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EXPERIMENTAL AND CFD STUDY ON ONE NEW TYPE OF AEROSTATIC BEARING

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ABSTRACT

The pressure depression is usually observed just after the gas supply hole. In order to improve the pressure distribution, a new type of aerostatic bearing (NT) is designed, which has a tapered chamber at the outlet of the gas supply hole. The Fluent software is used to simulate the working conditions of aerostatic bearings. The simulation results show the simulation method can effectively estimate the pressure depression and the pressure distribution of the NT is remarkably improved compared with the traditional annular orifice type(TT). It's found that the characteristics of the Mach Number (MN) distribution of the NT are different from those of the TT and the tapered chamber can effectively reduce the velocity at the bearing clearance entrance. A test rig is built. The pressure distributions are tested and the simulation results of the NT agree well with the experimental results. The simulation method provides a good theoretical method to study the aerostatic bearings and the new design will be helpful to the development of high load capacity aerostatic bearings.

KEY WORDS

aerostatic bearing, pressure depression, Mach Number, Fluent software

NOMENCLATURE

d : gas supply hole diameter
d_1 : tapered chamber outer diameter
D : bearing outer diameter
h : bearing clearance
h_1 : length of gas supply hole
h_2 : height of tapered chamber
P : pressure
P_a : ambient pressure
P_s : gas supply pressure
R : radial coordinate
T : absolute temperature
T_a : ambient temperature
T_s : gas supply temperature
μ : dynamic viscosity

INTRODUCTION

Aerostatic bearings have been widely applied to precision instruments, dental drills, jet engines and computer peripheral devices, because of their substantially low friction loss and heat generation. Recently, the application of aerostatic bearings in micro electro-mechanical system (MEMS) has attracted considerable attention [1]. However, there is a deep pressure depression just after the outlet of the gas supply hole in some cases, which limits the use of

aerostatic bearings [2]. In order to reduce the pressure depression and improve the load capacity of aerostatic bearings, Mori et al first proposed one new type of aerostatic bearing with a tapered chamber at the outlet of the gas supply hole [3]. They found that the pressure distribution of the aerostatic bearing with a tapered chamber is remarkably improved compared with the aerostatic bearing without a chamber. Under some assumptions, they simplified the control equations and calculated the pressure distribution, but the calculating results are not well agreed with experimental results.
In this paper, one of the NT is designed. The Fluent software is used to calculate the flow of aerostatic bearings. A test rig is built, the pressure distributions are tested.

SIMULATION AND EXPERIMENT SYSTEM

Simulation Models

Figure 1 shows the structure of the NT and its parameters are as follow: D=80mm; d=2mm; d_1=20mm; h_1=6mm; h_2=0.4mm. Fig.2 shows the structure of the TT and its parameters are as follow: D=80mm; d=2mm; h_1=6mm.Because of the axis-symmetry, this paper just takes the half of Figure 1 and 2 as the simulation models, which is helpful to densify calculation grids.

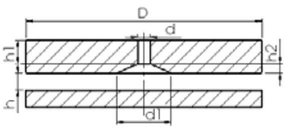

Figure 1 Structure of NT

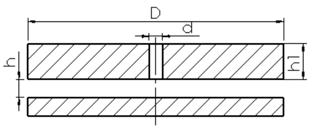

Figure 2 Structure of TT

Boundary Conditions

The SST k-omega model is used to calculate the flow, and the setting of the boundary conditions are as follow:
(1) P_a =1atm, T_a = 300K.
(2) P_s =6atm (absolute pressure), T_s =300K
(3) In the supersonic flow, the air temperature may change, and the dynamic viscosity of air is usually a function of temperature, so it is estimated using the Sutherland equation as shown below

$$\frac{\mu}{\mu_\infty} = \left(\frac{T}{T_\infty}\right)^{3/2} \frac{1 + S_1 / T_\infty}{T / T_\infty + S_1 / T_\infty}$$

Where μ_∞=1.716-e5; T_∞=273.11; S_1=110.56.

Experiment System

Figure 3 shows the experimental system. The system includes three parts: air source parts, load exertion parts; testing parts.
In the air source parts, the air from the compressor passes through the main filter and dryer and enters into the air tank. The high pressure air from the air tank is reduced by the pressure reducing valves installed in the pipeline and supplied into the bearing clearance.
In the load exertion parts, the load is exerted by an air cylinder. In order to avoid the bearing air supply pressure fluctuation, the air cylinder' air is not supplied by the high pressure air tank but by an independent low pressure air compressor with a 50 L air tank.
In the testing parts, bearing clearance, load and pressure distribution can be tested. The bearing clearance is measured by the inductance micrometer and the load is measured by the weighting sensor. The pressure distribution in the bearing clearance is measured by the multi-channel (16channel) pressure scanning module. During the experiment, the author used two pressure scanning modules to measure the pressure distribution.

