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*aerostatic bearing, metal foam,
porous thrust bearing,
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DEVELOPMENT OF A HIGH-SPEED AIR BEARING SPINDLE

This paper investigates an air spindle with both radial and thrust air bearings of newly developing one-directional porous materials. At present, orifice type and porous type are adopted for thrust air bearings. Orifice type thrust air bearing is fabricated by machining several micro-holes on a bearing pad and bearing load capacity is determined by clearance, pad size, air hole size, air hole position and number of air holes. In case of a porous type thrust bearing, permeability significantly affected by particle size and machining conditions is an important factor of performance, but it is hard to control and random direction air holes cause turbulent flow on bearing surface. In order to improve these problems, a thrust bearing with one-directional porosities is suggested. It has many micro-porosities through axial direction, so stable and plenty of air can be supplied to the thrust bearing pad. A radial air bearing also can be substituted by a radial direction porous bearing as the same reason. In case of driving parts, built-in motor type is widely applied. But it needs additional cooling parts to drop heat from a motor. So application of an air turbine drive with light-weight shaft is suggested and additionally it will reduce fabricating cost.

1. INTRODUCTION

Rapid growth of IT industries demands high speed, high quality and multi-axes control technology. To meet these demands, high stiffness, low run-out value, low heat generation characteristics of machine tools are required. Apart from these characteristics, rotating speed of a spindle is increasing in order to maximize cutting efficiency and precision.

Air bearings are sustained by air film of micrometer level. Aerostatic bearings can provide small variation of properties with temperature, high damping, high operating speed, limited wear and load capacity [3]. Because lubrication oil is not used, eco- machining is

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possible and conventional electric and chemical machining are trying to be substituted mechanical machining with spindles. But because air is compressible, load capacity is relatively lower than that of other types so various investigations were performed to increase load capacity.

Since air bearing was invented, many researchers have investigated a great deal of work in the field. Much of their concern is to increase load capacity and stability. Stiffler[1,2] proposed multiple inlets to increase stiffness and damping. Kazimierski and Trojnarski[6] have studied pocketed and annular orifice feeding systems by using the finite difference method. At present, most of radial bearings are applied by orifice type, but some researchers tried to apply porous metals as radial air bearings. Panzera[5] investigated high strength porous cementitious composite manufactured via cold-pressed compaction as a restrictor. Sun[4] investigated the hybrid instability of rotor whirling and pneumatic hammer effects in porous journal bearings.

2. AIR BEARING SPINDLE SYSTEM

The system consists of a porous radial bearing with radial direction porosities, two porous thrust bearings with axial direction porosities, and a turbine blade with a light-weight shaft. And the system is designed as a compact type for the next generation air bearing spindle.

2.1. RADIAL BEARING PARTS

Conventional radial bearing is fabricated by machining several rows of micro-drilled holes. Because micro-drilling depth is milli-meter level, it needs additional high level drilling processes so it takes to much time and cost. Fig. 1 shows an example of a conventional radial bearing with micro-drilled air holes. It has 12-holes of circumferential direction and 4-rows of axial direction. Therefore 96 drilling processes are required in this case. For that reason, porous ceramic materials are investigated as substitution materials for radial bearing. They have random orientation porosities inside hence drilling processes can be omitted. In case of porous bearings, permeability is an important factor of determining bearing performances. Because the orientation and the size of porosities are not uniform, it is hard to control bearing performances. So a radial bearing with radial direction porosities is suggested in this paper.

Fig. 1. An example of a conventional radial bearing with micro-drilled air holes

Fig. 2 shows a radial bearing with radial direction porosities. Current porous materials don't have uniform orientation of air holes. On the other hand it has uniform orientation porosities of perpendicular to the shaft. So air flow is more uniform and stable than that of current porous materials.

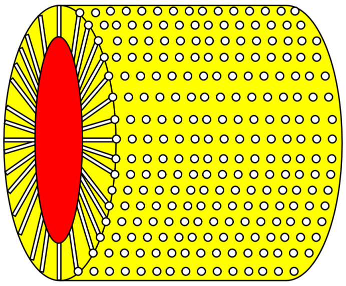

Fig. 2. A radial bearing with radial direction porosities

2.2. THRUST BEARING PARTS

Like radial bearings, thrust bearings are mostly fabricated by micro-drilling processes. Fig. 3 shows an example of pressure distribution of a micro-drilled thrust bearing. The main issue of micro-drilled thrust bearings is stiffness increase. To increase stiffness, various investigations for example number of air holes and position of air holes, have been tried. But they have geometric limits. So porous type thrust bearings are substituted but they also have problems of permeability and air hammer phenomenon. To improve such problems, a thrust bearing with axial direction porosities is suggested. Axial direction porosities will supply stable air so that high stiffness and high stability will be obtained. Fig. 4 shows comparison of a micro-drilled thrust bearing and a thrust bearing with axial direction porosities.

