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The Static Analysis of a Porous Aerostatic Bearing

Ming-Fei Chen[1], Kuo-Yu Chien [2], Yen-Ting Chen [2],
Chuang-Chin Yang [3] and Chin-Chia Liu [3*]

***Abstract*—A study was made of a porous aerostatic bearing by analysis of its relevant static characteristics. The purpose was to authenticate the theoretical computing results in terms of previously published data. The porous aerostatic bearing and its working mechanism was first introduced after which the mathematical model and the boundary conditions were built. Graphs of the characteristics of the porous aerostatic bearing were made that included data about capacity and clearance and a comparison was made between these findings and the accepted published data to establish and verify correctness of the theory.**

***Keywords*—Porous restriction, porous material, aerostatic bearing, finite difference method, orifice restriction.**

I. Introduction

The continuous development of technology has increased the need for high precision machinery. The characteristics of aerostatic bearing are relevant and important indexes for precision technology. An aerostatic bearing has serious advantages over the normal and commonly used hydrostatic bearing. They can allow higher speeds, greater precision, lower pollution and will have a serious influence on future precision technology.

Reynolds [1] derived a basic lubrication equation for aerostatic bearings, according to hydro mechanical principles and worked out a partial differential equation for pressure, density, relevant velocity and the thickness of the lubricating film. This became the Reynolds equation, which laid down a foundation for liquid lubrication theory. Fuzhang Zhao [2] et al optimized the parameter setting of two types of aerostatic bearing design and Togo Shinichi [3] derived the central finite difference method to calculate the pressure distribution of gas films in various bearings, including static, dynamic and mixed arc gas types.

1. Ming-Fei Chen
Department of Mechatronics Engineering, National Changhua University of Education
Taiwan

2. Kuo-Yu Chien, Yen-Ting Chen
Mold & Precision Machining Technology Section Metal Industries Research & Development Centre
Taiwan

3. Chuang-Chin Yang, Chin-Chia Liu*
Department of Industrial Education and Technology, National Changhua University of Education
Taiwan

Porous bearings, made from porous material, can be metallic or non-metallic. Metallic porous bearings are made by high temperature sintering and the bearings are permeable to air. The porosity is usually between 20% and 40% and must be uniform [4] throughout the bearing. Using Darcy's Law, Sheinberg [5] et al derived figures for the flow and incompressibility of liquid through porous material, and conducted the analysis of pressure distribution, bearing capacity, rigidity, etc.

Wenqi Ma et al [6] studied the characteristics of orifice restriction in aerostatic radial bearings and compared this with other methods of restriction. Li Yuntang et al [7] analyzed aerostatic thrust bearings in a quest for the best design parameters.

II. Basic theoretic structure

A mathematical model was derived to determine all the different characteristics of porous aerostatic bearings. Simulation analysis was done and Figure 1 shows the details of the aerostatic bearing [8] used in this paper.

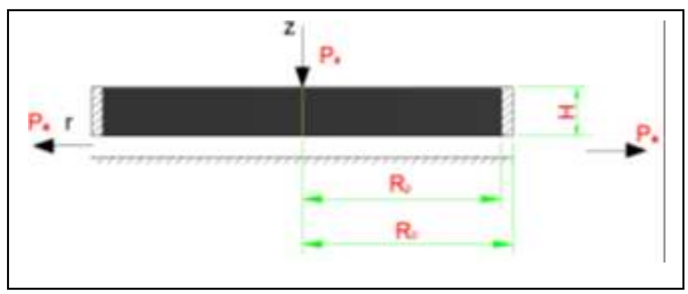

Figure 1. Configuration of the new porous air bearing [8]

P_s: supply gas pressure. P_a: atmospheric pressure. R_0: radius of porous bearing. R_p: radius of porous structure. H: thickness of porous structure.

