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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF HIGH-SPEED INSTABILITY OF AERODYNAMIC FOIL JOURNAL BEARINGS FOR MICRO TURBO-MACHINERY

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ABSTRACT

Foil bearings have been attracted considerable attention for applying to micro turbo-machinery such as blowers and compressors because of their excellent stability at high speeds and durability in high temperature environment. This paper investigated the high-speed instability of a rotor supported by small-sized aerodynamic foil journal bearings, experimentally and numerically. Two types of foil journal bearings were prepared. One was the 1st generation bump-type foil bearing and the other was the dimple-type foil bearing. These journal bearings consisted of a top foil and a support foil with bumps or dimples. The dynamic characteristics of a support foil were experimentally determined by using the frequency response and the threshold speed of instability at high speeds was also experimentally measured. Furthermore, the numerical threshold speed of instability was obtained by using the non-linear orbit method. As a result, it was experimentally and numerically confirmed that a 6mm diameter rotor with a mass of 4.7g supported by two types of foil journal bearings treated in this paper could stably rotate at speeds of more than 760,000 rpm.

INTRODUCTION

Recently, micro turbo-machinery such as blowers and compressors have required aerodynamic foil bearings to achieve low power consumption, excellent stability at high-speeds and durability in high temperature environment. Bump-type foil bearings are one of the most suitable candidates for these applications and many research works [1-2] were reported on these types of bearings. In most reports on a small-sized foil bearing, foil bearings with complicated structure such as 2nd/3rd generation bump-type foil bearing have been treated. The complicated bearing structure makes a small-sized foil bearing difficult to manufacture and fabricate. Therefore, it is troublesome to apply foil bearings to micro turbomachinery. The structure of small-sized foil bearings should be simple.

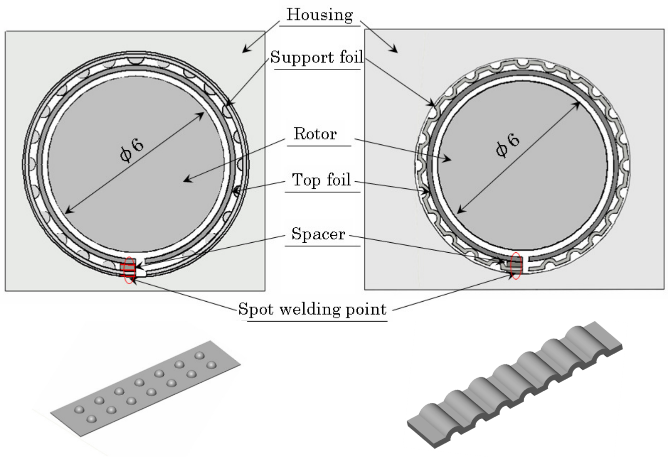
In this paper, two types of foil journal bearing with relatively a simple structure were prepared and the instability of a rigid rotor supported by these foil journal bearings is clarified, experimentally and numerically.

FOIL JOURNAL BEARINGS

Figure 1 shows the geometrical configurations of small-sized aerodynamic foil journal bearings treated in this paper. The treated foil journal bearings consist of a top foil and a support foil with dimples or bumps. The top foil and a support foil are made from bare SUS304 foil of 0.05mm in thickness and 5mm in width. The support foil formed by stamping has 24 dimples or 18 bumps of 0.2mm in height. Figure 2 shows the measured initial shapes of the top foil with dimple-type or bump-type support foil.

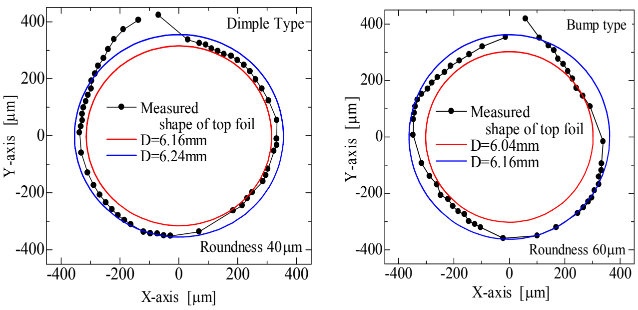
EXPERIMENTAL RESULTS ON INSTABILITY

Figure 3 shows the experimental apparatus for measuring the threshold speed of instability. A rotor with a mass of 4.7g was set vertically and supported by aerostatic thrust bearings located at the lower and upper part of the rotor. The rotor displacement is measured by two optical fiber sensors. The rotor was driven by air jets from turbine nozzles.