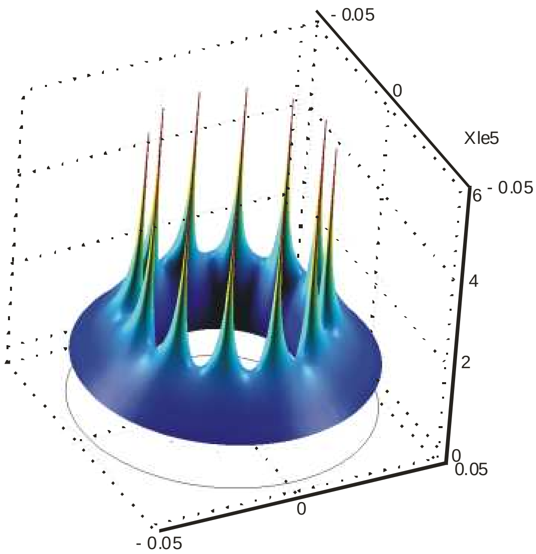

Fig. 3. A pressure distribution example of a thrust bearing with 12 micro-holes

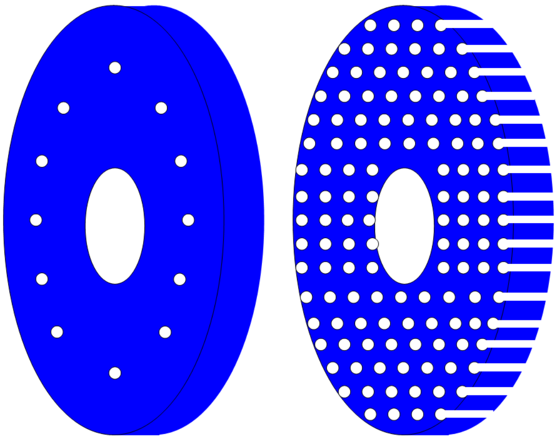

Fig. 4. Comparison of a micro-drilled type and porous type with axial direction porosities

2.3. DRIVING PARTS

Built-in motor type is widely adopted as driving parts. The power of a motor type is higher than that of other types but it needs additional cooling parts. Consequently the spindle system size should be bigger and as a result fabricating cost increases. So air turbine driving method is suggested. It can be minimize the system and fabricating cost is lower than motor driving method. Fig. 5 shows an example of a blade for air turbine drive.

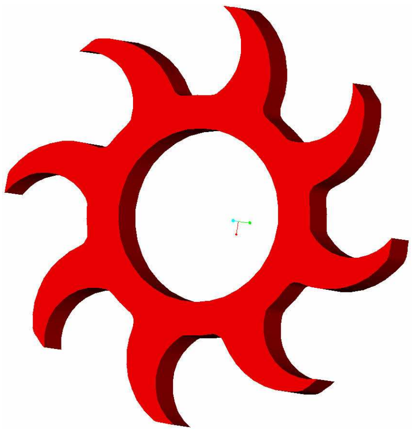

Fig. 5. An example of a turbine blade

2.4. LIGHT-WEIGHT SHAFT

Rotating speed of an air turbine drive is affected very much by blade shape and shaft weight. Apart from blade shape, one of weight reducing methods is using a light shaft. A hollow shaft is also good method, but stiffness of a shaft reduces. So a shaft filled with a foam metal is suggested. In that case, reduced weight is affected by shaft size but in case of 20-mm diameter, compared with the original shaft, at least 10~20% weight will reduce. Fig. 6 shows an example of a light-weight shaft filled with a foam metal.

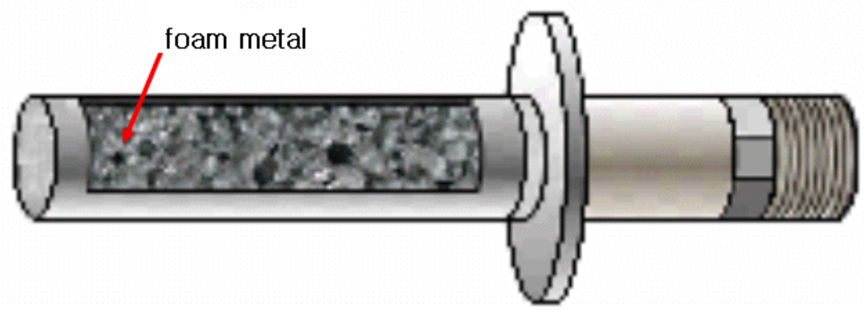

Fig. 6. An example of a light-weight shaft filled with a foam metal

3. RESULTS

The system is designed as shown in Fig. 7. Each of bearings has an air tank to supply stable air. Blade parts have 4 holes of dual inlets and dual outlets. Thrust bearing parts have 4 radial direction outlets and one axial direction outlet. The shaft has 12 tapping holes to adjust balance of rotating parts. Weight change of the shaft using foam metal is 16%. Size of the system is 84mm x 84mm x 124mm and diameter of the shaft is 20mm.

