Theoretical Analysis of Externally Pressurized Porous Journal Gas Bearings*
(1st Report)

By Haruo Mori**, Hiroshi Yabe***, Hidemi Yamakage†, and Jun Furukawa††

For externally pressurized porous journal gas bearings, an analytical solution has been obtained by introducing the concept of the so-called equivalent clearance, but it is not good enough because of the circumferential flow being neglected.

In this paper, the authors have analyzed the gas flow of the bearing with added consideration of the circumferential flow in the bearing clearance and the porous bushing. The theoretical results are investigated experimentally, yielding a good conformity between them enough to certify the theory. Then, the optimum design conditions of the externally pressurized porous journal gas bearing are determined theoretically for the various factors which affect the bearing characteristics. Thus, it is made clear that the bearings with the porous bearing surface can have excellent static characteristics.

1. Introduction

The externally pressurized bearing with porous bearing surface is considered to be advantageous for its working stability and its large load capacity. The authors have analyzed(1) (2) the externally pressurized porous bearings by introducing the concepts of equivalent clearance and effective restricting length of the porous media so that the flows in the bearing clearance and porous media may be represented by an equivalent flow-model composed of fundamental parallel flows of two layers. For the porous journal bearing, however, the results by this model were not sufficiently suitable since no circumferential flow was taken into account(1).

In this paper, the porous journal bearing is analyzed using the same flow-model including the circumferential flow, and experiments are made to investigate the theoretical results. Then, the effects of dimensionless characteristic factors are investigated by numerical calculation of the theoretical results in order to give the optimum design condi-

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* Received 15th May, 1967.
** Professor, Faculty of Engineering, Kyoto University, Sakyo-ku, Kyoto.
*** Assistant Professor, Faculty of Engineering, Kyoto University.
† Graduate Student, Faculty of Engineering, Kyoto University.
†† Student, Faculty of Engineering, Kyoto University.

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2. Theoretical analysis

Fig. 1 shows the externally pressurized journal gas bearing with porous bushing analyzed here. The compressed gas is fed from the circumferential supply port behind the porous bushing and restricted by it into bearing clearance, then made to flow out from both ends of the bearing. Some of the gas flows axially and circumferentially in the porous bushing.

When both ends of the porous bushing are not sealed, the gas can flow out into atmosphere; this will be designated "open-end type", while the bearing with sealed ends will be called "closed-end type".

The flow in the clearance and porous media of
the bearing is analyzed with consideration of circumferential component as well as axial and radial ones under the following assumptions:

Assumptions:

(1) Porous media are homogeneous with permeability \( \kappa \). The \( \kappa \) is defined by the following equation of Darcy's law,

\[
\eta = \frac{\kappa}{\mu} \frac{\partial p}{\partial z}
\]

where \( p \), \( \eta \), and \( \mu \) are pressure, flow velocity and viscosity coefficient of the fluid, respectively.

(2) Porous bushing can be substituted by an equivalent clearance of thickness \( h_0 \) where

\[
h_0 = \sqrt{12\kappa t}
\]

in which \( t \) is thickness of porous bushing.

(3) The gas flow in the porous media is divided into three components of axial, radial and circumferential flows.

(4) The pressure in the bearing clearance is different from that in the equivalent clearance of a porous material, but both fluid layers are so thin that the pressures do not vary in radial direction in each layer.

(5) The flow rate from porous bushing into bearing clearance is proportional to the permeability and the pressure difference between the equivalent clearance and the bearing clearance, and is inversely proportional to the thickness of porous bushing.

(6) The effective restricting lengths, \( t_0 \) and \( t_1 \), are introduced for the radial flow in the porous material (\( t_0 \)). The \( t_0 \) and \( t_1 \) can be assumed to be \( \frac{1}{2} t \).

(7) The fluid is incompressible.

(8) The rotating speed of shaft can be ignored comparing with the flow velocity of fluid.

Fig. 2 shows the schematic diagram of the bearing with the dimensional letters. The \( p \) is pressure, and \( \eta \) and \( \bar{\eta} \) are average flow velocities in circumferential and radial direction, respectively. The letters which are followed by subscript 0 mean the inside of the porous media, and 1 means the bearing clearance space. The flow velocity \( v_0 \) is a velocity from gas supply port to porous bushing, and \( v_1 \) is from porous bushing to bearing clearance. The superscripts I and II denote the region of central supply port (\( s < b \)), and the other region with solid wall behind the bushing (\( b < z < l \)), respectively.

