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Experimental study of small-size air turbo blower supported by externally pressurized conical gas bearings

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ABSTRACT

This paper describes a several ten thousand rpm class small-size air turbo blower. This has been newly developed using externally pressurized conical gas bearings and blower impeller with centrifugal suction blades on both faces. This bearing can reduce the number of machine parts since it is possible to support the thrust and radial load components in both directions. Calculations of the characteristics were conducted and investigated using the manufactured test bearings. A test rig was manufactured, and the characteristics were experimentally verified. These bearings have a conical bearing surface with diameters of 10 mm and 8 mm and a length of 15 mm. A pair of length is 30 mm. The actual bearing clearances are 0.012 mm and 0.014 mm, respectively. The measured bearing characteristics agreed with the designed values. It was clarified that the proposed calculation method is useful for predicting the characteristics in a relatively simple way. The air turbo blower impeller has a 15 mm diameter and a 3 mm thickness with centrifugal suction blades on both faces that were made by precision machining. The measured rotational frequency of the rotor exceeds 350 Hz (21,000 rpm) in the test. The rotor vibration was verified as a forward whirl with a conical mode. The blower characteristics were also investigated. The maximum discharge air flow rate and the pressure were 19.2×10^{-5} m^3/s and 1.77 kPa, respectively, at the maximum rotational frequency of 350 Hz. This may be used as a small-size air supply blower.

1. Introduction

Externally pressurized gas bearings have been used for various types of rotary machines and devices, for instance, machine tools, high-temperature or cryogenic turbo machines, food-related machines, and medical devices. Journal and thrust gas bearings are needed in these machines to support the rotor loads. If conical-shape bearings can be used, it is possible to support the thrust and radial load components in both directions, and the number of machine parts can be reduced. In addition, bearing loss caused by gas viscosity can be largely decreased since the bearing does not have a thrust collar. This support mechanism is effective since the loss increases with the cube of the diameter [1–3].

Our research group has been developing novel maintenance-free air turbo blowers. The blowers will be used as cathodes of portable fuel cells and air cycle machines for aircrafts in cruise conditions, and require high rotational speeds (20,000–30,000 rpm). For spatial convenience, the maximum bearing diameter is approximately 10 mm. The load capacity of the bearing is at least 10 N. This system is assumed to operate by gases bled from other sources. Therefore, gas bearings are appropriate. In this

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endeavor, we constructed a thin centrifugal blower from super duralumin. The blower features symmetric blades on both faces of the impeller, which increase the gas flow rate and the outlet pressure. Since the thrust exerted by the airflow is counterbalanced on the impeller, thrust bearing is required only to support the rotor mass in the vertical rotor, thereby minimizing the supporting force in the thrust direction. For this reason, we adopt a thrust–journal combined bearing. However, conventional use of thrust and journal bearings increases the rotor length and mass. Depending on the arrangement of the bearings, overhang is also increased, which reduces the natural frequency of the rotor. This frequency reduction is the primary technical barrier to realizing high-speed rotation. Thrust–journal combined bearings offer an effective solution to this problem. For instance, Miyatake et al. [4] researched the static characteristics of combined thrust–journal aerostatic porous bearings (inner diameter = 25 mm and outer diameter = 40 mm). While this approach is beneficial in practice, it appears inappropriately large-scale for our purpose. Furthermore, small-sized sintered porous bearings with controlled air breathability would be difficult and costly to fabricate. Park [5] researched radial–thrust combo metal mesh foil bearing. While this approach is beneficial in actual use same as mentioned above, thrust bearing has large outer diameter (19.4 mm) compared with radial diameter (11.6 mm). For these reasons, the use of conical bearings could support the thrust and radial load components in both directions, reducing the number of machine parts, and hence the weight of the machine. However, the characteristics of small-scale machine parts are sensitive to shape accuracy and the part dimensions, and must therefore be experimentally verified.