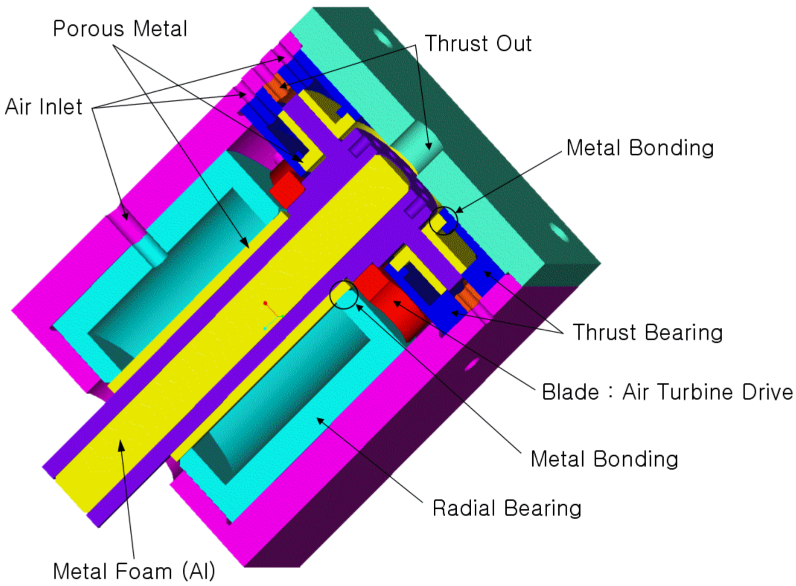

Fig. 7. Design of an air bearing spindle

Revolution analysis is performed to evaluate vibration characteristics using ARMD V5.6^{TM}. Table 1 shows mechanical properties of the material and Fig. 8 shows analysis model of the shaft. Table 2 shows comparisons of the natural frequency. As the result of weight reduction, the natural frequencies increased 5% or more.

Table 1. Mechanical properties of the material

Properties	Units	Value
Density(steel)	kg/m^3	7,860
Density(steel + foam metal)	kg/m^3	6,600
Young's Modulus(solid)	GPa	210
Young's Modulus(steel with foam metal)	GPa	192

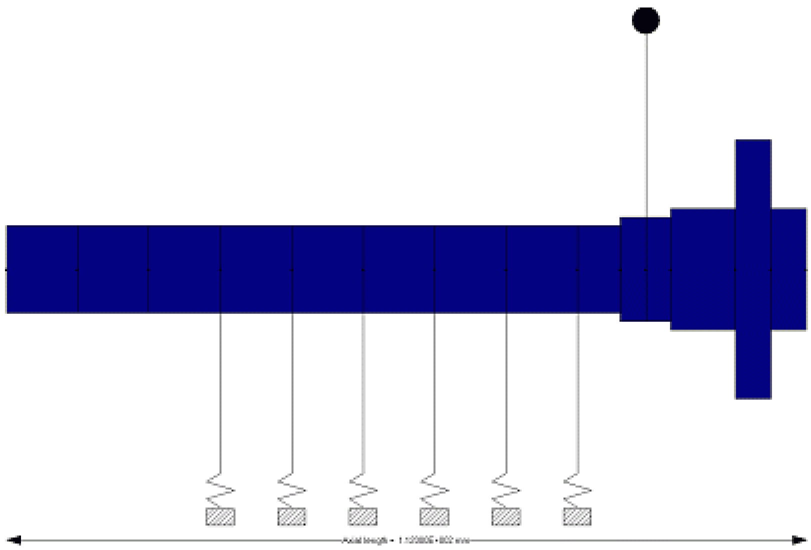

Fig. 8. Analysis model of the shaft

Table 2. Comparisons of the natural frequencies

	1st mode	2nd mode	3rd mode
Steel shaft	56,906	150,640	399,640
Steel shaft with foam metal	61,280	163,670	422,460
Change of the natural frequency	7.7%	8.6%	5.7%

4. CONCLUSION

From the investigations, the following conclusions are obtained:

1. A radial bearing with radial direction porosities is suggested instead of orifice type or porous type radial bearing. The bearing will be operated by more stable condition and high stiffness will be obtained.

2. A thrust bearing with axial direction porosities is suggested as the same reason like a radial bearing.
3. Air turbine driving method can reduce system size and fabricating cost.
4. A foam metal reduces weight of a shaft therefore rotating speed of air turbine driving method also increase.

ACKNOWLEDGEMENT

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