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Influence of supporting clearance distribution on performance of suspension pad

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ABSTRACT

The performance of suspension pad is investigated in consideration of nonuniform clearance distribution. Firstly, a novel method to determine the supporting clearance of a suspension pad is proposed based on the geometrical configuration. Then, the flow model of the liquid in the suspension pad is established. For the sake of solving this model, a finite volume discrete algorithm is derived and a new approach is used for updating the pressure field during iteration. Based on these algorithms, the pressure distribution of the flow field is obtained. Further, this pressure distribution is used to calculate the supporting force and moment. Finally, the influences of the displacement and flux of the suspension pad on the supporting force and moment are analyzed. The results demonstrate that the axial displacement can result in the increase of the supporting force, while the radial displacement can produce the supporting moment which disturbs the attitude stabilization of the inner sphere. Increasing flux is an effective way to strengthen the supporting force and to restrict the supporting moment. During the design of the floated inertial platform, a proper combination of the initial edge clearance and the flux should be chosen to improve the supporting property of the suspension pad and to restrain the supporting moment in the controllable range of the torquers on the floated inertial platform.

1. Introduction

In industry, fluid lubrication is a mature technology and has been extensively utilized in terms of hydrostatic, hydrodynamic, and hybrid bearings, etc. It has some excellent characteristics, such as low friction, high load-carrying capacity, large fluid film stiffness and damping, reduced vibrations. In the inertial field, the fluid lubrication has been mainly applied to support the rotor of a fluid floated gyroscope. This application is similar to the hydrodynamic journal bearing, which is generally used to support the rotors at a high rotating speed. However, the research subject of this paper is a floated inertial platform [1–3], which is an advanced inertial platform using hydrostatic supporting system instead of the gimbal system of the traditional inertial platform [4–6]. Ref. [7] has detailed the structure and the operating principle of the floated inertial platform. As shown in [7], the inner sphere is supported in the outer shell by the hydrostatic supporting system consisting of eight suspension pads, so as to be separated with the outer shell resorting to the fluid film between the suspension pad and the outer shell. The inner sphere is regarded as the stable platform relative to the inertial space. Thus, during the vehicle moving, the inner sphere keeps stable in the inertial space and the outer shell rotates around the inner sphere due to the change of the vehicle's attitude. The suspension pad not only reduces the friction of the inner sphere by fluid film lubrication, but also generates supporting force to resist the inertial force from the acceleration of the vehicle. The rotation of the outer shell is not continuous and at low speed. Thus, there is a recess at the center of the suspension pad for the fluid supplied from the pump in the center of the inner sphere to provide sufficient generation of the supporting force and the fluid film lubrication.

According to the above characteristics, the hydrostatic supporting system of the floated inertial platform is similar to the hydrostatic thrust bearing, which has been widely investigated by many researchers. Dwivedi et al. [8] studied the influence of the recess number and size on the performance of hybrid journal bearing. Sharma et al. [9] evaluated the performance characteristics of a circular thrust pad hydrostatic bearing with different geometric shape of recess by Finite Element Method. In addition, their work indicates that the orifice compensated bearing can provide the maximal load-carrying capacity, while the constant flow valve compensated bearing gives the maximal value of the fluid film stiffness and damping. On the basis of Christensen's stochastic model of rough surfaces, Lin [10] calculated the dynamic stiffness and damping coefficients of the bearings using a small perturbation method. The results demonstrate that the mean

