface (axial, bearing and floating-ring) and its friction loss in different eccentricities was obtained. The results show that the inner friction of three-leaf dislocated bearing increases from 390.875 to 1091.65, and the inner friction of three-leaf dislocated floating-ring bearing increases from 94.2523 to 114.5069 with eccentricity varying from 0 to 0.075 in nondimensional. So changing the pressure and flow field of bearing by adding floating-ring is more stability and less wasted work of friction than three-leaf dislocated bearing.

Key words: three-leaf dislocated floating-ring bearing; hydrodynamics; boundary element method; stability; inner friction

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With the development of the modern industry and the improvement of mechanical running speed, the people have put forward higher demand for the mechanical dynamic characteristics. The phenomena of friction loss and destabilization of lubricating bearing often lead to the destruction of the whole mechanical system. Therefore, there is an urgent need to develop the bearing with low-friction loss, high carrying capacity and good stability.

In the way of altering the shape of bearing^[1-4], hydrodynamic characteristics in dislocated bearing was studied by boundary element

method in 1993. It was found that not only the stability of dislocated bearing was improved but also the friction loss had been reduced in the same load^[5]. And the conclusion was proved by Ref. [6] with experiment in 2002 and by Ref. [7] with theoretical calculation in 2005.

In the way of adding floating-ring, Li et al.^[8-9] studied the mechanism of dislocated bearing, and concluded that the friction loss was lower and the stability was better in floating-ring bearing. According to using Galerkin's approximation, the performance of the floating-ring journal bearing was obtained by CHI et al.^[10] in

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1990. And then the floating-ring journal bearing was compared with the equivalent ordinary journal bearing in the characteristics in order to determine a scheme for bearing system which will be designed. SONG et al.^[11] used CFD method to study the performance of hydrodynamic bearings in 2010. It has been found that the load capacity of both films had periodical fluctuation because of the bush rotation, and the pulsation of flow rate in the oil holes was induced by the pressure drop between the two oil films and the existence of oil groove.

To further study the function of floating-ring^[12-16], XING et al.^[17] studied the floating-ring bearing in different eccentrics with boundary element method in 2004. The hydrodynamic characteristics had been compared between floating-ring bearing and ordinary bearing, concluded that floating-ring bearing was more stability and less friction loss than ordinary bearing.

In this paper, the ways of altering the shape of bearing and adding floating-ring are combined and three-leaf dislocated floating-ring bearing is schemed out. Its stability with boundary element method was studied^[18-19], and results show that it is more stability and less wasted work of friction than three-leaf dislocated bearing^[20].

1 Mathematical model and boundary integral equations

Assumed that Ω is a flow region of incompressible viscous fluid, and Γ is the boundary surface, the differential equations are

$$\begin{cases} \nabla \cdot \mathbf{T}(\mathbf{V}) = \nabla \cdot (\mathbf{V}\mathbf{V}) \\ \nabla \cdot \mathbf{V} = 0 \end{cases} \quad \text{in } \Omega \quad (1)$$

Boundary conditions are

$$\begin{cases} \mathbf{T} \cdot \mathbf{n}|_{\Gamma} = t_s \\ \mathbf{V}|_{\Gamma} = \mathbf{V}_s \end{cases} \quad \text{on } \Gamma \quad (2)$$

Where $\mathbf{V}_s$, t_s are velocity and stress of fluid on Γ ; $\mathbf{n}$ is the unit normal direction vector of Γ ; $\mathbf{T}(\mathbf{V})$ is the stress vector of $\mathbf{V}$.

Regarding fundamental solutions of Navier-Stokes (N-S) equation as weight function, differential equations of flow region of lubricant are changed into boundary integral equations.

$$C(\mathbf{X}) v_k(\mathbf{X}) =$$

$$\begin{aligned} & \oint_{\Gamma} n_i(\mathbf{X}_0) T'_{ij} [\mathbf{W}^k(\mathbf{X} - \mathbf{X}_0)]_0 v_j(\mathbf{X}_0) d\Gamma_0 - \\ & \oint_{\Gamma} n_i(\mathbf{X}_0) T_{ij} [\mathbf{V}(\mathbf{X}_0)]_0 w_j^k(\mathbf{X} - \mathbf{X}_0) d\Gamma_0 + \\ & \oint_{\Gamma} n_i(\mathbf{X}_0) v_i(\mathbf{X}_0) v_j(\mathbf{X}_0) w_j^k(\mathbf{X} - \mathbf{X}_0) d\Gamma_0 - \\ & \oint_{\Omega} v_i(\mathbf{X}_0) w_{j,i_0}^k(\mathbf{X} - \mathbf{X}_0) v_j(\mathbf{X}_0) d\Omega_0 \end{aligned} \quad (3)$$