(a) Dimple-type (b) Bump-type

Fig. 1 Outline of dimple and bump-type foil journal bearings



(a) Dimple-type (b) Bump-type

Fig.2 Top foil initial shape of test foil journal bearings before experiments

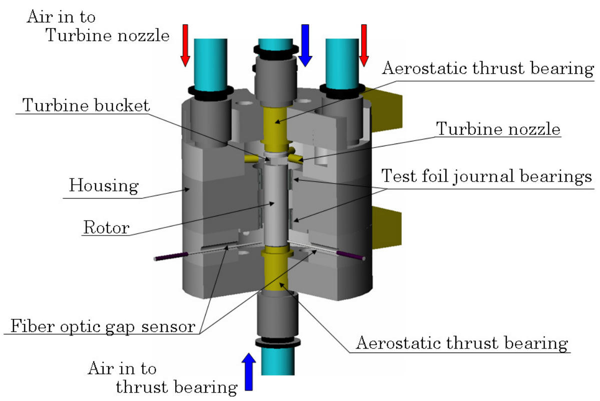
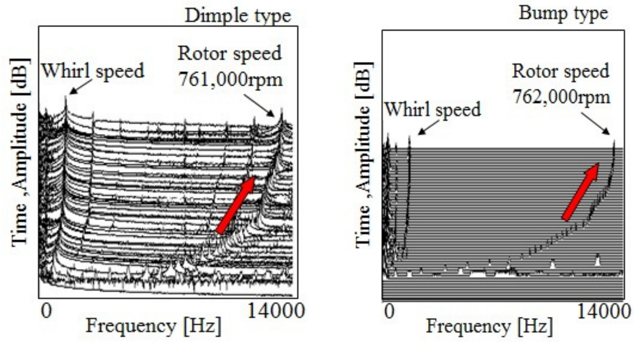


Fig.3 Experimental apparatus

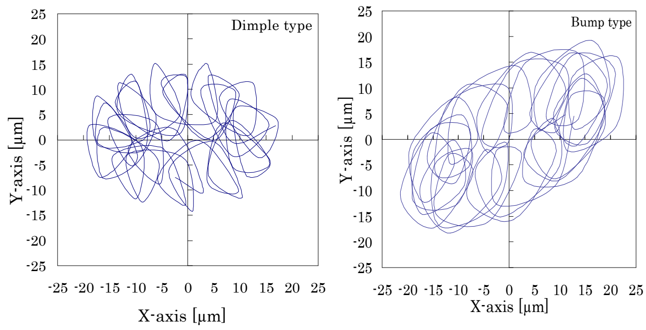
Figure 4 shows the power spectrum of a rotor displacement in both dimple-type foil bearing and conventional 1st generation bump-type foil bearing. In both treated foil bearings, the threshold speed was not observed until 761,000 rpm, which was the highest rotational speed in the experiments because of the limitation of air jet power.

Figure 5 shows the locus of the rotor center at speed of 761,000 rpm. Though the whirling amplitude appeared



(a) Dimple-type (b) Bump-type

Fig.4 Waterfall diagram for power spectrum of rotor displacement



(a) Dimple-type (b) Bump-type

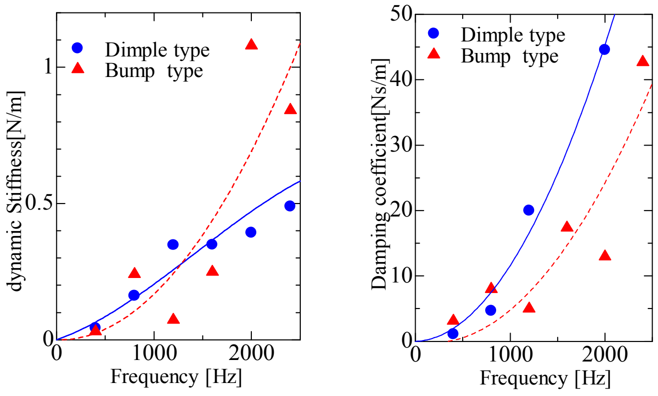
Fig.5 Locus of the rotor center

obviously at 2000Hz, it is conceivable that the rotor is stably rotating because the rotational speed was not reduced during the experiment.