The fundamental equations are as follows:

\[
\eta_o = \frac{h_0^3}{12\mu} \frac{\partial p_0}{\partial z}
\]

\[
\eta_t = \frac{h_t^3}{12\mu} \frac{\partial p_t}{\partial z}
\]

\[
\bar{\eta}_t = \frac{h_t^3}{12\mu} \frac{\partial p_0}{\partial z}
\]

The continuity conditions are

Region I:

\[
\left( \frac{\partial \eta_o}{\partial z} + \frac{\partial \bar{\eta}_t}{\partial z} \right) v_o - v_1 = 0
\]

Region II:

\[
\left( \frac{\partial \eta_t}{\partial z} + \frac{\partial \bar{\eta}_t}{\partial z} \right) v_1 - v_o = 0
\]

The boundary conditions are:

(1) The pressure distribution is even and periodic with respect to \( x \).

(2) The pressure distribution is even with respect to \( z \) in region I.

(3) The pressure and pressure gradient are continuous at the boundary between region I and II.

(4) For the open-end type, the pressure is equal to the ambient pressure at bearing end.
For the closed-end type, the pressure in bearing clearance is ambient, and the pressure gradient in the porous bushing becomes zero at bearing end.

Denoting the coordinates \( \theta \) and \( \xi \) instead of \( x \) and \( z \) by

\[
\theta = x/r, \quad \xi = z/r
\]

and substituting \( \mu = \text{constant}, \ t = \text{constant} \) and \( h = \text{constant} \), the following equations can be derived from Eqs. (9) and (10) for region I:

\[
\frac{\partial}{\partial \theta} \left[ \frac{h}{C_r} \frac{\partial^2 p}{\partial \theta^2} + \frac{\partial}{\partial \xi} \left( \frac{h}{C_r} \frac{\partial^2 p}{\partial \xi^2} \right) \right] - \frac{1}{r^2} \left( \frac{h}{C_r} \right)^2 (p - p_0) = 0
\]

Substituting Eq. (13) into Eq. (14), the governing equation is obtained for pressure solution \( p_0 \) as follows:

\[
\frac{\partial}{\partial \theta} \left[ \frac{h}{C_r} \frac{\partial^2 p}{\partial \theta^2} + \frac{\partial}{\partial \xi} \left( \frac{h}{C_r} \frac{\partial^2 p}{\partial \xi^2} \right) \right] + \frac{\partial}{\partial \xi} \left( \frac{h}{C_r} \frac{\partial^2 p}{\partial \xi^2} \right) - \frac{1}{r^2} \left( \frac{h}{C_r} \right)^2 (p - p_0) = 0
\]

where \( C_r \) is the radial clearance. The solution \( p_1 \) in the bearing clearance can be obtained from Eq. (13) substituting the solution \( p_0 \) in the porous material.

The pressures \( p_0 \) and \( p_1 \) are now expanded with respect to eccentricity ratio \( \varepsilon \) as follows:

\[
p_0^i = p_0 + P_{00}^i + \varepsilon P_{01}^i + \varepsilon^2 P_{02}^i + \cdots \quad \text{(16)}
\]

\[
p_1^i = p_1 + P_{10}^i + P_{11}^i + P_{12}^i + \varepsilon P_{13}^i + \varepsilon^2 P_{14}^i + \cdots \quad \text{(17)}
\]

\[
p_0^x = p_0 + P_{00}^x + P_{01}^x + P_{02}^x + \varepsilon P_{03}^x + \varepsilon^2 P_{04}^x + \cdots \quad \text{(18)}
\]

\[
p_1^x = p_1 + P_{10}^x + P_{11}^x + P_{12}^x + P_{13}^x + \varepsilon P_{14}^x + \varepsilon^2 P_{15}^x + \cdots \quad \text{(19)}
\]

The \( P^i \)'s are pressure distribution solutions of each order of \( \varepsilon \). The first subscript denotes the porous bushing 0 or the bearing clearance 1, the second subscript does the order of \( \varepsilon \), and the third one the eigenvalue. The integration constants have the same subscripts mentioned later. The superscript I or II denotes its region.

