EXPERIMENTAL AND THEORETICAL STUDY FOR SEALING EFFECTS OF SQUEEZ AIR FILM.

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ABSTRACT

The sealing effects of squeeze air film were analyzed experimentally and theoretically .The air flow rate and the sealed pressure were measured in a squeeze face seal. The air flow rate can be expressed as the difference between the flow rate by the pumping and the flow rate by the leakage. The air flow rate by the pumping increases proportionally to the square of the vibration amplitude of the surface, as does the sealed pressure. The air flow rate by the leakage increases proportionally to the pressure difference between the vessel pressure and the ambient pressure. The experimental results showed good agreement with the theoretical results.

الخلاصة

اجري تحليل عملي ونظري لتأثيرات منع التسريب لطبقة الهواء المضغوط.تم قياس معدل التـدفق للهـواء وضغط منع التسريب عند وجه مائع التسريب المضغوط.

إن معدل التدفق للهواء يمكن التعبير عنه بالفرق بين معدل التدفق بالضخ ومعدل التدفق بالتسريب ، حيث أن معدل التدفق للهواء بالضخ يزداد بالتناسب مع مربع الطول الموجي لإهتزاز السطح وكذلك الحال مع ضغط منع التسريب بينما يزداد معدل التدفق بالتسريب تناسباً مع فرق الضغط بين ضغط الوعاء وضغط المحيط .

كانت النتائج العملية متوافقة بصورة جيدة مع النتائج النظرية.

KEY WORD

Sealing effect, Squeeze, Air film, squeeze face seal.

INTRODUCTION

There are very few reports about sealing effects of a squeeze air film, although research findings pertaining to squeeze films have been reported by various authors, e.g., Salbo [Salbo1964] , Pan[Pan 1967],from different points of view. The pressure distribution between two disks is reported by Taylor and Saffman [Taylor 1957].

In this paper we deal with gas sealing effects of the squeeze air film. This research is the sequel to a report [Takáda1983] on air flow through the a spherical squeeze air film.The outer gap between two discs is thicker than the inner gap see in **Fig.(1).**In this case,air flows outward due to the vibration of the disk.The air flow by the pumping effect shows that the squeeze air film has a gas sealing effect.

The present report deals with the measurement of gas sealing effects and a comparison with the theoretical results.

Analysis

The isothermal Reynolds equation for an annular disk squeeze film is[Langlois 1962]

$$\sigma\frac{\partial(PH)}{\partial Y}=\frac{1}{R}\frac{\partial}{\partial R}(PRH^{3}\frac{\partial P}{\partial R}) \qquad (1)$$

where

$$\sigma=\frac{12\mu\omega}{p_{a}}(\frac{r_{2}}{r_{0}})^{2}=squeezenumber \qquad (2)$$

In equation(1), the boundary conditions are

P=1 at $R=R_1$
P=1+ΔP at $R=R_2$ (3)
ΔP=0

The geometry of the annular disk squeeze film is shown in **Fig. (2)**.In equation (1), it is assumed that the squeeze film and the disk's vibration are axially symmetrical , so that H and P are function of R and T alone.

The normalized gap H can be expressed as

$$H=1+\frac{2\alpha}{R2-R1}(R-R_{0})+\varepsilon\sin T \qquad (4)$$

Where α is a dimensionless slope of gap, and ε<<1.

To obtain the pressure distribution ,we apply the difference method proposed by Michael [Michael 1962],using Crank-Nilsson's formula to equation(1).This procedure is applied recurrently until the computed results of pressure are periodic .From the pressure distribution obtained above .the dimensionless air flow rate per unit cycle through the squeeze film is

$$Q=-\frac{1}{2\pi}\int_{0}^{2\pi}RPH^{3}\frac{\partial P}{\partial R}dT \qquad (5)$$

Or in terms of the original variables

$$q=-\frac{\omega}{2\pi p_{a}^{2}h_{0}^{3}}\int_{0}^{2\pi}rph^{3}\frac{\partial p}{\partial r}dt \qquad (6)$$

The reason why air flows could be as follows: the pressure distribution in the wedge film is asymmetric, as shown in **Fig. (3)**.and an symmetry in case of (a) is more pronounced than that in case (b), that is, air flow rate in the direction of R is larger than that on the opposite direction .Therefore, steady air flow rate with respect to time.