$$C(\mathbf{X}) p(\mathbf{X}) =$$

$$\begin{aligned} & - \oint_{\Gamma} n_i(\mathbf{X}_0) q^j(\mathbf{X} - \mathbf{X}_0) T_{ij} [\mathbf{V}(\mathbf{X}_0)]_0 d\Gamma_0 + \\ & \oint_{\Gamma} n_i(\mathbf{X}_0) q^j(\mathbf{X} - \mathbf{X}_0) v_i(\mathbf{X}_0) v_j(\mathbf{X}_0) d\Gamma_0 + \\ & \frac{2}{Re} \oint_{\Gamma} n_i(\mathbf{X}_0) q_{i_0}^j(\mathbf{X} - \mathbf{X}_0) v_j(\mathbf{X}_0) d\Gamma_0 - \\ & \oint_{\Omega} v_i(\mathbf{X}_0) v_j(\mathbf{X}_0) q_{j_0}^i(\mathbf{X} - \mathbf{X}_0) d\Omega_0 \end{aligned} \quad (4)$$

Where $v_k(k=1,2)$ is velocity; subscript "0" is the field point; p is the pressure; n_i is the normal cosine of surface of boundary; $\mathbf{W}^k$ and q^k are fundamental solutions of N-S equation; $T_{ij}(\mathbf{V})$ is stress of $\mathbf{V}$; $T'_{ij}(\mathbf{W}^k)$ is stress of $\mathbf{W}^k$; when $\mathbf{X} \in \Omega$, $C(\mathbf{X})=1$; when $\mathbf{X} \in \Gamma$, $C(\mathbf{X})=1/2$.

$$w_j^k(\mathbf{X} - \mathbf{X}_0) =$$

$$-\frac{Re}{4\pi} \left[\delta_{jk} \ln \frac{1}{|\mathbf{X} - \mathbf{X}_0|} + \frac{(x_j - x_{j0})(x_k - x_{k0})}{|\mathbf{X} - \mathbf{X}_0|^2} \right]$$

$$q^k(\mathbf{X} - \mathbf{X}_0) = -\frac{1}{2\pi} \frac{x_k - x_{k0}}{|\mathbf{X} - \mathbf{X}_0|^2}$$

$$T_{ij}(\mathbf{V}) = -p\delta_{ij} + \frac{1}{Re}(v_{i,j} + v_{j,i})$$

$$T'_{ij}(\mathbf{W}^k) = -q\delta_{ij} + \frac{1}{Re}(w_{j,i}^k + w_{i,j}^k)$$

2 Discrete forms of boundary integral equations

Assumed that the boundary surface Γ is divided into N elements, Γ_{β} denotes β th element ($\beta=1,2,\dots,N$). So the following discrete forms on the boundary points and in the domain points are obtained.

$$C_{\alpha} v_{ka} = \sum_{\beta=1}^N \sum_{i=1}^2 \sum_{j=1}^2 L_{ijk\alpha\beta} n_{i\beta} v_{j\beta} - \sum_{\beta=1}^N \sum_{j=1}^2 M_{jka\beta} t_{j\beta} + \sum_{\beta=1}^N \sum_{i=1}^2 \sum_{j=1}^2 M_{jka\beta} n_{i\beta} v_{j\beta} \quad (5)$$

$$C_{\alpha} p_{\alpha} = - \sum_{\beta=1}^N \sum_{j=1}^2 R_{ja\beta} t_{j\beta} + \sum_{\beta=1}^N \sum_{i=1}^2 \sum_{j=1}^2 S_{ija\beta} n_{i\beta} v_{j\beta} \quad (6)$$

Where $L_{ijk\alpha\beta}$, $M_{jka\beta}$, $R_{ja\beta}$, $S_{ija\beta}$ are integral coefficient.

cients after discrete.

$$L_{ijk\alpha\beta} = \int_{\Gamma_\beta} T'_{ij} [\mathbf{W}^k(\mathbf{X}_\alpha - \mathbf{X}_0)]_0 d\Gamma_0$$

$$M_{jka\beta} = \int_{\Gamma_\beta} \omega_j^k(\mathbf{X}_\alpha - \mathbf{X}_0) d\Gamma_0$$

$$R_{ja\beta} = \int_{\Gamma_\beta} q^j(\mathbf{X}_\alpha - \mathbf{X}_0) d\Gamma_0$$

$$S_{ija\beta} = \frac{2}{Re} \int_{\Gamma_\beta} q_{j,i_0}(\mathbf{X}_\alpha - \mathbf{X}_0) d\Gamma_0$$

3 Analysis of results

With nondimensional radius of bearing-neck, floating-ring are 1.0 and 1.2 (all the results are nondimensional). In the case of relative rotational speed of bearing-neck, floating-ring and bearing are 1.0, 0.7 and 0 respectively, and the running states of the three-leaf are simulated to dislocate floating-ring bearing with different eccentricities ($e=0, 0.015, 0.030, 0.045, 0.060, 0.075$).