A. *The Reynolds equation[1]*

To design a gas bearing, all its characteristics, such as bearing capacity, pressure etc, should be known. Pressure distribution can be deduced by the gas lubrication equation as follows:

$$\frac{\partial}{\partial x}\left(Ph^3\frac{\partial P}{\partial r}\right)+\frac{\partial}{\partial y}\left(Ph^3\frac{\partial^2 P^2}{\partial y}\right)=6\eta\left[U\frac{\partial}{\partial x}(Ph)+2\frac{\partial}{\partial t}(Ph)\right] \quad (1)$$

However, on the left side of the equals sign, the results refer to speed and squeeze film effect. But in this paper, we only consider stability and used a round flat bearing, so we can ($x = r$, $y = r\theta$) adapt equation (1) as follows:

$$\frac{\partial}{\partial r}\left(Ph^3 \frac{\partial P}{\partial r}\right) + \frac{\partial}{\partial r\theta}\left(Ph^3 \frac{\partial^2 P^2}{\partial r\theta}\right) = 0 \qquad (2)$$

B. *Flow equation[3]*

The mass flow at the inlet of a porous gas pressure bearing can be represented by equation (3):

$$Q_{in} = \frac{\phi \cdot A(P_s^{\ 2} - P_r^{\ 2})}{2 \cdot \Re \cdot T \cdot \mu \cdot H} \qquad (3)$$

C. *Basic parameter setting*

In this paper the simulation analysis was conducted using Matlab. The relationship diagram of various characteristics of porous aerostatic bearing and pressure distribution within the bearing can be obtained. And its relevant basic parameters are shown in Table I.

TABLE I. BASIC PARAMETERS OF A POROUS BEARING[8].

Name	*Value*	*Unit*
Radius of porous bearing (R_0)	2.65	cm
Thickness of porous structure(H)	0.6	cm
Radius of porous structure(R_0)	2.5	cm
Atmospheric pressure(P_a)	1.0	kg/cm^2
Supply gas pressure(P_s)	5.5	kg/cm^2
Absolute temperature (T^o)	288	K
Atmospheric constant(R)	2927	cm/K
Air permeability of porous material(ψ)	5.69×10^{-12}	cm^2
Air density (ρ_a)	1.31×10^{-7}	kg/cm^3
Gas specific weight (γ)	1.226×10^{-5}	kg/cm^3

A flow diagram of the procedures used for calculating the porous aerostatic bearing data is shown in Figure 2.

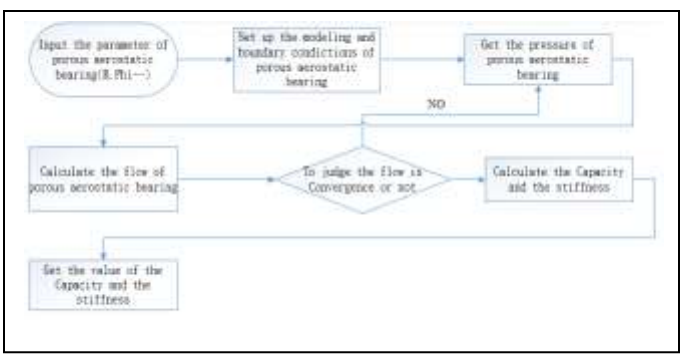

Figure 2. Procedures used for calculating porous aerostatic bearing data.

III. Verifying the correctness of the equation

After the program had been coded, its correctness also needed to be verified, so the simulation results were compared to those in the literature [9]. Table II shows the basic parameters as previously published in the literature.

TABLE II. BASIC PARAMETERS FOR POROUS AEROSTATIC BEARINGS FROM THE LITERATURE[9].

Name	*Value*	*Unit*
Radius of porous bearing (R_0)	2.5	cm
Thickness of porous structure(H)	0.5	cm
Radius of porous structure(R_0)	2.25	cm
Atmospheric pressure(P_a)	1.0	kg/cm^2
Supply gas pressure(P_s)	5.0	kg/cm^2
Absolute temperature (T^o)	293	K
Atmospheric constant(R)	2927	cm/K
Air permeability of porous material(ψ)	7.95×10^{-15}	cm^2
Air density (ρ_a)	1.31×10^{-7}	kg/cm^3
Gas specific weight (γ)	1.226×10^{-5}	kg/cm^3

Figures 3 and 4 are comparisons between published data from the literature and the simulation figures for bearing capacity and rigidity obtained in this study using the same supply gas pressure in both cases.