The bearing clearance \( h \) is given by

\[
h = C_r \left( 1 + \varepsilon \cos \theta \right)
\]

Substituting Eqs. (16) and (20) into Eq. (15), the succeeding equations for each order of \( \varepsilon \) are obtained as follows for the region I:

\[
e^0: \quad \frac{\partial^2 P_{00}^0}{\partial \theta^2} + \frac{\partial^2 P_{00}^0}{\partial \xi^2} + \frac{\partial^4 P_{00}^0}{\partial \theta^4} + \frac{\partial^4 P_{00}^0}{\partial \theta^2 \partial \xi^2} - (A+B) \left( \frac{\partial^2 P_{00}^0}{\partial \theta^2} + \frac{\partial^2 P_{00}^0}{\partial \xi^2} \right) + CP_{00}^0 = 0
\]

where

\[
A = \frac{r_l^2}{r_l^4} \left( 1 + \frac{t_l}{t_0} \right), \quad B = \frac{r_l^4 h_{03}^3}{r_l^2 t_l^4 C_r^3}, \quad C = \frac{r_l^4 h_{03}^3}{t_l^4 t_l^2 C_r^3}
\]

Defining a calculus \( D^1 \) which is given by the following equation,

\[
(D^1) P^1 = \frac{\partial^2 P^1}{\partial \theta^2} + \frac{\partial^2 P^1}{\partial \xi^2} + \frac{\partial^4 P^1}{\partial \theta^4} + \frac{\partial^4 P^1}{\partial \theta^2 \partial \xi^2} - (A+B) \left( \frac{\partial^2 P^1}{\partial \theta^2} + \frac{\partial^2 P^1}{\partial \xi^2} \right) + CP^1 = 0
\]

The solution of \( P^1 \) is given as follows using the boundary conditions (1) and (2):

\[
P^1 = A_{01} \cos k \theta \cosh \sqrt{\alpha + k^2 \xi^2} + B_{01} \sin k \theta \sinh \sqrt{\alpha + k^2 \xi^2}
\]

where

\[
\alpha = \frac{1}{2} (A+B) \pm \sqrt{(A+B)^2 - 4C}
\]

In which \( A_{01} \) and \( B_{01} \) are integration constants, and \( k \) and \( k' \) are eigenvalues.

Similar analysis can be made of the region II. The relationship between \( p_0 \) and \( p_1 \) corresponding to Eq. (15) is

\[
p_{1i} = p_{0i} - \frac{r_l^2}{r_l^4} \left( \frac{\partial^2 P_{00}^0}{\partial \theta^2} + \frac{\partial^2 P_{00}^0}{\partial \xi^2} \right)
\]

The governing equation for \( P^1 \) corresponding to Eq. (24) is

\[
(D^2) P^1 = \frac{\partial^2 P^1}{\partial \theta^2} + \frac{\partial^2 P^1}{\partial \xi^2} + \frac{\partial^4 P^1}{\partial \theta^4} + \frac{\partial^4 P^1}{\partial \theta^2 \partial \xi^2} - (A+B) \left( \frac{\partial^2 P^1}{\partial \theta^2} + \frac{\partial^2 P^1}{\partial \xi^2} \right) + CP^1 = 0
\]

Then, the fundamental solution of \( P^1 \) is obtained as follows using the boundary conditions:

\[
P^1 = \cos k' \theta (C_{01} \cos k' \xi + D_{01} \sin k' \xi)
\]

\[
+ \cos k'' \theta (C_{01} \cos k'' \xi + D_{01} \sin k'' \xi)
\]

\[
+ H_{01} \sinh \sqrt{k''^2 + k^2} \xi
\]

\[
+ H_{01} \sinh \sqrt{k''^2 + k^2} \xi
\]

where

\[
\gamma = \frac{A}{1 + \frac{t_l}{t_0}} + B
\]

in which \( C_{01} \) and \( H_{01} \) are integration constants, and \( k' \) and \( k'' \) are eigenvalues.
Zero-th order solution

The zero-th order solution, that is the pressure distribution for noneccentric state, is to be independent of \( \theta \), hence the solution of

\[
(D^1) P_{01} = 0 \tag{31}
\]

\[
(D^1) P_{02} = 0 \tag{32}
\]

can be obtained from Eqs. (25) and (29) with \( k = k' = k'' = 0 \), namely

\[
P_{01} = A_{000} \cos \sqrt{\alpha} \xi + B_{000} \cos \sqrt{\beta} \xi \tag{33}
\]

\[
P_{02} = C_{000} \xi + D_{000} + G_{000} \cos \sqrt{T} \xi + H_{000} \sin \sqrt{T} \xi \tag{34}
\]