When flow is small, equation (6) may also be written in the following linear form (see Appendix):

$Q = Q_p - Q_l$ (7)

Where Q_p is the dimensionless flow rate of air flowing outward (in the direction of R) by the pumping effect. In the case ,$\Delta P=0$ in the boundary conditions(3). Q_p increases proportionally to the square of in the ε range of 0 to 0.2 by the numerical calculation, therefore

$$Q_p = K_p \varepsilon^2 \tag{8}$$

Where K_p is a function of σ alone. **Fig. (4)** shows the values for K_p in case of R_1 =5/55 and R_2=1.

Q_l is a dimensionless flow rate of air flowing inward by the leakage. In this case ,$\varepsilon=0$ in equation (4),so that $\bar{H}$ and P are function of R alone .There fore ,equation(5) becomes

$$Q = -PRH^3 \frac{dP}{dR} \tag{9}$$

With regard to Q_l ,the plus is taken in the opposite direction of R .Therefore ,equation (9) becomes

$$Q_l = PRH^3 \frac{dP}{dR} \tag{10}$$

Solving equation (10) results in

$$\frac{d(P^2)}{dR} = \frac{2Ql}{RH^3}$$

$$= \frac{2Ql}{R(1+\frac{2\alpha}{R_2 - R_1}(R-R_o))^3} \tag{11}$$

With the boundary conditions (3) and $\Delta P<<1$.So, the solution of equation (11) is

$$Q_l = K_l \Delta P \tag{12}$$

Where

$$K_l = \frac{\left(1-\alpha\frac{R_2 - R_1}{R_2 - R_0}\right)^3}{\beta} \tag{13}$$

And where

$$\beta = \ln\left(\frac{1+\alpha\ R_1}{1-\alpha\ R_2}\right) + \frac{2\alpha\left(1-\alpha\frac{R_2+R_1}{R_2-R_1}\right)}{1-\alpha^2} + \frac{2\alpha\left(1-\alpha\frac{R_2+R_1}{R_2-R_1}\right)^2}{\left(1-\alpha^2\right)^2} \tag{14}$$

Values for K_l may be read from **Fig. (4)**.Using equation (8) and (12),we rewrite equation(7) as

$$Q = K_p\varepsilon^2 - K_l \Delta P \tag{15}$$

EXPERIMENTAL RESULTS AND DISCUSSION

An experimental apparatus is shown in **Fig. (5)**.An upper disk is supported by ball bearing over a lower disk .The lower disk was driven sinusoidally in the direction normal to the surface by a vibrator at frequencies between 1000 Hz to 2000 Hz. The disk's surfaces are very smooth. The outer diameter and the inner diameter of the surfaces are 110 mm and 10mm respectively.

The mean gap between the upper disk is adjusted by three micrometer heads .One can measure the mean gap and the amplitude of vibration with three displacement sensors which are mounted in the lower disk .The gap becomes wider with an increase of R .Two kinds of disks, whose gradients of the gap are 0.75 μm/mm and 0.33 μm/mm ,are investigated to clarify the sealing effect .The mean gap is the time averaged gap at R_0 .The pressure $R=R_l$ is ambient ,and the pressure $R=R_2$ (vessel pressure) is higher then the pressure at $R=R_l$ by ΔP.

MEASURE OF AIR FLOW RATE

The air flow rate is that of the volume flow rate at 25C̃,1atm.With regard to the value of air flow rate , the plus is taken in the direction of R.

Fig. (6) shows the air flow rate of the squeeze film which has 0.7 μm/mm gradient .In case of f=2000 Hz , ΔP=1.0kPa and d=4 μm at the mean gap less than 46 μm the squeeze air film has pumping effect , and the mean gap more than 46 μm ,the air leaks .When the mean gap is 46 μm ,the squeeze film can hold a pressure difference of 1.0 kPa .Here ,the pumping force and the force by pressure gradient are equal .In this figure ,the air flow when ΔP=0 is the air flow caused by pumping alone when ΔP=1.0 kPa and that when ΔP=0is the air flow rate by the leakage alone when ΔP=1.0 kPa.