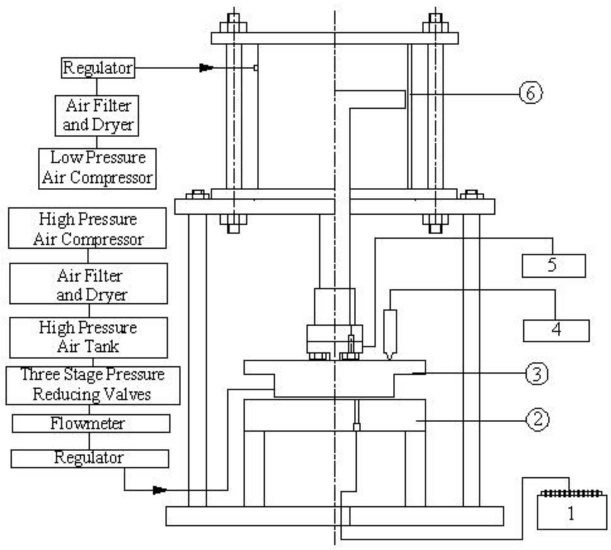

Figure 3 Experiment System
1 pressure scanning module, 2 pressure measuring board, 3 gas bearing, 4 inductance micrometer, 5 weighting sensor, 6 gas cylinder

COMPARISONS AND DISCUSSION

Figure 4～7 shows the pressure distributions obtained from simulations and experiments of the two types of aerostatic bearing under different bearing clearances.

(1) Under four different bearing clearances（Figure 4～7）, both simulation and experiment pressure distributions of the NT are higher than those of the TT. The pressure distributions of the NT are remarkably improved, which are the same to the results of Mori et al [3].
(2) Under 30μm and 40μm bearing clearance（Figure 6～7）, pressure depressions occur in both types of aerostatic bearing. And there are two pressure

depressions occurring in the NT, one occurs just after the outlet of the gas supply hole, which is similar to the pressure depression of the TT after the gas supple hole. The other occurs at the outlet of the tapered chamber. After the first pressure depression, the pressure increases a little, after the second one, no increase occurs. The pressure depression amplitudes of the NT are much smaller than those of the TT, the reason will be explained after.

(3) For the NT, the simulation results are well agreed with the experiment results. For the TT, when the bearing clearance is 10μm, the simulation results are in good accord with the experiment results（Figure 4）, but with the increase of the bearing clearance（Figure 5～7）, the deviation of simulation and experiment results increases, and the experiments are not able to capture the minimum pressure, the experimental pressure distributions are higher than the simulation results. This phenomenon is caused by the arrangements of the pressure testing holes. The arrangements of the pressure testing holes are fixed in the experiment system, but the position of the minimum pressure is changing under different bearing clearances and multi pressure testing holes have influence on the pressure distributions, which increase the pressure distribution under high MN working conditions.

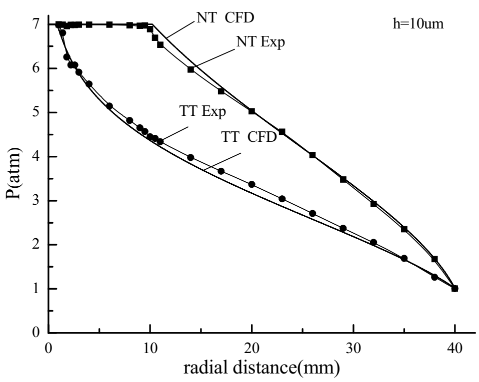

Figure 4

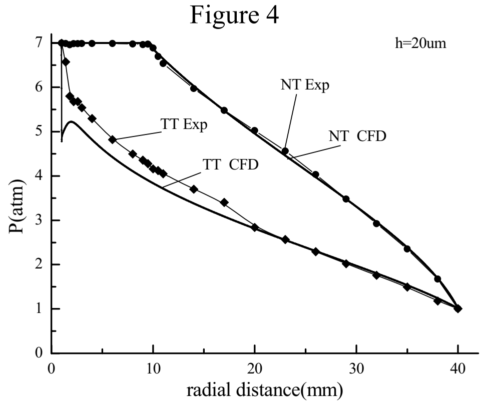

Figure 5

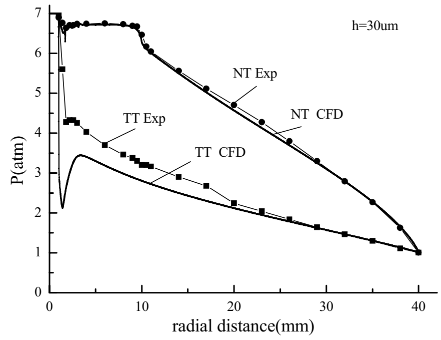

Figure 6

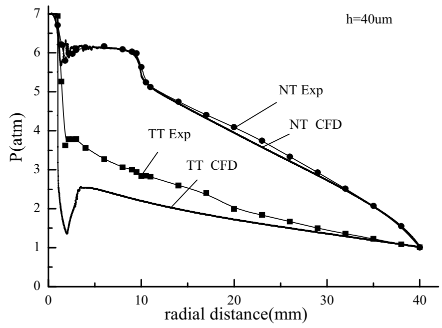

Figure 7

EFFECTS OF CHAMBER ON MN DISTRIBUTION

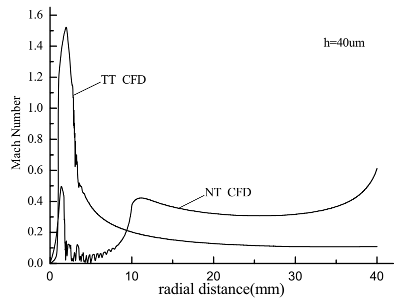

Figure 8 MN distributions of two types of aerostatic bearing under 40μm bearing clearance