The pressure distributions in the bearing clearance, \( P_{01} \) and \( P_{02} \), become as follows from Eqs. (13) and (27):

\[
P_{10} = A_{000} E_0 \cos \sqrt{\alpha} \xi + B_{000} E_0 \cos \sqrt{\beta} \xi \tag{35}
\]

\[
P_{10} = C_{000} \xi + D_{000} + G_{000} E_0 \cos \sqrt{T} \xi + H_{000} E_0 \sin \sqrt{T} \xi \tag{36}
\]

where

\[
E_0 = 1 + \frac{L_1}{L_0} - \frac{L_1}{L_0} \frac{L_2}{L_3} \alpha, \quad E_1 = 1 - \frac{L_1}{L_0} - \frac{L_1}{L_0} \frac{L_2}{L_3} \beta, \quad E_2 = 1 - \frac{L_1}{L_0} \frac{L_2}{L_3} \tag{37}
\]

in which \( \alpha, \beta, \tau, E_0, E_1, E_2 \) are the constants determined by bearing dimensions. The \( A_{000} \sim H_{000} \) are integration constants determined by the conditions (3) and (4), which, for example, can be expressed as follows for the open-end type:

\[
\begin{bmatrix}
-\cosh \sqrt{\alpha} \xi_1, & -\cosh \sqrt{\beta} \xi_1, & \xi_1, & 1, & \cosh \sqrt{T} \xi_1, & \sin \sqrt{T} \xi_1 \\
0, & 0, & 0, & 0, & \xi_1, & 1, & \cosh \sqrt{T} \xi_1, & \sin \sqrt{T} \xi_1 \\
0, & 0, & 0, & 0, & \xi_1, & 1, & \cosh \sqrt{T} \xi_1, & \sin \sqrt{T} \xi_1 \\
\end{bmatrix} \times \begin{bmatrix}
A_{000} \\
B_{000} \\
C_{000} \\
D_{000} \\
G_{000} \\
H_{000}
\end{bmatrix} = \begin{bmatrix}
p_r - p_a \\
p_r - p_a \\
0 \\
0 \\
0 \\
0
\end{bmatrix} \tag{38}
\]

where \( \xi_1 = b/r, \quad \xi_2 = l/r \tag{39} \)

The zero-th order solution can be obtained with these constants determined by Eq. (38), and it is the same solution that was obtained in the previous paper\(^9\) in which the circumferential flow has not been taken into consideration.

First order solution

The general solution of pressure distribution is obtained by solving the following equation with the zero-th order solution above considering \( \partial P_{01}/\partial \theta = 0 \) in Eq. (22):

\[
(D^1) P_{01} = 3 \cos \theta \left( -\frac{\partial^2}{\partial \xi^2} + A \frac{\partial^2}{\partial \xi^2} \right) P_{01} \tag{40}
\]

The fundamental solution of Eq. (40) is as follows from Eq. (22):

\[
P_{01} = A_{01} \cos \beta b \cosh \sqrt{\alpha + k^2 \xi} + B_{01} \cosh \sqrt{\beta + k^2 \xi} \tag{41}
\]

in which the eigenvalues are determined as \( k = k' = 1 \) by the boundary conditions. The particular solution of Eq. (40) is

\[
P_{11} = A_1 \cos \theta \cosh \sqrt{\alpha} \xi + B_1 \cos \theta \cosh \sqrt{\beta} \xi \tag{42}
\]

where

\[
A_1 = 3 \alpha A_{000} (\alpha - \alpha) \frac{\beta - \alpha + 1}{\beta - \alpha + 1}, \quad B_1 = 3 \beta B_{000} (\alpha - \beta) \frac{\beta - \alpha + 1}{\alpha - \beta + 1} \tag{43}
\]

Then, the general solution of Eq. (40) becomes

\[
P_{01} = \cos \theta \left( A_{01} \cosh \sqrt{\alpha + \xi} + B_{01} \cosh \sqrt{\beta + \xi} + A_1 \cosh \sqrt{\alpha} \xi + B_1 \cosh \sqrt{\beta} \xi \right) \tag{44}
\]