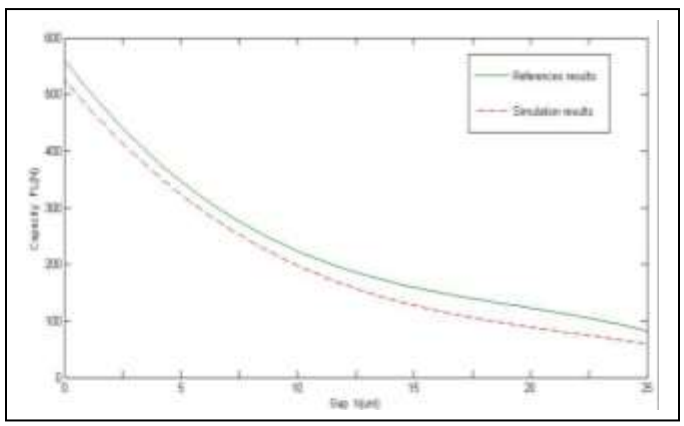

Figure 3. Bearing capacity to clearance relationship comparison diagram [9] with supply gas pressure of $5kg/cm^2$.

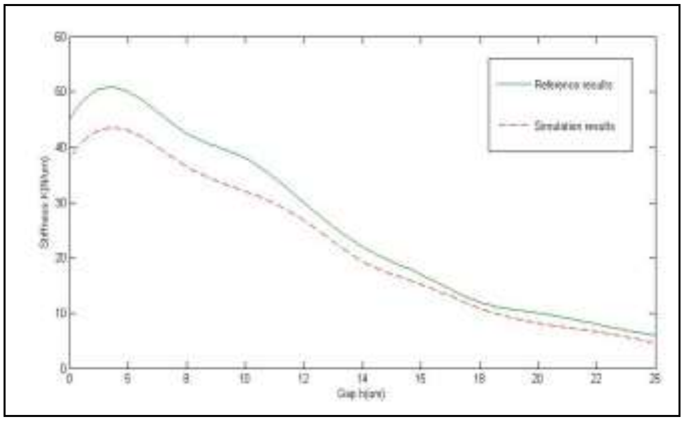

Figure 4. Bearing rigidity to clearance relationship comparison diagram [9] with supply gas pressure of 5kg/cm^2.

As shown in Figure 3, when the clearance is 5µm the bearing capacity as given in the literature is 342N, and that of the simulation is 321N, the difference being 6.14%. With other clearance values the maximum error value is 18%. The reason for these differences may be that the method used for the analysis itself is different. However, further analysis revealed that the higher the supply gas pressure the lower the error.

From Figure 4 it can be seen that in both the literature and simulation values the maximum rigidity of 50N/µm and 43N/µm is reached with a clearance of 5µm. In Figure 3 and 4 we can also see that the trend in both the literature values and the simulation results are quite similar, so the correctness of the program code used in this study is validated.

A. *Analysis of the static characteristics of a porous aerostatic bearing*

After validating the correctness of the porous aerostatic bearing program, a simulation was conducted according to the parameters given in Table I and the relationship diagram of various characteristics is shown in Figure 5.

