XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

DEVELOPMENT OF ACTIVE JOURNAL SQUEEZE AIR BEARING WITH PIEZOELECTRIC ACTUATORS

H. Isobe and A. Kyusojin
Nagaoka University of Technology
Department of Mechanical Engineering
Kamitomioka 1603-1, Nagaoka-shi, Niigata 940-2188, Japan

Abstract: Squeeze air bearings are based on a phenomenon known as the squeeze effect, which causes a pressured air film with relative perpendicular oscillation between two planes. The aim of this study is to achieve non-contact active motion error correction with squeeze effect. Hence, it has ability to be operated even if no pressured air supply and no relative sliding motion between them. The experimental device has piezo-driven oscillating pads and central rotating shaft. Piezos are controlled by two kinds of signals. One is the sinusoidal signal stimulate the squeeze motions. The other is the operation signal, which controls the floating shaft movement by the travel of oscillating pads. Therefore, application of a controllable pattern on piezos allows the shaft to be manipulated in the multi degree-of-freedom. The run-out of shaft was reduced from 8.1 um to 2.4 um and variation of attitude became to be undetectable. The run-out was improved by decreasing the clearance between shaft and pads by increasing the air film stiffness. Applying the feedback control to make the device more accurate, the run-out was reduced successfully.

Keywords: squeeze gas bearing, piezoelectric actuator, motion error correction

1 INTRODUCTION

The aim of this study is to develop the squeeze air bearing which has functions of run-out correction and precise shaft positioning with active control. Because the squeeze effect induces load carrying capacity by relative normal oscillation between two planes, no external air supply is required. It can be applied in special space admit of no air entrance, e.g. hermetically sealed case, as far as air exists. The researches respect to basic squeeze bearings have been reported since 1960's [1]-[3].

Essentially, air bearings have disadvantage that is extremely high sensitivity to the disturbance because of the low stiffness and damping. Furthermore it is difficult for squeeze air bearings to improve the stiffness rather than the hydrostatic ones. In our research, a special function, the positioning ability of a rotating shaft, is added to the piezo-driven squeeze air bearing by applying the controllable piezo driving waveforms. In addition, observing the motion error such as run-out in real time, it can be corrected with the active controlled piezoelectric actuators.

2 PRINCIPLE OF ACTIVE SQUEEZE AIR BEARING

The simple and effective principle of positioning via squeeze air films excited by piezoelectric actuators is proposed and shown in Fig. 1. A pair of oscillating pads excited by piezoelectric actuators are arranged to generate high-pressured squeeze air films. In operating condition, the squeeze films support the rotating shaft in radial direction. Because the phase lag between a pair of pad motions placed opposite is π, the shaft is placed on the center of them via squeeze films. When the run-out, e.g. referred by high-precise ball as illustrated in Fig. 1 (b), is detected by Δ, the pad displacement patterns are shifted with keeping the squeeze motion and the shaft follows the motion of them. The advantages of this principle are that the piezoelectric actuators are appropriate for precise positioning mechanism and no additional equipment is required to the squeeze air bearing.