Figure 8 shows the MN distributions of the two types of aerostatic bearing under 40μm bearing clearance, the MN distribution of the NT is quite different from that of the TT.

Before R=10mm, the MN of the NT is smaller than that of the TT; after R=10mm, the MN of the NT is bigger than that of the TT. For the TT, the MN increases first and then decreases. For the NT, generally speaking, there are three increases and two decreases. The first pair of increase and decrease occurs just after the outlet of the supply hole, which is similar to the pair of increase and decrease of the TT, is caused by the change of the flow passage. The second pair of increase and decrease occurs at the entrance of the bearing clearance or the outlet of the tapered chamber. After the second pair of increase and decrease, the MN increases with the increase of R before the outlet of the bearing clearance. For the TT, the maximum MN occurs just after the gas supply hole and is greater than one. While for the NT, the chamber inhibits the increase of velocity in the chamber, the maximum MN is less than 0.6 and the position of the maximum MN is at the outlet of the bearing clearance. Because the increase of MN in the chamber is inhibited, so the MN of the NT is smaller than that of the TT, and the pressure depression is suppressed. After the gas supply hole, with the increase of R in the chamber, the flow passage area decreases, based on the continuity equation, the velocity must increase. After the bearing clearance entrance, the velocity decrease is caused by the gas viscosity and the increase of flow passage area, but the phenomena that the MN increases with the increase of R before the outlet of the bearing clearance after the second pair of increase and decrease can't be explained now and needs further study.

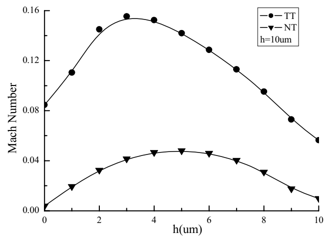

Figure 9

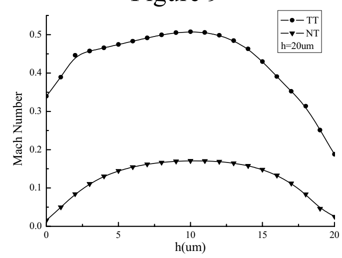

Figure 10

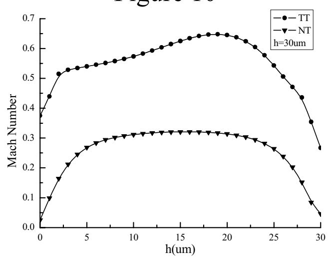

Figure 11

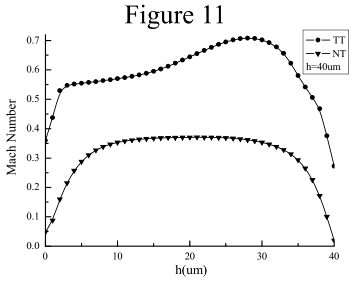

Figure 12

Figure 9～12 shows the MN distributions of the two types at the bearing clearance entrance under four different bearing clearances. It's obvious that the MN distributions of the NT are smaller and more regular than those of the TT because of the tapered chamber. The MN distribution of the NT is less affected by the bearing clearance and accords with the characteristics of laminar flow, it is because in the chamber the flow becomes uniform and the flow passage changes a little before and after the bearing clearance entrance. While in the TT, the flow passage changes abruptly before and after the bearing clearance entrance, the direction of velocity changes much and the maximum MN position move towards the up wall with the increase of bearing clearance. The distribution accords with the characteristics of turbulence flow. Because the MN of the NT is smaller than that of the TT, the effect of inertial force will be less too.

CONCLUSIONS

(a) A tapered chamber at the outlet of the gas supply hole can effectively reduce the pressure depression amplitude and improve the pressure distribution.
(b) A tapered chamber at the outlet of the gas supply hole inhibits the increase of velocity and the appearance of the supersonic velocity after the gas supply hole. It changes the style of MN distribution. It reduces the velocity in the tapered chamber, but it improves the MN distribution after it, the cause of this kind of phenomena needs further study.
(c) The multi-hole pressure testing method can't effectively capture the minimum pressure and has influence on the pressure distributions.
(d) The simulation method can effectively calculate the flow of aerostatic bearings and provides a good theoretical method to study the aerostatic bearings.

ACKNOWLEDGMENTS

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