Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P1-28

DESIGN OF RUNNING-IN AEROSTATIC SPHERICAL BEARING WITH INHERENT COMPENSATION AND LARGE WRAP ANGLE

Wenqi MA, Ang SUN, Zuwen WANG

Transportation and Logistics Engineering college, Dalian Maritime University
1 Linghai Road, Dalian, 116026, China
(E-mail: mawq71@yahoo.com.cn)

ABSTRACT

Aerostatic spherical bearings can operate in places which requiring three degrees of freedom in rotation with a minimum of frictional drag. It is one of the key components of aerocraft motion simulator. With the development of large-scale simulation equipment, the requirement of aerostatic bearing with heavy-duty is widely and imminent. Compared with aerostatic spherical bearing with multi-orifices compensation, the bearing with inherent compensation and integrated socket is newly developed, and it has admirable stability in large scale of supply pressure. A new type of running-in aerostatic spherical bearing with inherent compensation and large wrap angle is designed and optimized. At the same time, the pressure and velocity field distributions in region of gas film are obtained by CFD software. Experimental results are proved that the bearing capacity of the new aerostatic spherical bearing is far improved than conventional one.

KEY WORDS

Aerostatic spherical bearings, Heavy-duty, CFD, Inherent compensation

NOMENCLATURE

e : offset of center point
p : radial pressure
p_s : supply pressure
p_a : ambient pressure
d : diameter of supply hole
θ_0, θ_1 : wrap angle of supply holes
R : diameter of spherical bearings

INTRODUCTION

Gas lubrication is a new technique because of the rapid development of spaceflight and industry since 50 ages. Especially, aerostatic spherical bearings can operate in places which requiring three degrees of freedom in rotation with a minimum of frictional drag, and widely applied by precision bearing on spacecraft simulator, inertial navigation, principal axis of ultra precision machine and so on. The disadvantages such as lower bearing capacity stiffness and stability limit the application, so the research of aerostatic bearings with high-pressure and heavy-load is very necessary.

One key technique of large-space structure is flexibility, the complete physical simulation must be tested to insure the safe of aerocraft, such as the space intersection kinetics and the effect of difficult foundation of precision math model on control system including friction of flywheel on dry condition, 3 axe coupling of twist roller, flexibility of solar panel.

There are special departments to study on physics simulated equipments of large flexibility structure such as Germanic Space Navigation Academe, American Langley Research Center. Especially, Langley Research Center carried the simulation technique, equipments and experiments for space shuttle and manned space station including "Apollo Airship" and "Air Laboratory" since 1960s; they have obtained great achievement by 40 years.

The gas lubrication system is one of the core systems. Chinese some graduate school fetched in a suit of gas lubrication system on condition of high pressure and heavy loading, aerostatic spherical bearings is the main part which can offer lower friction and micro-gravity, the supply pressure is $30\times10^5 N/m^2$, the fact using pressure is $15\times10^5 N/m^2$，carrying capacity is over five tons，the diameter of sphere is only 400mm, the using pressure outclassed that of traditional structure. The working mechanism should be more lucubrated.

There are three common types of aerostatic spherical bearings, one is running-in aerostatic spherical bearing with single orifice which first put forward by Robert[1], the second is aerostatic spherical bearing with multi-orifices and portion spherical socket[2], the third is new aerostatic spherical bearings with inherent compensation having integrated spherical socket. The running-in aerostatic spherical bearing with single orifice was first used, but has been fall into disuse because of instability. The second kind of bearing is often applied on limited structure because of the worse carrying efficiency and flow characteristic. The third type of bearing is a new type of aerostatic bearing developing with the rising of international researching on micro-satellite. This paper designs a new running-in aerostatic spherical bearing with inherent compensation and large wrap angle, and gave the numerical simulation results of static characteristic.

DESIGN OF RUNNING-IN AEROSTATIC SPHERICAL BEARING

Because of air hammer at higher pressure, structure of controlling exhaust including two lines of exhaust holes in spherical socket is applied to keep the air bearing in working order. The air entering into the bearing is divided into three parts: some air outflow through the top gap between the spherical socket and spherical bulb, the two others outflow through the exhaust holes. This kind of structure can avoid the appearance of air hammer and improve the stability of the bearing, shown as Fig.1

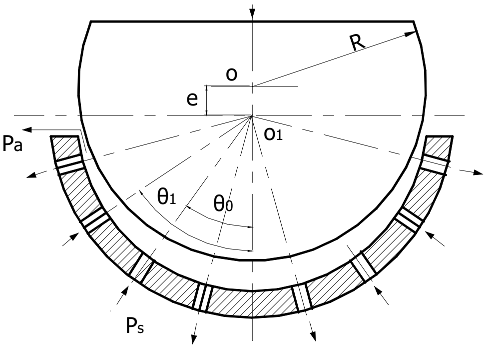


Figure 1 The running-in aerostatic spherical bearing with inherent compensation and large wrap angle

Spherical bulb and spherical socket has the same radiu R=75mm, the wrap angle of spherical socket is 160°. The wrap angle of supply holes θ_0, θ_1 is separately 36° and 50° which there are 10 uniform holes. The angle of exhaust holes is separately 12° and 70° which there are separately 4 and 12 uniform holes of every array.