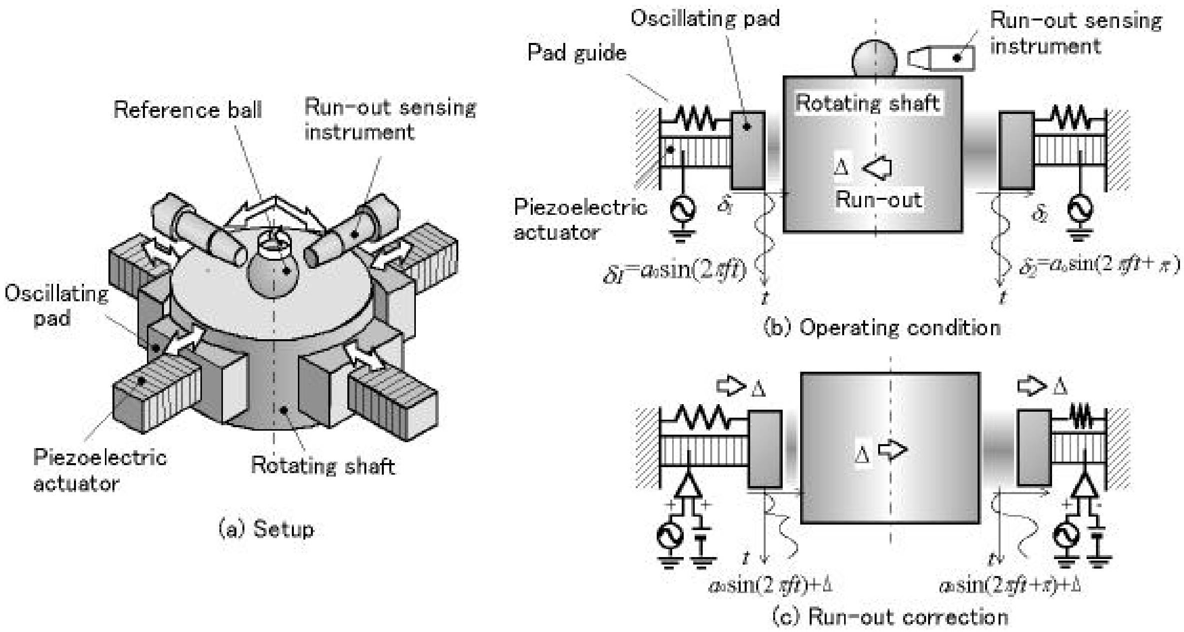

Figure 1. Principle of shaft positioning

3 EXPERIMENTAL APPARATUS

The constructed experimental apparatus is shown in Fig. 2, which consists of the rotating shaft and four oscillating pads excited by piezoelectric actuators. The shaft is suspended via connecting rod with flexure pivot, which makes the shaft to travel in radial direction without friction while the shaft displacement is small. The equivalent spring constant of pivot at the pad center below 165 mm from the pivot is 0.03 N/µm, which is efficiently less than squeeze air film stiffness. Therefore it will not affect the characteristics of air film. The shaft has an outer diameter of 69.941 mm and height of 50 mm.

The component of oscillating pad, illustrated in Fig. 2 (b), is based on monolithic flexure-hinged translation guides to provide frictionless smooth motion and inherently infinite resolution. The four piezo units with initial position adjustment screw are installed. The oscillating pad has an effective pad area of 855 mm2 and the natural frequency of 2.2 kHz in the driven direction as shown in Fig. 2 (c).

It goes without saying that the bearing performance will strongly depend on the geometric parameters of oscillating pads and shaft listed in Table 1, because the clearance between them have to be closed in order to produce effective squeeze air films. The bearing inner and shaft outer diameters are about 70 mm with the difference of 30 µm between them and it is adjusted to be 20 µm by the screw. The roundness, cylindricity and surface roughness is significantly smaller than the clearance.

Table.1 Geometric parameters of squeeze air bearing and shaft

	Squeeze air bearing	Shaft
Internal / external diameter	*D*=70.001 mm	*d*=69.941 mm
Clearance between pad and shaft	$\frac{D-d}{2} = 30\ \mu\text{m}$	
Roundness	0.5 µm	0.0 µm
Cylindricity	0.5 µm	0.5 µm
Surface roughness	R_a=0.8 µm	R_a=0.8 µm