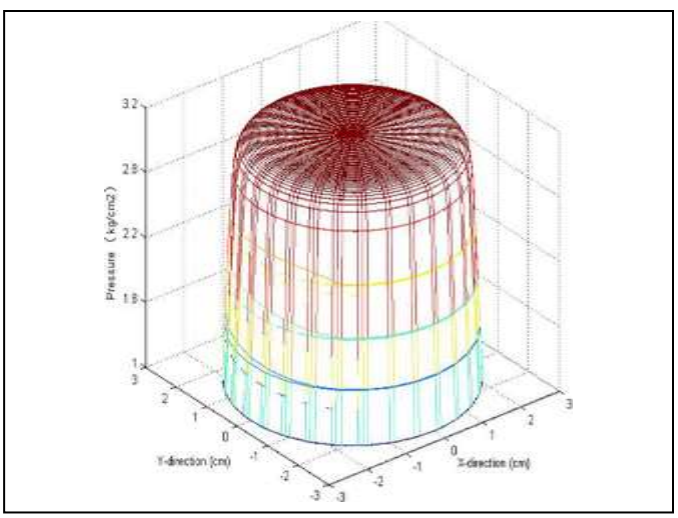

Figure 5. The pressure distribution situation [8] with a supply gas pressure of 5.5kg/cm^2.

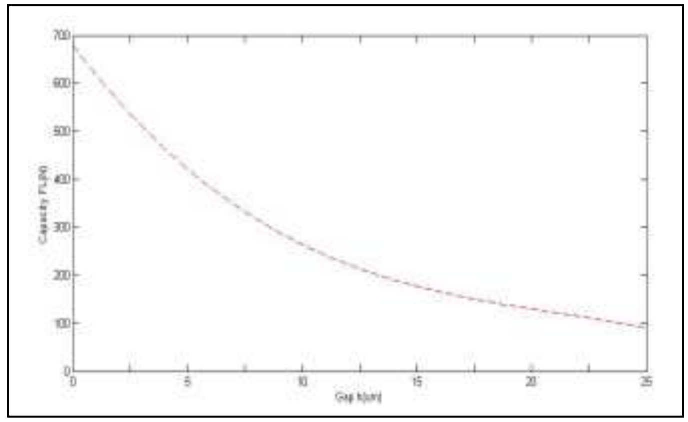

Figure 6. The bearing capacity to clearance relationship diagram [8] with a supply gas pressure of 5.5 kg/cm^2.

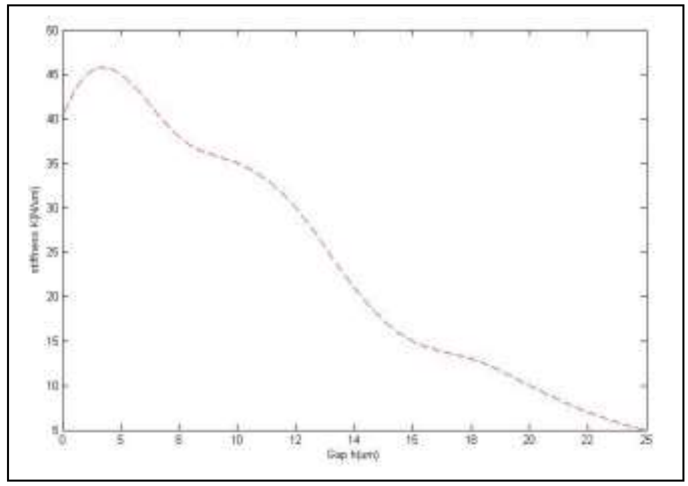

Figure 7. The rigidity to clearance relationship diagram [8] with a supply gas pressure of 5.5 kg/cm^2.

From the pressure distribution situation, as shown in Figure 5, we can see that the pressure value from the simulation program is 3.18kg/cm2 and from Figure 6 we can see that when the supply gas pressure is 5.5 kg/cm2 and the clearance 5µm, the bearing capacity is 450N. In Figure 7 it can be seen that maximum rigidity of 45N/µm is reached when the clearance is 7µm, and the gas pressure is 5.5kg/cm2.

IV. CONCLUSION

The results of this simulation study on porous aerostatic bearings have an error value of between 6 and 18% when compared to published values. However the trends of bearing capacity and rigidity are very similar as can be clearly seen in the graphs. The program code used in this study will definitely be of value in an initial stage of bearing design.

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