CONTROL EQUATIONS OF SIMULATION

Conventional Reynold control equations are deduced based on neglect of inertia force. But with increasing of the supply pressure and gas film, the effect of inertia force is gradually intensive, the complete N-S equation is adaptive on the working condition[3].

$$\rho\frac{du}{dt}=\rho X-\frac{\partial p}{\partial x}+\eta\nabla^2 u+\eta\frac{1}{3}\frac{\partial}{\partial x}(div\upsilon) \qquad (1)$$

$$\rho\frac{d\upsilon}{dt}=\rho Y-\frac{\partial p}{\partial y}+\eta\nabla^2 \upsilon+\eta\frac{1}{3}\frac{\partial}{\partial y}(div\upsilon) \qquad (2)$$

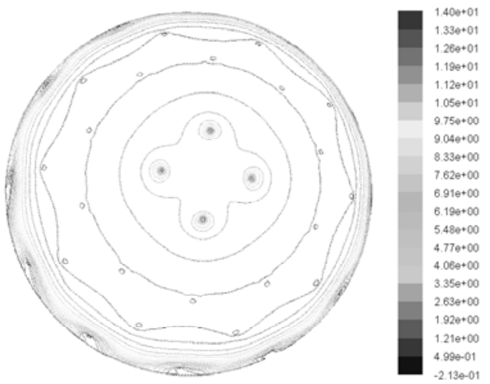
$$\rho\frac{d\omega}{dt}=\rho Z-\frac{\partial p}{\partial z}+\eta\nabla^2\omega+\eta\frac{1}{3}\frac{\partial}{\partial z}(div\upsilon) \qquad (3)$$

Steady continuity equation:

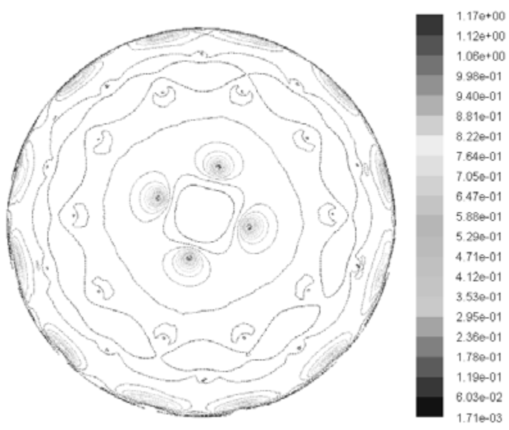
$$\frac{\partial}{\partial x_i}(\rho u_i)=0 \qquad (4)$$

NUMERICAL SIMULATION ANALYSIS

Fluent is general CFD software which the control equations are dispersed and solved with finite volume method. In this paper, explicit coupled solvers linearize the coupled equations of high-speed compressible flows. This method may give it a performance advantage over the segregated solver for the flow on greater inertia force. Pressure equations are solved by linear difference format; density and momentum are solved by second order upwind format. Comparisons of pressure distribution and Mach number are shown as Fig.2.



（a） Pressure distribution of gas film



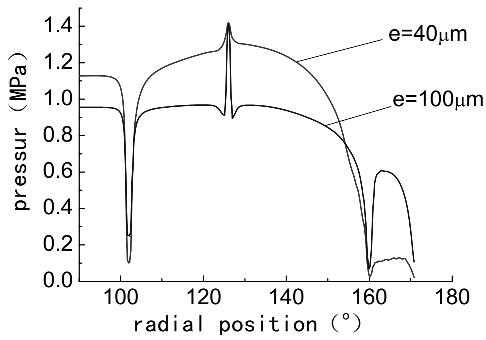
（b） Mach number distribution of gas film

Figure 2 $p_s/p_a=14$, d=1.2mm, e=40μm

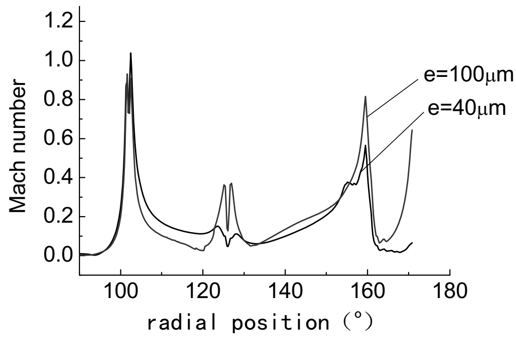
Though the pressure at exhaust holes reduce to ambient pressure, the average pressure value still hold high near the sock, shown as Fig.2(a). The results of Mach number is corresponding as that of pressure, shown as Fig.2(b).

However, when the gas film gets larger to 100μm(shown as Fig.3), pressure depression beyond the supply hole already occurs and the pressure value at 40μm is obviously higher than that at 100μm near ball socket which the maximum difference can reach to 0.5Mpa. Especially, the pressure profile is different, there is a process of falling and recovering near supply hole. The phenomena are caused by interaction between inertia force and viscous force.