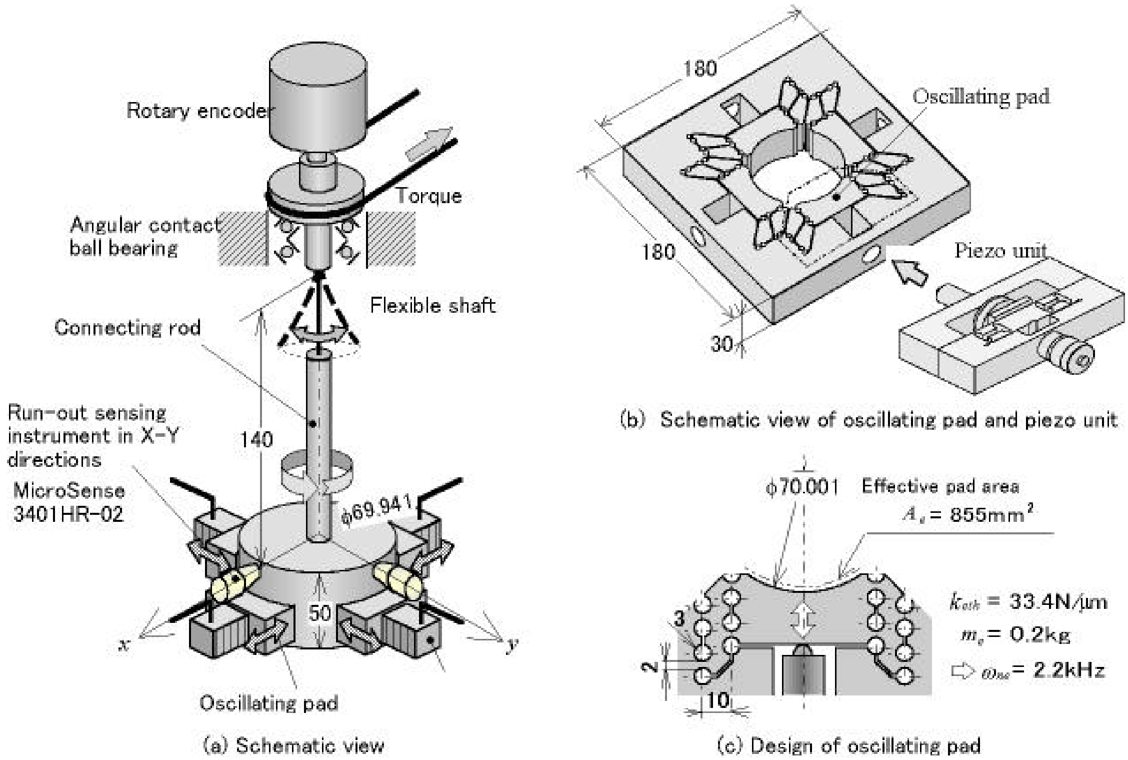

Figure 2. Constructed apparatus

4 RESULTS

4.1 Non-contact guide with squeeze air film

In order to demonstrate that the rotating shaft can be guided via producing squeeze air films, the variations of shaft position for a revolution is compared in Fig. 3. The amplitude of oscillating pad was 1.0 µm and the rotational speed of shaft was 1rpm. The upper graph was obtained in case of driving frequency of 1 Hz. The displacement was fluctuated because no air film was generated and the oscillating pad contacted the shaft and disturbed it directly. The run-out of 8.1 µm in y-direction was observed. Under the operating condition with the driving frequency of 700 Hz, the run-out was reduced to 2.4 µm. The stable air film, positive film thickness for one period and sufficiently small vibration of floating shaft, was obtained. Hence it was verified that the constructed device has performance to guide the rotating shaft. On the other hand, it has to be taken account that the shaft has a slight vibration of 0.15 µm amplitude synchronizing with squeeze motion for short interval results as shown in Fig. 3 (c).