The pressure distribution solution in the bearing clearance \( P_{11} \) becomes as follows from Eq. (13):

\[
P_{11} = \cos \theta \left( A_{11} E_0 \cosh \sqrt{\alpha + \xi} + B_{11} E_0 \cosh \sqrt{\beta + \xi} + A_1 E_1 \cosh \sqrt{\alpha} \xi + B_1 E_1 \cosh \sqrt{\beta} \xi \right) \tag{45}
\]

where

\[
E_1 = \left( 1 + \frac{L_1}{L_0} \right) - \frac{L_1}{L_0} \frac{L_2}{L_3} (\alpha - 1), \quad E_2 = \left( 1 + \frac{L_1}{L_0} \right) - \frac{L_1}{L_0} \frac{L_2}{L_3} (\beta - 1) \tag{46}
\]

By similar reduction, the pressure distribution solutions in the region II are

\[
P_{10} = \cos \theta \left( C_{01} \cosh \xi + D_{01} \sin \xi + G_{01} \cosh \sqrt{T + \xi} + H_{01} \sin \sqrt{T + \xi} \right) \tag{47}
\]

\[
P_{11} = \cos \theta \left( C_{11} \cosh \xi + D_{11} \sin \xi + G_{11} E_0 \cosh \sqrt{T + \xi} + H_{11} E_0 \sin \sqrt{T + \xi} \right) \tag{48}
\]
in which \( E_{11}, \ G, \)  and \( B_{1} \) are constants determined by the bearing dimensions and given in similar forms as \( E_{02} \) and \( A_{1} \). The integration constants \( A_{021} \sim H_{021} \) are determined by the boundary conditions, as was done for the zero-th order solution, yielding the first order pressure distributions.

**Second order solution**

The second order solution is obtained by making the same reduction, resulting in:

\[
P_{12} = \cos 2\theta (A_{022} \cos \sqrt{\alpha + 4z} + B_{022} \cos \sqrt{\beta + 4\xi}) + A_{022} \cos \sqrt{\alpha + 4\xi} + B_{022} \cos \sqrt{\beta + 4z} + C_{022} \cos \sqrt{\alpha + 4z} + D_{022} \cos \sqrt{\beta + 4\xi} + E_{022} \cos \sqrt{\alpha + 4\xi} + F_{022} \cos \sqrt{\beta + 4z} + G_{022} \cos \sqrt{\alpha + 4\xi} + H_{022} \cos \sqrt{\beta + 4z}
\]

\[
P_{12} = \cos 2\theta (A_{122} \cos \sqrt{\alpha + 4z} + B_{122} \cos \sqrt{\beta + 4\xi}) + A_{122} \cos \sqrt{\alpha + 4\xi} + B_{122} \cos \sqrt{\beta + 4z} + C_{122} \cos \sqrt{\alpha + 4z} + D_{122} \cos \sqrt{\beta + 4\xi} + E_{122} \cos \sqrt{\alpha + 4\xi} + F_{122} \cos \sqrt{\beta + 4z} + G_{122} \cos \sqrt{\alpha + 4\xi} + H_{122} \cos \sqrt{\beta + 4z}
\]

where \( A_{1}'s \sim B_{1}'s \), and \( C_{1}'s \) are constants determined by the bearing dimensions, and the integration constants \( A_{022}, A_{002} \sim H_{022} \), and \( H_{002} \) are determined by the boundary conditions.

The higher order solutions can be obtained as well.

**Load capacity and flow rate**

The load capacity is obtained by integrating the pressure distribution over the bearing surface, namely

\[
W = -\int_{\theta_{1}}^{\theta_{2}} \int_{0}^{\pi} (p_{1} - p_{2}) r \cos \theta d\theta d\phi
\]

\[
= -\int_{\theta_{1}}^{\theta_{2}} \int_{0}^{\pi} (p_{1} - p_{2}) r \cos \theta d\theta d\phi
\]

The volume rate of flow is found as follows using Eq. (7):

\[
Q = 4 \int_{0}^{\pi} \int_{0}^{\pi} v_{r} r d\theta d\phi
\]

\[
= 4 \int_{0}^{\pi} \int_{0}^{\pi} v_{r} r d\theta d\phi
\]

For the calculation of the theoretical pressure distribution, the second order solutions may give sufficiently accurate results. The convergency for load capacity solution differs with the value of \( h_{0}/C_{r} \); but it is comparatively good except the value corresponding to the peak value of the load capacity (Refer the section 4-1). And also, the first order solution may give sufficient results if the eccentricity ratio is not so large.
3. Experimental investigations

The theoretical results developed above are investigated experimentally.

