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A Study on Indicial Response Characteristics of a Gas-Lubricated Spiral-Grooved Journal Bearing

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Indicial response characteristics of a rotor supported by a gas-lubricated, spiral-grooved journal bearing are studied theoretically to develop a fundamental investigation for the bearing design with considering NRRO characteristics. The trajectory of rotor movement is calculated by applying the non-linear orbit scheme against a prescribed impulse load, then two characteristic quantities are introduced to evaluate the indicial response performance of the bearing, i.e., "maximum deviation of rotor center" and "integrated rotor center deviation". The effects of some design parameters of spiral grooves to these representative quantities are studied so that "robust" design against impulse load is discussed.

Keywords: Spiral-Grooved Journal Bearing, Gas Bearing, Indicial Response, NRRO Characteristics, Robust Design

1. INTRODUCTION

The NRRO (non-repeatable run-out) is one of the most important characteristics of the bearing, when the bearing is applied to a precision instrument such as polygon-mirror scanner motor spindle.

It may be considered that the subjects relating with the NRRO characteristics of the rotor can be classified into two groups: one is the "causing factors" such as unpredictable external disturbing forces that bring NRRO, and the other is "responding factors" such as damping ability of the bearing, which govern the characters of NRRO induced by the former causing factors.

In this paper, the latter bearing characteristics, i.e., the indicial response characteristics of the rotor supported by a gas-lubricated, spiral-grooved journal bearing are investigated theoretically, apart from the former causing factors. The orbit of the rotor center against a prescribed impulse load is calculated by applying the non-linear orbit scheme. The indicial response character of the bearing is evaluated by introducing two characteristic quantities, so that the "robust" design of the bearing against impulse load is discussed.

2. ANALYZED BEARING MODEL

Figure 1 shows schematic diagram of a gas-lubricated spiral-grooved journal bearing to be analyzed in this study.

The design parameter values of the spiral grooves are chosen as follows:

Groove width ratio : $\alpha = b_g/(b_g + b_r) = 0.5$
Dimensionless groove depth : $\delta = \bar{\delta}/C_r = 1.1$
Groove angle : $\beta = 32.8°$

where b_g , b_r : widths of groove and ridge, respectively, $\bar{\delta}$: groove depth, and C_r : radial clearance. These values will be used throughout this study unless noted otherwise. Bearing length ratio is supposed to be $L/D = 1.0$, and the number of grooves is assumed as $N_g = 8$.

Dimensionless parameters for bearing operation are defined as

Bearing number: $\Lambda = (6\mu\omega/p_a)\cdot(R/C_r)^2$
Mass parameter: $M = (m/LD)\cdot(Rp_a/\mu^2)\cdot(C_r/R)^5$

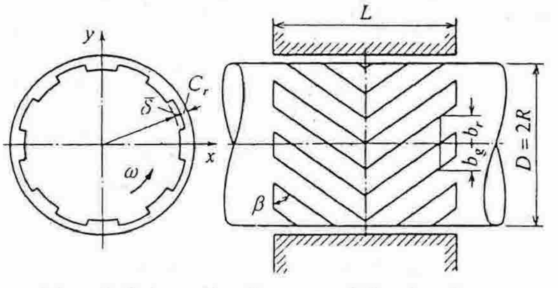

Fig. 1 Schematic diagram of the bearing

3. ANALYTICAL PROCEDURES

The gas film pressure distribution under dynamic state is analyzed by applying finite difference scheme formulated on the boundary-fitted coordinate system[1], thus the gas film forces are calculated at each time step. Non-linear orbit scheme[2] is, then, used to obtain the trajectory of rotor center movement assuming that a prescribed impulse load is applied to the rotor.

In the followings, such a situation is assumed at the numerical calculation as:

- Initially, the rotor is rotating steadily in concentric state.
- At time $\tau = 0$, impulse load towards x -axis is applied to the rotor.
- The amount of dimensionless impulse load (dimensionless force F_0 ×dimensionless period τ_0) is assumed to be constant as $I_0 = 0.001$ ($F_0 = 0.04$ and $2\tau_0 = 0.05$).

An example of the calculated results of the rotor center trajectory is shown in Fig. 2, in which the displacement of the rotor is diagrammed in terms of x - and y -components of rotor eccentricity.

In order to evaluate the feature of indicial response of the rotor, we introduce two characteristic quantities from the viewpoint for discussion of the bearing NRRO performances. One is "maximum deviation" of the rotor center from the steady-state position (i.e., concentric state), which is defined as

$$\varepsilon_{max} = \max\{\varepsilon\} = \max\{(\varepsilon_x^{\,2} + \varepsilon_y^{\,2})^{1/2}\}$$

and the other is "integrated rotor center deviation" defined by

$$\Sigma = \int_0^\infty |\,\varepsilon\,|\, d\tau$$

The latter can be considered to represent the restoring characteristic of the rotor to the original steady-state position after the impulse loading.

These bearing characteristics against impulse loading are possibly dependent on the dimensions of spiral groove configuration. Figure 3 shows the effects of groove configuration (which can be characterized by α, δ and β) to the characteristic quantities defined above.

It can be seen that, when we evaluate the bearing performance for impulse loading through ε_{max}, smaller α and δ values result in a smaller ε_{max} value, while there exist optimum values for α and δ which realize minimum Σ value. It should be noted that the groove dimensions, which make the bearing stiffness to be maximum (dotted lines in the figures), bring nearly minimum value of Σ. The effect of groove angle, β, is rather small.