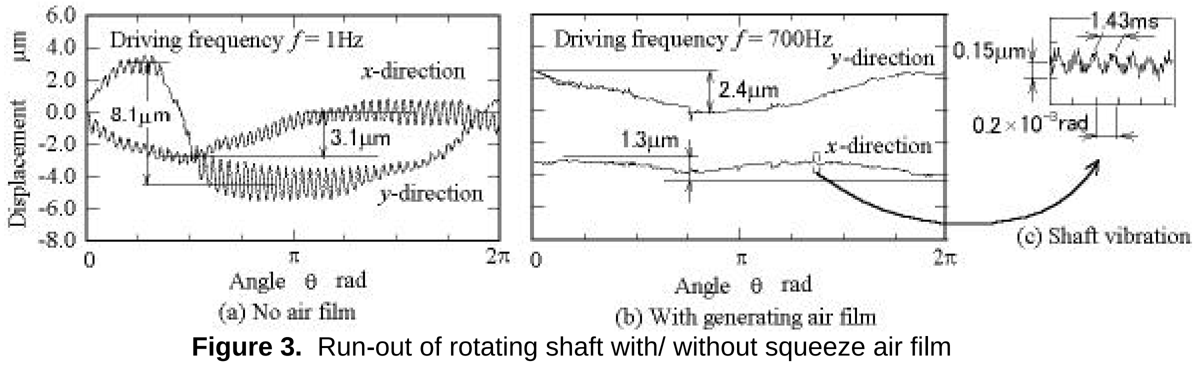

Figure 3. Run-out of rotating shaft with/ without squeeze air film

4.2 Effect of initial clearance

Because the squeeze air film has non-linear spring characteristic, decrease in initial clearance between pad and shaft makes the air film stiffness higher. The change of shaft position for one revolution is shown in Fig. 4. When the clearance was 20.0 µm, the run-out was 4.0 µm in x-direction and 6.2 µm in y-direction. On the other hand, the run-out is reduced into two-third by decreasing the clearance only to 18.6 µm.

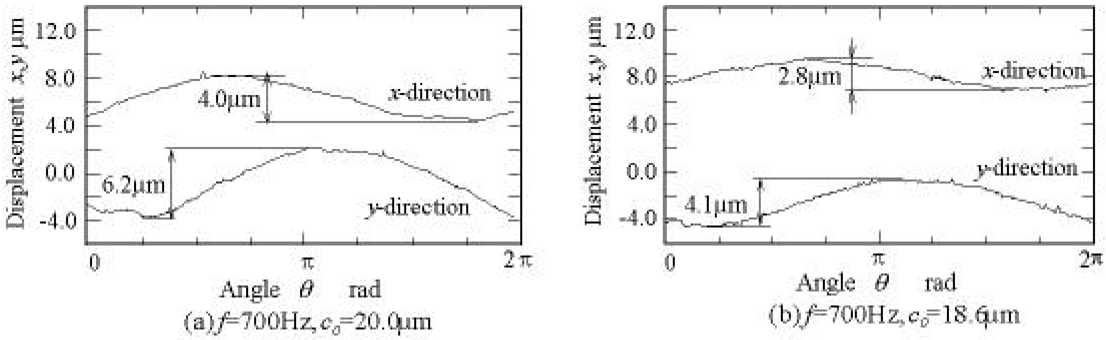

Figure 4. Decrease of run-out with initial clearance

4.3 Run-out correction

The main advantage of proposed piezo-driven squeeze air bearing is that it can correct the motion errors of the floating object by operating the driving signals of it. As the first step, the simple PI feedback control system is constructed as illustrated in Fig. 5. The proportional and integral gains were determined by trial and error so as to sure to be stable. The control signal is added to the sinusoidal signal to produce squeeze motion and fed to the piezo-driver. The L.P.F. with the cut-off frequency of 11.3 Hz avoids the frequency component of squeeze motion to be fed back. The step response of non-rotating shaft for step width of 0.5 μm is shown in Fig. 5 (b). They were acquired at point A in Fig. 5 (a) to find the actual motion. Obviously, the step width of 0.5 mm could be observed with the oscillation of ±0.15 μm excited by squeeze motion. As a result, it was demonstrated that the squeeze air bearing had capability of accurate manipulation.