Fig. (7) shows the air flow rate plotted against the vibration amplitude of the lower disk .The plotted results give straight lines on a log scale because the flow rate by the pumping increases proportionally to the square of d($\varepsilon=d/h_0$,see equation(8)).

Fig. (8) shows the flow rate plotted against the pressure difference ΔP between the pressure at $r=r_l$ (the ambient pressure) and the pressure at $r=r_2$ (the vessel pressure) .The leakage flow rate increases proportionally to the pressure difference(see equation(12)) ,so the plotted results give straight lines.

MEASURE OF SEALED PRESSURE

Fig. (9) shows the sealed pressure plotted against the vibration amplitude .Let Q=0 in equation (15).Setting $\Delta P=\Delta P/P_a$ and $\varepsilon=d/h_0$,we express the sealed pressure as follows:

$$\Delta P_s = \frac{p_a K_p}{K_l h_0^2} d^2 \qquad (16)$$

Therefore ,the sealed pressure increases proportionally to the square of d .The plotted results give straight lines on log scale .The scaled pressure for the slop a= 0.70μm/mm is larger than the sealed pressure at a=0.33 μm/mm when the mean gap is same ,as shown in **Fig.(9).**

CONCLUSION

Sealing effects of a squeeze air film were analyzed .The results obtained in a squeeze face seal are as follows:

1- The air flow rate by the pumping increases proportionally to the square of the amplitude of the squeeze vibration.

2- The flow rate by leakage increases proportionally to the pressure difference between the vessel pressure and the ambient pressure.

3- The sealed pressure increases proportionally to the square of the amplitude of the squeeze vibration.

4- As the mean gap increases ,the pumping effect decreases rapidly .

5- The experimental results showed good agreement with the theoretical results for both the flow rate and the sealed pressure.

6- A wedge shaped squeeze air film can be used as a non-contact gas seal.

REFERENCES

Salbo ,E . O. J., (1964), Compressible squeeze films and squeeze Bearings, ASME journal of basic engineering.Vol.86,June.

Pan ,C.H.T., (1967), On asymptotic Analysis of Gaseous Squeeze –film Bearing, ASME journal of LUBRICATION TECHNOLOGY,Vol.89,July.

Taylor, G. I., and Saffman, P.G., (1957), Effects of Compressible at Low Reynolds Number, Journal of the aeronautical Science,Vol.24,No.8,Aug.

Takada. H., Kamigaichi, S., and Miura, H., (1986), Characteristics of Squeeze Air Film Between Non Parallel Plates, ASME journal of LUBRICATION TECHNOLOGY,Vol.105,June.

Gallous, W. E., (1999), Isothermal Squeeze Films, Quarterly of Applied Mathematics, Vol.XX,No.2,Jan.

Michael, W. A., (1988), Approximate Method for Time-Dependent Gas Film Lubrication Problem, IBM Research Report RJ-205,Feb.

APPENDEX

Derivation of equation(7)

Let Q_p a nondimensional flow rate at $\Delta P=0$(pumping flow rate).In case of $\Delta P<<1$, Q_p can be approximated as follows:

$$Q= Q_p - K_l \, \Delta P + \text{higher order terms} \qquad (A1)$$

On the other hand ,Let Q_l nondimensional flow rate at $\varepsilon=0$(leakage flow rate).In case of $\varepsilon<<1$, Q_l can be approximated as follows(Coefficient of first term of ε becomes zero by numerical calculation):

$$Q=-Q_l+K_p \, \varepsilon^2+\text{higher order terms} \qquad (A2)$$

From equations(A1)and(A2) , we have

$$Q = Q_p - Q_l \qquad (7)$$

NOMENCLATURE

a = slope of gap between upper disk and lower disk.

α =normalized slop of gap.$2ar_2(ho/(R_2-R_1)$

d = vibration amplitude of lower disk.