Figure 4 shows the effect of Λ value to the bearing performances. We can see in the figure that a smaller Λ value results in larger ε_{max} and Σ values, which is, of course, due to smaller bearing stiffness. It should be noted that, when Λ increases, ε_{max} value reduces to be almost zero but Σ value remains to be a finite value. This means that, under a high Λ condition, maximum deviation of the rotor from steady-state position against a given impulse load becomes small, but the induced vibration remains not to be ceased for a comparatively long period, though its amplitude is rather small.

4. CONCLUSIONS

The conclusions obtained in this study can be summarized as follows:

1. Indicial response characteristics of a rotor are investigated by applying non-linear orbit scheme in order to develop a fundamental concept for NRRO of the bearing.
2. Two characteristic quantities are introduced to evaluate the rotor performance against impulse loading.
3. The effects of the groove configuration to these quantities are discussed.

NOMENCLATURE

D : rotor diameter (= $2R$)
F_0 : dimensionless force (= f/p_aLD)
I_0 : dimensionless impulse load
L : bearing length
M : mass parameter
m : mass of the rotor
p_a : ambient pressure
α : groove width ratio
β : groove angle
δ : dimensionless groove depth
ε : eccentricity ratio
Λ : bearing number
μ : viscosity of lubricant
Σ : integrated rotor center deviation
τ : dimensionless time (= ωt ; t =time)
ω : angular velocity of the rotor

REFERENCES

[1] Kawabata, N., "A Study on the Numerical Analysis of Fluid Film Lubrication by the Boundary-Fitted Coordinates System (The Case of Steady Gas-Lubrication), JSME Int. J., Ser. III, 32-2, 281-288, 1989.

[2] Castelli, V. and Elrod, H. G., "Solution of the Stability Problem for 360 Deg Self-Acting, Gas-Lubricated Bearings", Trans. ASME., J. Basic Eng., 87-1, 199-212, 1965.

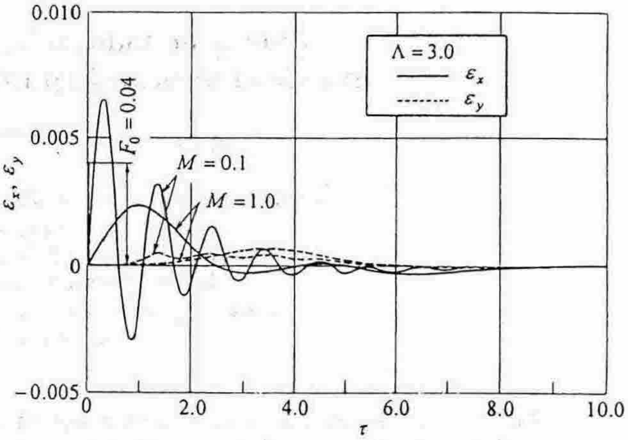

Fig. 2 Indicial response of the rotor

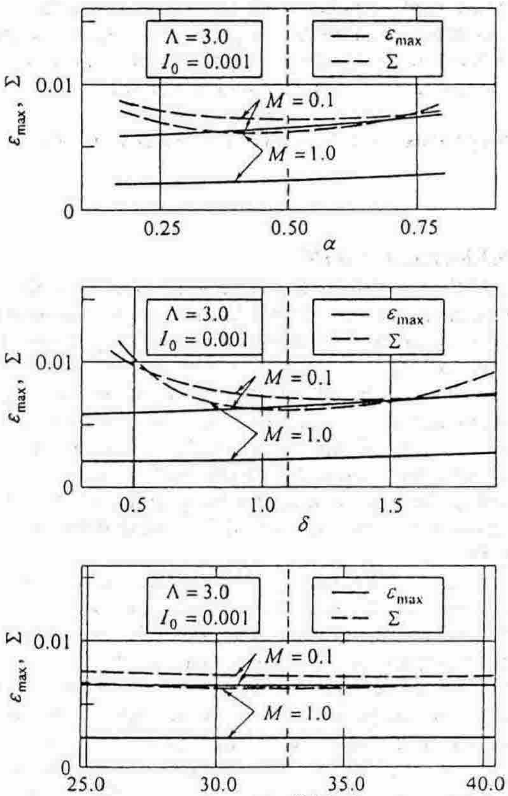

Fig. 3 Calculated results of characteristic quantities

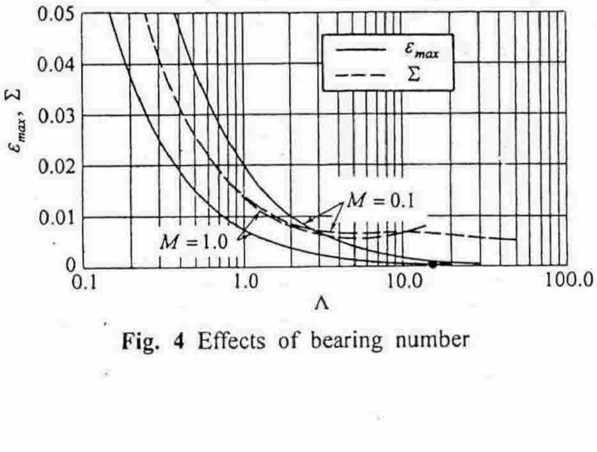

Fig. 4 Effects of bearing number