Fig. 3 shows the experimental apparatus. The bearing is given a certain load upward and downward by dead weights. The shaft locates on the shaft-supporting stand, which can traverse in axial direction on several steel balls in race-ways of the base. Thus, the shaft can also be traversed with the shaft-supporting stand, and rotated in its axis, hence the pressure distribution in the bearing clearance can be measured continuously through pressure-measuring holes made on the shaft. The eccentricity is measured from the displacement of the bearing by dial-gages placed on the flat plate fixed on the bearing. The gas is fed from the compressor to the bearing through a reservoir, a filter, a control valve and a flow-meter. The porous bushings are made of sintered copper.

The dimensions of the bearing employed for the experiments are:

\[ l=4 \text{ mm} \quad b=5 \text{ mm} \quad l=20 \text{ mm} \]
\[ r=15 \text{ mm} \quad h_0=40 \sim 100 \text{ microns} \]

Figs. 4 and 5 show examples of the experimental results of axial pressure distributions with theoretical curves. The experimental and theoretical load capacity are shown in Fig. 6 with respect to \( h_0/C_r \) and Figs. 7 and 8 with respect to eccentricity ratio. The theoretical calculations are made for the second order solutions.

For the various of \( h_0/C_r \) which are achieved by varying the bearing clearance, the experimental pressure distributions agree well with theoretical results both in axial and circumferential directions up to a comparatively large eccentricity ratio, so
that the flow-model introduced for theoretical analysis may be justified for the actual gas flow in the porous bearing.

In Fig. 6, the solid curves show the load capacities at \( \varepsilon = 0.3 \) and 0.4 according as \( \frac{b_0}{C_v} \) varies. The experimental data are also shown in the figure with notation of each eccentricity ratio, from which assumed load capacity curves by experiments are drawn as broken curves for \( \varepsilon = 0.3 \) and 0.4. When the most important parameter \( \frac{b_0}{C_v} \) is changed, the experimental results agree well qualitatively and become somewhat different quantitatively from the theoretical ones at the large load capacity. This tendency seems to be caused by the fact that the theoretical load capacity varies remarkably near the maximum value of it for the change of \( \frac{b_0}{C_v} \), while the actual bearing may have a local difference of permeability so that the flow in the bearing may not be so ideal as assumed by the flow-model. In Fig. 7, where the value of \( \frac{b_0}{C_v} \) is nearly optimum, the theoretical load capacity becomes larger than the experimental one.

The theoretical results, however, may show apparently the qualitative effect of \( \frac{b_0}{C_v} \), and they agree quantitatively well with experimental one except in the peak region of the load capacity, for example, as shown in Fig. 8.

4. Theoretical design conditions

As the experimental results justify theoretical analysis made in the above taking the circumferential flow into consideration, the design conditions of this type of the bearing are investigated from the theoretical results in the following.

The performance of the porous bearing is dominated by the bearing dimensions, and permeability or equivalent clearance of the porous media, hence, these parameters are investigated as dimensionless numbers, \( \frac{b_0}{C_v} \), \( b/l \), \( l/r \), and \( t/r \) in connection with bearing characteristics.

Figs. 9, 10 and 11 show the load capacity and
volume rate of flow versus $h_0/C_r$, $b/l$, and $l/r$, respectively. Figs. 12, 13 and 14 show the load capacity versus $h_0/C_r$, $b/l$ and $l/r$, respectively, with parameter of $t/r$. In Fig. 15, the maximum load capacity and its conditions of $h_0/C_r$, $l/r$ and $t/r$ are shown for the closed-end type bearing with $b/l=0.5$. In these theoretical calculations, higher order solutions than third order are neglected for load capacity, and ones higher than first order are neglected for flow rate.

The closed-end type bearing has larger load capacity and less volume rate of flow than the open-end type as shown in Figs. 9, 11. Hence, considering the practical application, the closed-end type is mainly investigated for its load capacity in the following.