ε = excursion rtio,d/h_0

f = squeeze frequency

h = instantaneous gap

h_o = mean gap(time averaged gap at $r=(r_1+r_2)/2$)

H = normalized gap,h/h_o

μ = viscosity

P = pressure in squeeze film
P_0 = ambient pressure
Δp= pressure difference between vessel pressure at ($r=r_2$)
ΔP = normalized pressure
Δp_s=sealed pressure squeeze film can hold
ΔP_s = normalized sealed pressure $\Delta p_s/p_a$
q = air flow rate per unit cycle, defined in (6)
q_v= volume air flow rate ,at25 C 1atm
Q = normalized air flow rate ,defined in(5)
Q_p = normalized air flow rate by pumping ,defined in (8)
Q_l = normalized air flow rate by leakage ,defined in (12)
difference, $\Delta p/p_o$
R = dimensionless radial coordinate,r/r_2
R_l= dimensionless inside radius of disk,r_1/r_2
R_2 = dimensionless outside radius of disk,$r_2/r_2=1$
R_0 = $(R_1+R_2)/2$
r = radial coordinate
r_1= inside radius of disk
r_2= outside radius of disk
σ = squeeze number ,defined in(2)
T = dimensionless time,$\omega t=2\pi ft$
t = time
$\omega = 2\pi f$

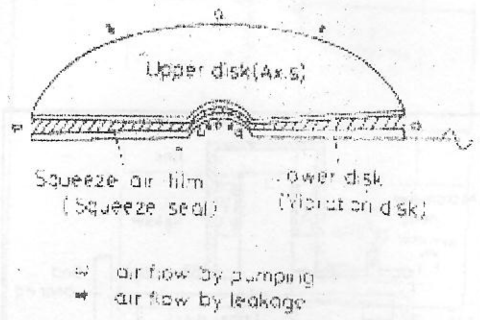

Fig. 1 Squeeze face seal

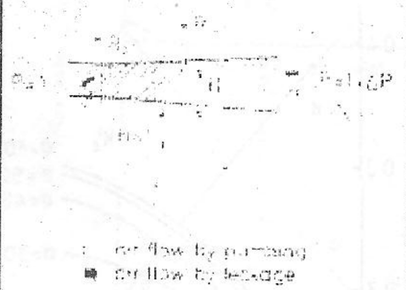

Fig. 2 Squeeze film geometry
(The variables are nondimensional)

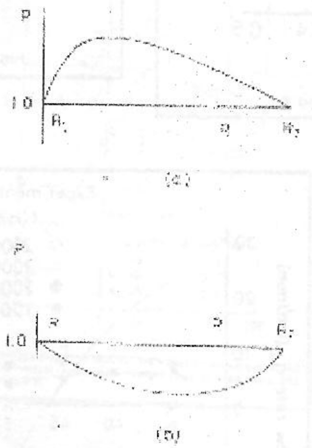

Fig. 3 Model for pressure distributions in a wedge film, (a) Typical pressure distribution at [illegible] (b) Typical pressure distribution at [illegible]