In like manner, the tendency of velocity distribution also proved the changes. The velocity at the center of ball socket is zero which forming a stagnant air flow region. The gas at entrance flow into bearing with low velocity, then gradually accelerate along the flow direction which is more obvious at small gas film. The flow velocity reaches to maximum near supersonic flow at exhaust hole because of pressure depression.



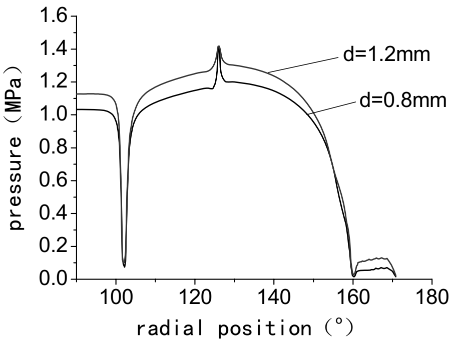
（a） Pressure contrast



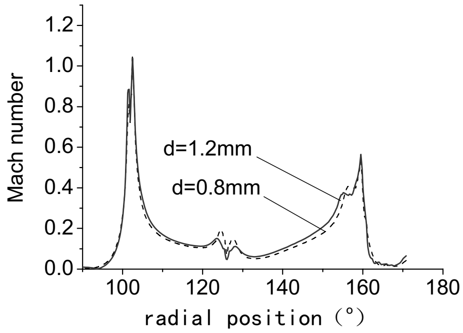
（b） Mach number contrast

Figure 3 Effect of offest e to flow characters

When the diameter of supply hole gets larger (shown as Fig.4), the values of pressure and mach number are very close at the same position. Especially, the mach number profiles are almost superposition. So we should design greater supply hole in favor of machining.



（a） Pressure contrast

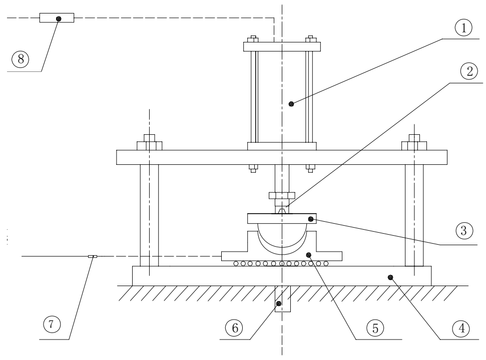


（b） Mach number contrast

Figure 4 Effect of diameter of supply hole to flow characters

CHARACTERISTICS EXAMINATION

The characteristics examination system mainly includes gas source, filter, loading devices, testing apparatus, etc. (shown as Fig.5)



1-Loading system, 2-Force sensor, 3- Spherical bulb, 4-Support plan, 5-Spherical socket, 6-Distance sensor,

Figure 5 Sketch map of testing system

The contrastive results of load between numerical simulation and experimental test are shown as Fig.6. Though the tendency of the variety is basically close agreement each other. The value of carrying force by

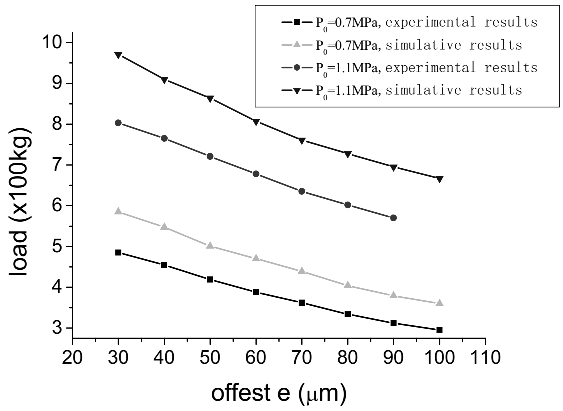


Figure 6 Contract of carrying capacity

simulation is greater 20% than that by testing. The first reason is caused by the simplified flow field as laminar flow; the second reason may be that the beginning offset e is not very precision.

CONCLUSIONS

The new running-in aerostatic spherical bearing has integrated socket, and can offer admirable stability and carrying capacity in large scale of supply pressure. Experimental results are also proved that the bearing capacity of the new aerostatic spherical bearing can steady work at over conventional supply pressure 0.6Mpa. These conclusions give some valuable references for studying on heavy-duty fields.

ACKNOWLEDGMENTS

This project is supported by National Natural Science Foundation of China (No.50335010).

REFERENCES

1. Grossman R L. Application of flow and stability theory to the design of externally pressurized spherical gas bearings [J].Trans of ASME, Journal of Basic Engineering, 1963, 85 (4):495-502.
2. Liu Dun, Liu Yuhua, Chen Shijie. Externally Pressurized Gas Lubrication [M]. Haerbin, China: Haerbin Institute of Technology Publishing Company, 1990.
3. Dang Genmao. Gas Lubrication Technique [M]. Nanjing：Dongnan Institute Publishing Company, 1990.