The law of pressure on the surface of bearing with the change of eccentricity is given in Fig. 1. Vertical ordinate p is the pressure on the surface of bearing, and horizontal ordinate θ moves counterclockwise. With the emergence of disturbance on bearing, oil film is not vibrant due to oil film load in inverse proportion to oil film thickness, so the running states of bearing are safe. From the Fig. 2, the pressure of bearing-neck is basically equal to inner floating-ring at every point respectively. While eccentricity increases, the pressure increases.

Figure 3 are the visual picture of the curve of $e=0.015$ and $e=0.045$ in the Fig. 1. The size of pressure is shown by the length of the arrow.

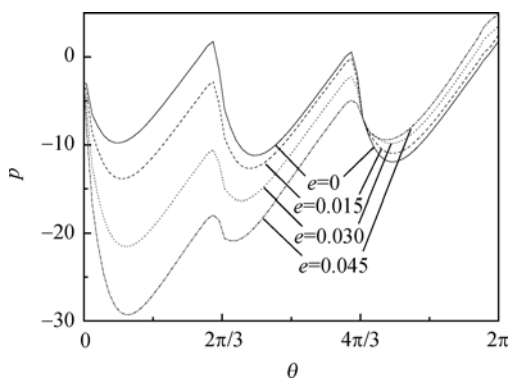


Fig. 1 Pressure on surface of bearing

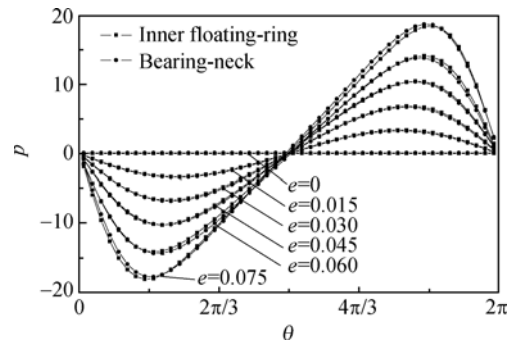


Fig. 2 Pressure on surface of bearing-neck and inner floating-ring

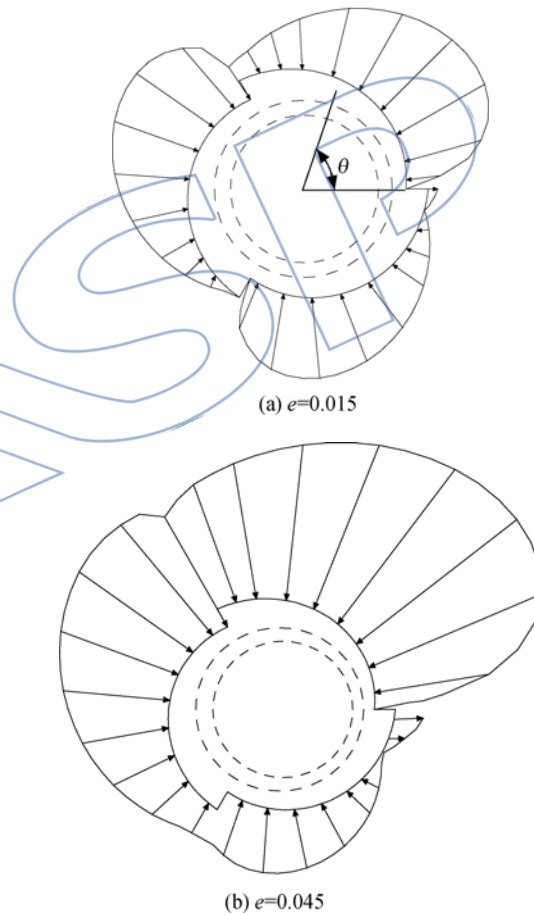


Fig. 3 Visual picture of curve of pressure on surface of bearing

The bearing-neck can be centralized in the function of pressure in order to run well.

Figure 4 is the flow field of three-leaf dislocated floating-ring bearing with different eccentricities. In all cases the flow field has the vertex, and the vertex increases with the eccentricity increasing. The phenomenon of hydrodynamic characteristics show that the increase of

the vertex has larger inner friction.

As shown in Table 1, the inner friction of three-leaf dislocated floating-ring bearing is lower than that of three-leaf dislocated bearing in all

kinds of eccentricities. Therefore, the three-leaf dislocated floating-ring bearing is more efficient than the three-leaf dislocated bearing.