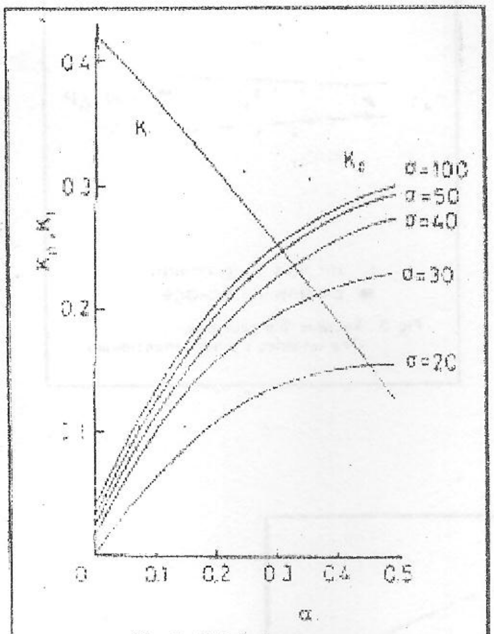

Fig. 4 Values for K_p and K_i

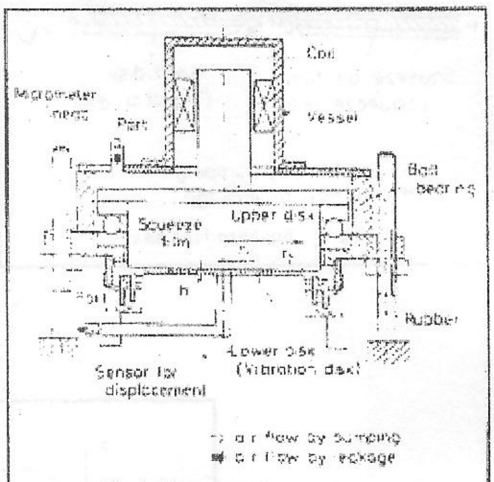

Fig. 5 Experimental arrangement

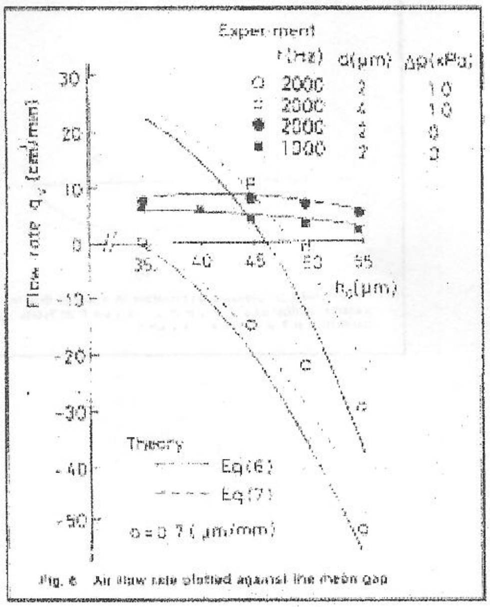

Fig. 6 Air flow rate plotted against the mean gap

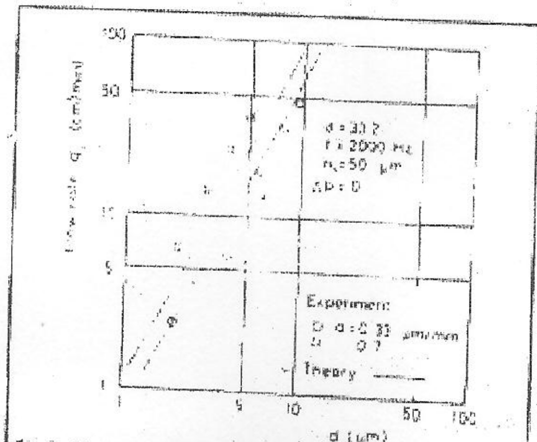

Fig. 3 . Air flow rate versus the vibration amplitude of the lower disk. The numerical results give straight lines on a log scale. The slopes of the two are 2.

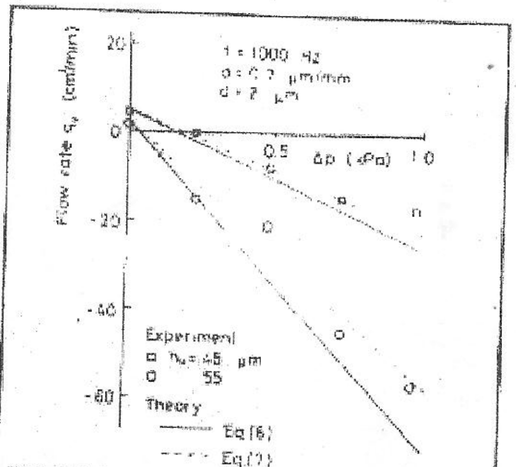

Fig. 4 Air flow rate versus the pressure difference between the vessel pressure and the ambient pressure

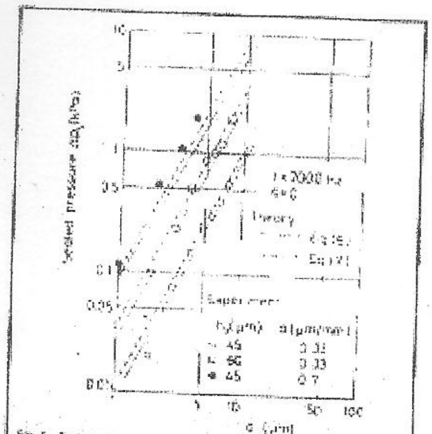

Fig. 5 Sealed pressure profiles against the vibration amplitude of the lower disk. The numerical results give straight lines on a log scale. The slopes of the two are 3