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Nomenclature

$\boldsymbol{d}$	displacement of the suspension pad
d_x, d_y, d_z	X, Y, Z displacement of the suspension pad in the current suspension pad coordinate frame
$\mathbf{C}$	center of the inner sphere
$\mathbf{C_p}$	center of the plane of the suspension pad
$\mathbf{C_{ps}}$	initial center of the plane of the suspension pad
F_P	supporting force of the suspension pad
h	local supporting clearance of the pad
h_0	edge supporting clearance of the suspension pad
h_{0i}	initial edge supporting clearance of the suspension pad
N	amount of redial grid
M	amount of circumferential grid
$\boldsymbol{M_P}$	supporting moment of the suspension pad
m	mass of the inner sphere
O	center of the outer shell
p, P_1, P_2, P_a	local pressure, pressure in pad, pressure out of pad, and ambient pressure
p_n	updated pressure field
p_m	desired pressure field
Q_r	fluid flux through any circumferential profile (radius of r)
Q_T	fluid flux flowing into the suspension pad from the pump
Q_{sr}	fluid flux squeezed out of any circumferential profile (radius of r)
Q_{rc}	calculated fluid flux through any circumferential profile (radius of r)
R_0, R_1, R_2	inner radius of outer shell, inner radius of pad, and outer radius of pad
r	radial axis of the current suspension pad cylindrical coordinate frame
u, v, w	radial, circumferential, and axial velocity of the flow
v_{xp}, v_{yp}, v_{zp}	X, Y, Z velocity of the suspension pad with respect to the outer shell in the current Suspension pad coordinate frame
$v_{ShellR}, v_{Shell\Theta}, v_{ShellZ}$	X, Y, Z velocity of the outer shell in the current suspension pad cylindrical Coordinate frame
$\mathbf{X_C}$, $\mathbf{Y_C}$, $\mathbf{Z_C}$	X, Y, Z axis of the inner sphere coordinate frame
$\mathbf{X_p}$, $\mathbf{Y_p}$, $\mathbf{Z_p}$	X, Y, Z axis of the current suspension pad coordinate frame
$\mathbf{X_{ps}}$, $\mathbf{Y_{ps}}$, $\mathbf{Z_{ps}}$	X, Y, Z axis of the initial suspension pad coordinate frame
z	vertical axis of the current suspension pad cylindrical coordinate frame
θ	circumferential coordinate of the current suspension pad cylindrical coordinate frame
μ	fluid viscosity
ρ	fluid density

Subscript

i	number of redial grid
j	number of circumferential grid
n	upper boundary of control area
s	bottom boundary of control area
w	west boundary of control area
e	east boundary of control area
c	center of control area

Superscript

n	number of iteration

stiffness and damping behaviors are significantly affected by the pattern and height of the roughness. Wang et al. [11] studied the relationship among the load-carrying capacity, pocket pressure, film thickness, and leakage flow rate for the bearing. This bearing is made of a combination of stainless steel/stainless steel and stainlesss teel/plastics. Their results manifest that the load-carrying capacity expressed by the ratio of hydrostatic balance is dependent on the supply pressure and the elastic modulus of materials. The above investigations are just suitable for the hydrostatic supporting system fixed on the ground and the object supported on a plane or cylindrical surface. However, the hydrostatic supporting system used in the inertial instruments is mounted on a moving base. Especially, the hydrostatic supporting system of the floated inertial platform supports the inner sphere in a spherical shell. In view of these features, we have explored the characteristics of the hydrostatic supporting system for the floated inertial platform in dynamic environments [7]. This study is implemented on the assumption of uniform supporting clearance in the circumferential direction.

However, the deviation of the inner sphere, from the vehicle's acceleration, can make the supporting clearance nonuniform. This situation is analogous to the tilt of the hydrostatic supporting pad, due to the affection of partial load, manufacturing errors, local deformation, etc. Correspondingly, the vehicle's acceleration can be regarded as a dynamic load. Generally, the applications of tilting hydrostatic supporting system are classified as tilting pad journal bearing and tilting pad thrust bearing in the industry. There are many publications reporting the investigations on these two kinds of bearings. Yamaguchi [12,13] gave the optimal design for the oil-lubricated metallic bearings with consideration of the effect of elastic deformations. Beek [14] used the equivalent hydraulic network method to analyze the hydrostatic multi-pad bearing on the assumption of laminar flow, both capillary and orifice restrictors. Wang et al. [15] researched the effect of the eccentric load on the power loss and the leakage ratio for the hydrostatic thrust bearing. Srikanth [16] proposed a novel interpolation of a single pad's angular stiffness to determine the characteristics of the tilting pad thrust bearing. The tilting effect in this literature mainly takes the pad deformation into account. Guo [17] measured the relative and absolute displacement vibrations of the test experimental bearing with the static load and the dynamic load, respectively. Based on the experimental results, it is found that the operating conditions largely affect the pad static and dynamic characteristics. To analyze the impact of the grooves and shape of the recess on the performance of the tilting pad thrust bearing, Pellegrin [18] calculated the pressure and temperature distribution using an isoviscous and isothermal model. On this basis, the addition of certain types of grooves can promote oil-film thickness and reduce power loss. Wasilczuk [19] studied the issue of the heat dissipation for the large tilting pad thrust bearings. A novel idea of reducing heat generation is proposed. For the tilting pad journal bearing, a compliant liner with a pivot is usually applied to comply with the inclination of the shaft [20]. Yan [21] proposed a new analytical model to calculate the global oil-film forces, stiffness and damping coefficients acting on the journal. Compared with the traditional reduced model, the new model is