In previous studies, these conical bearing shapes were developed and investigated by several researchers. Lester et al. [6] researched externally pressurized bearings using incompressible fluid. They reported on the configuration, the design method, and the calculated characteristics. Srinivasan and Prbhu [7] numerically analyzed the characteristics of externally pressurized gas bearings with a conical bearing shape. Sinha et al. [8] analyzed a non-constant-gap externally pressurized conical bearing with a temperature- and pressure-dependent viscosity. Ingle and Ahuja [9] experimentally investigated the characteristics of externally pressurized conical bearings, where the bearing diameter and length were both 42 mm. As described above, conical-shape bearings have only been evaluated using numerical analysis, with incompressible fluids, and for rotor diameters of tens of millimeters. Dynamic characteristics such as rotor vibration have not been experimentally verified in these studies.

The authors developed a small-size air blower using externally pressurized gas bearings with a 10 mm maximum diameter for rotating several hundred Hz as one example of a small-size high-speed machine. The aim is to downsize, decrease the bearing loss, and save weight in the turbo machines. This paper presents the configuration of the rotor, bearings, blower, and driving turbine impellers. The bearing characteristics, rotor vibration and blower characteristics were experimentally verified.

2. Configuration of the bearing-rotor system

The configuration of the bearing-rotor system in this study is shown in Fig. 1. A pair of conical-shape gas bearings supports the rotor, and the bearings are installed in a casing. The bearings have the following dimensions: a minimum diameter of $D_1 = 8$ mm, a maximum diameter of $D_2 = 10$ mm, a bearing length of $L = 15$ mm, a flow-out length of $L_2 = 5$ mm, and a feed hole diameter of $d = 0.4$ mm. The bearing type is a double-row inherent orifice bearing. Four feed holes are fabricated per row. It is assumed that the vertical rotor is supported by this bearing. The impellers are installed at the end of the rotor in practical applications. The rotor mass loads the bearing in the thrust direction, and the centrifugal force caused by the static and dynamic imbalance loads the bearing in the radial direction. Therefore, the taper angle θ from the centerline of the bearing was decided small ($\theta = 3.8°$) since the rotor rotates tens of thousands of rpm. This angle provides a large load capacity in the radial direction compared with the thrust direction

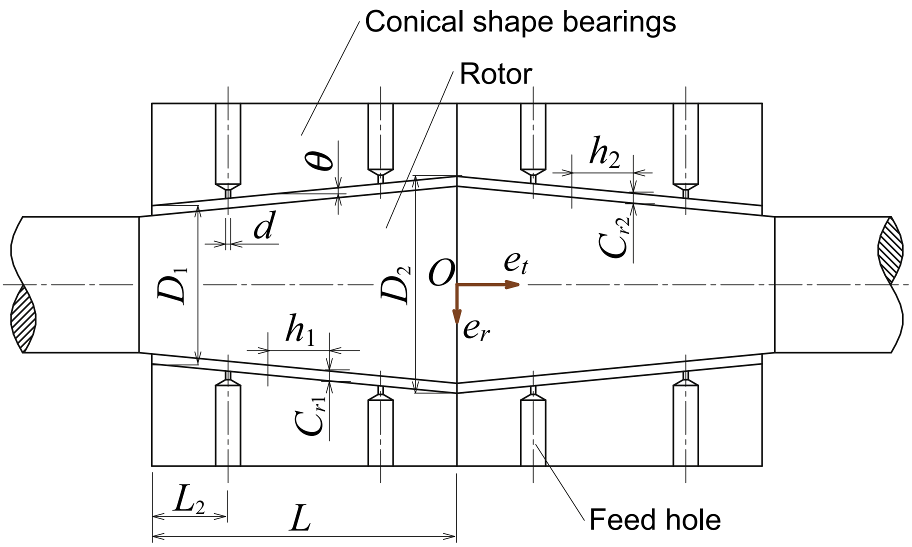

Fig. 1. Configuration of the bearing-rotor system.