(1) Concerning $h_0/C_r$:

The effects of $h_0/C_r$ on the load capacity and volume rate of flow are shown in Figs. 9 and 12.

There exists the maximum load capacity for a certain value of $h_0/C_r$, which is plotted in Fig. 15 with various values of $l/r$ and $t/r$. The value of the maximum load capacity is not so much influenced.
by $t/r$, but, for small $t/r$, the load capacity varies remarkably with $h_0/C_r$ near the maximum load capacity, and for an increased $t/r$, the change of it becomes less. Where the value of $h_0/C_r$ is smaller than the optimum value of maximum load capacity, the decrease of load capacity is remarkable compared with a larger $h_0/C_r$, and the volume rate of flow also increases.

It should be noted that $h_0/C_r$ should have a certain margin in design from the standpoints of the material and manufacturing. Hence it is concluded that $h_0/C_r$ is recommended to be more than 0.5 though it is dependent on $t/r$.

If there are no material and manufacturing problems, the smaller $C_r$ is preferable for a certain value of $h_0/C_r$. It is partly because the shaft displacement is small for a certain eccentricity ratio when $C_r$ is small, which means a large bearing stiffness. The other reason is that the larger $C_r$ which corresponds to the larger $h_0$ means the smaller restriction by porous bushing and larger volume rate of flow, hence the supply pressure as well as load capacity becomes less under a constant gas supply ability.

Concerning $b/l$: The load capacity and flow rate are shown in Figs. 10 and 13 with the effect of $b/l$. The relation between $b/l$ and flow rate has almost the same tendency even if $h_0/C_r$ is varied. The load capacity increases as $b/l$ increases and becomes maximum when $b/l=1$, where the flow rate, however, also becomes maximum. In the neighborhood of $b/l=1$, the rate of increase of flow rate becomes larger than that of load capacity, hence the large $b/l$ is not preferable for the design unless the flow rate problem can be ignored. Then, the value of $b/l$ is recommended generally to be 0.3~0.7.

Concerning $i/r$: Figs. 11 and 14 show the effect of $i/r$. The $i/r$ does not influence so much the flow rate, but influences much the load capacity. The load capacity takes maximum value for a certain value of $i/r$, and decreases remarkably for less values than it. This maximum load capacity increases as $i/r$ decreases.

As the $i/r$ ratio is frequently limited by other design conditions in the practical design, the optimum $i/r$ should be determined for a given $i/r$, and then it should be checked if $i/r$ may not become so small as mentioned above for $h_0/C_r$.

Thus, $i/r$ is generally recommended to be 0.7~1.5.

It should be noted that the absolute load capacity increases with an increase of $i/r$, even if the specific load capacity decreases for a large $i/r$, but the rate of the increase drops there.

Concerning $t/r$: The maximum value of the load capacity increases with a decrease of $t/r$, but, for a small $t/r$ the load capacity decreases remarkably when the other parameters deviate from their optimum values. Among these parameters, one should consider especially the effect of $h_0/C_r$ in order to obtain a desirable design for load capacity.

Concluding from the above considerations, one can obtain a bearing with the following recommendation for the design so that dimensionless load capacity $W/4rt(p_r-p_a)\varepsilon$ may become more than 0.5 theoretically:

\[
(b/l)=0.3~0.7
\]

(When the flow rate is out of the question)

For a small $i/r$ ratio ($0.7~1.0$)

\[
i/r=0.2~0.4
\]

\[
h_0/C_r=0.5~1.0
\]

For a large $i/r$ ratio ($1.0~1.5$)

\[
i/r=0.3~0.5
\]

\[
h_0/C_r=0.6~1.5
\]

It is better to make $h_0$ and $C_r$ smaller.

5. Summary

The externally pressurized journal bearing with porous bushing had been investigated theoretically in the previous paper for the concentric state with the circumferential flow ignored, resulting in some difference from experimental data especially at a large eccentricity ratio. In this paper, the porous journal bearing is analyzed with a similar flow-model considering the circumferential flow; and the theoretical pressure distribution, load capacity and flow rate are obtained.

The experimental results agree well with the theoretical ones for the pressure distribution and load capacity qualitatively as well as quantitatively, justifying the theoretical analysis.

The effects of characteristic factors are calculated, yielding the optimum design conditions of the externally pressurized porous journal gas bearing and proving its good capability as an externally pressurized gas bearing.

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References