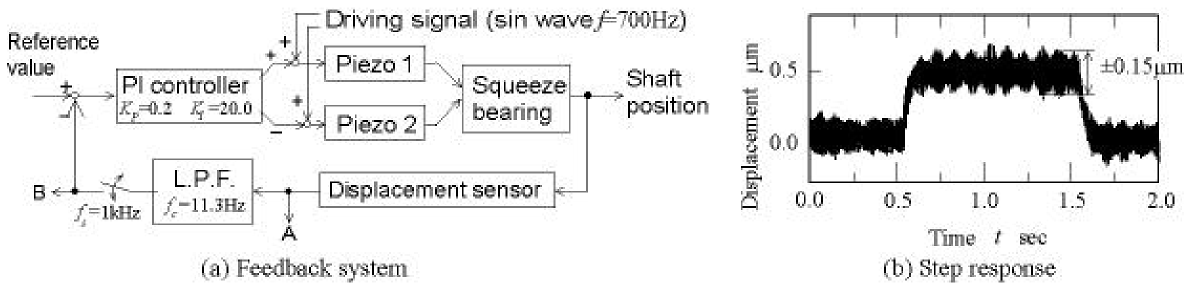

Figure 5. Shaft positioning / run-out correction system with squeeze air film

The run-out was compensated for low rotational speed of 1 rpm as shown in Fig. 6 where the correction was started at angle of 0.0 radian. Even if the rotating shaft position gradually shifted with rotation, it was remained constant with the application of feedback operation via squeeze air film. Because the measured values pass through the L.P.F., no vibration could be observed. Note that the undesired vibration caused by squeeze motion cannot be eliminated by means of additional active control, and so have to be improved by the appropriate driving condition, i.e. initial clearance, driving frequency, pad area etc..

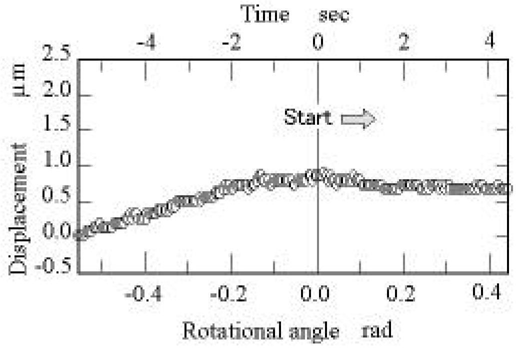

Figure 6. Result of run-out correction

5 CONCLUSIONS

A concept of active squeeze air bearing was suggested that could manipulate the floating shaft by the operation of piezoelectric actuator deformations. In this paper, a radial bearing was constructed, which had four oscillating pads surrounding the rotating shaft.

1) The squeeze air film has an ability to support the rotating shaft. The run-out was reduced to 2.4 µm under the operating condition with the driving frequency of 700 Hz, compared with 8.1 µm under no air film condition.
2) The run-out was reduced with the decrease of clearance between shaft and oscillating pads.
3) The run-out correction with active control system was performed successfully. The gradually moving shaft center with its rotation was perfectly kept its position.

ACKNOWLEDGEMENT

This work was supported by Grant-in aid for Encouragement of young scientists (No.11750117) from Japanese Ministry of Education.

REFERENCES

[1] E.O.J. Salbu: Compressible Squeeze Films and Squeeze Bearings, Journal of Basic Engineering (1964) p.358-366
[2] W.A.Michael: Approximate Methods for Time-Dependent Gas-Film Lubrication Problems
[3] H.Takada, S.Kamigaichi and H.Miura: Characteristics of Squeeze Air Film Between Nonparallel Plates, Journal of Lubrication Technology, Vol.105, 1983, pp.147

AUTHORS: Hiromi ISOBE and Akira KYUSOJIN, Nagaoka University of Technology, Department of Mechanical Engineering, Kamitomioka 1603-1, Nagaoka-shi, Niigata 940-2188, Japan