Figure 6 shows the dynamic stiffness and damping coefficient of the support foil determined by using the frequency response experimentally when the vibrational frequency was in the range 400 to 2400Hz. The experiment for measuring the dynamic characteristics was conducted using the experimental apparatus shown in Fig. 7. Looking at Fig. 6(a), the dynamic stiffness of dimple-type support foil increases linearly with increasing vibrational frequency whereas that of bump-type increases rapidly near the frequency of 2000Hz. In Fig. 6(b), the damping coefficients of both types also increase with the vibrational frequency. The dimple-type support foil has higher damping coefficient compared with the bump-type support foil.

NUMERICAL CALCULATIONS

In this paper, the threshold speed of instability was numerically solved by using the non-linear orbit method. The equation of motion and the Reynolds equation are simultaneously solved at every time step. The initial shapes of top foils as shown in Fig. 2 were used in calculations and in addition, it was assumed that the top foil was not deformed during rotation.



(a) Dynamic stiffness (b) Damping coefficient

Fig.6 Dynamic characteristics of support foils

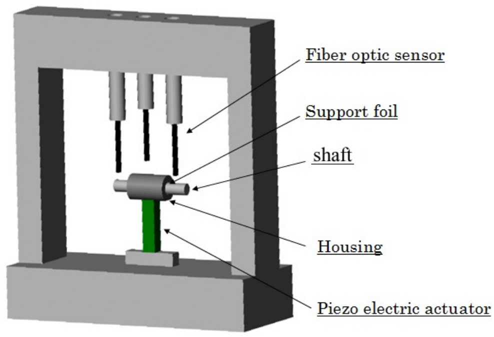


Fig.7 Experimental apparatus for measuring the dynamic characteristics of support foils

Figure 8 shows the numerical relationship between the threshold speed of instability and the equivalent critical rotor mass. Below Λ=20, the rotor loci could not be converged due to small dynamic pressure generated by rotation. The rotor supported by both foil journal bearings could stably rotate above 760,000 rpm under the assumption that top foil was not deformed by the dynamic pressure. Namely, it was numerically demonstrated that non-circular bearings supported elastically by support foils have high threshold speed of instability. Comparing the dimple-type foil bearing with the bump-type foil bearing, the dimple-type foil bearing has higher threshold speed of instability in the range from the bearing number from 30 to 40.

CONCLUSIONS

In this paper, the stability of a rigid small rotor supported by foil journal bearings with relatively a simple structure is investigated, experimentally and numerically. As a result, the following conclusions can be drawn from these investigations.

(1) It was experimentally and numerically confirmed that a 6mm diameter rotor with a mass of 4.7g supported by two

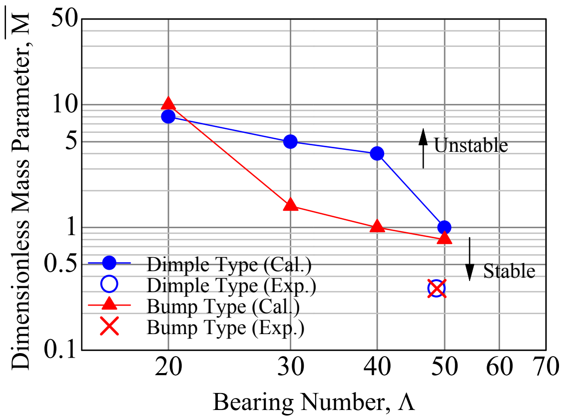


Fig.8 Numerical and experimental results for the threshold speed of instability

types of foil journal bearings treated in this paper could stably rotate at speeds of more than 760,000 rpm.

(2) The dimple-type support foil has lower dynamic stiffness and higher damping coefficient compared with the bump-type support foil when the vibrational frequency was in the range from 400 Hz to 2400 Hz.

(3) It was clearly confirmed that in a small-sized bearing, a rigid rotor elastically supported by non-circular bearings could achieve a high threshold speed of instability.

ACKNOWLEDGMENTS

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