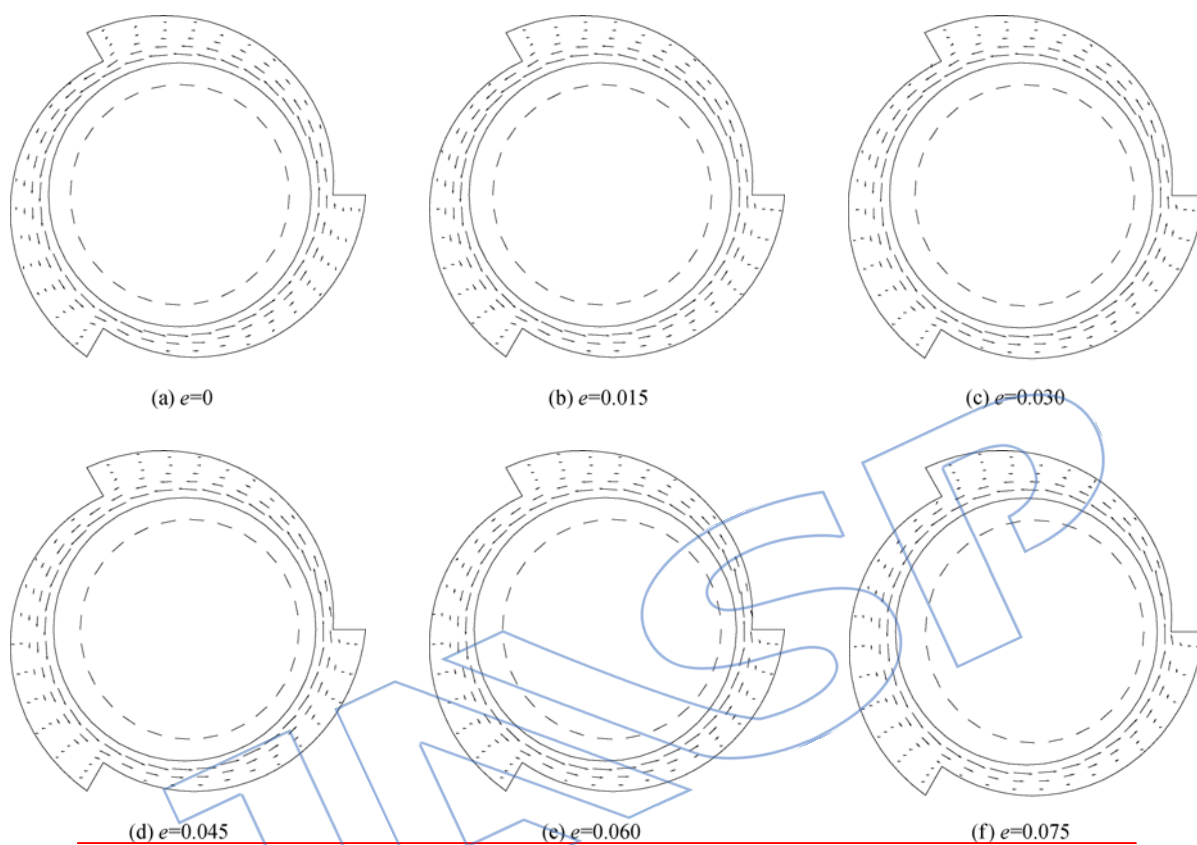


Fig. 4 Flow field of lubricant

Table 1 Comparison of inner friction between three-leaf dislocated bearing and three-leaf dislocated floating-ring bearing

	e					
	0	0.015	0.030	0.045	0.060	0.075
Three-leaf dislocated bearing	390.875	436.0476	529.9656	669.1569	855.8838	1091.65
Three-leaf dislocated floating-ring bearing	94.2523	95.03652	97.3998	101.3772	107.0387	114.5069

4 Conclusions

In this paper, the stability of three-leaf dislocated floating-ring bearing is studied by boundary element method, and the distribution of pressure on boundary surface (axial, bearing and floating-ring) and its friction loss in different eccentricities is given. The results are as follows:

1) For the three-leaf dislocated floating-ring bearing, the more eccentricity, the more bearing load.

2) Inner friction of the three-leaf dislocated floating-ring bearing is less than that of the three-leaf dislocated bearing in all kinds of eccentricities. Inner friction can also be reduced greatly when adding floating-ring in the bearing.

3) The stability of the three-leaf dislocated floating-ring bearing is better than that of the three-leaf dislocated bearing, and the load is also better than it.

From the above results, three-leaf dislocated floating-ring bearing is more stability and

less wasted work of friction than three-leaf dislocated bearing.

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