Design and Manufacturing the Air Rotary Bearing Using In Standard Torque Machine

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Abstract

The moment measurement machines are widely used in many measuring systems. However, these current machines using in Vietnam Metrology Institute have lower precision owing to mechanical contact friction. From requiring highly accuracy in calibration of the torque tester, the standard torque machine is designed and manufactured successfully using air rotary bearings which separate the mechanical contact between rotary shaft and cover. This paper presents results of design and producing the air rotary bearing with air clearance in working area from 8-15µm, load capacity up to 400N, the friction torque is 0.001Nm at Department of Precise Mechanical and Optical Engineering – Hanoi University of Science and Technology. Based on researching effect of elements which influence to system operations, it is proposed a standardization of moment newly with high precision.

Introduction

Standard Torque Machine is a system combination of a ponderous spindle (40 kg) and two air rotary tables, which removes the mechanical contact.

This model is manufactured, which is expected to solve the problem in the demand of torque standard measurement: *high precision*, *low cost*, *high load capacity*, *stiffness.* In specification, the spindle is supported by ten air bearings, which are at the lateral face of the spindle. Plus, two round air bearings that are located in two sides of the spindle. Compressed air (4~5 bar) is continuously supplied to 12 bearings. The perpetual flow of compressed air through 12 bearings creates a high pressure thin film between each pair of air bearing and the spindle surface from 1÷4 bar.
Some of design requirements:

1. Radial Force: Air bearing is bored by radial force with standardized moment is 200Nm.
2. Stiffness: There are some factors affect directly stiffness proportionally such as pressure and surface area, geometrical dimension of air bearing, however, the most significant element is the idea and use of compensation. Through a range of loads and measuring the change in air gap, it is tested the stiffness.
3. Friction: Parallel importantly, friction force is the heart of precision positioning problems. With standard torque machine, it must be required for removing friction at rotary joint to avoid affecting the value of standard moment [3]. Some surveys have figured out the coefficient of friction of the three most commonest bearing in log scale: Plain bearings - 0.1; rolling bearings - 0.001; Air bearing – 0.00001 finally [2]. By testing resistance between air bearings and rotating spindle using a multifunctional measurement device, the system is removed the contact friction as possible as well.

4. Load Capacity: Although the load capacity of air bearings is limited compared to rolling element bearings, they carry the same load per unit area as traditional plain bearings for machine tools. This is usually more than sufficient for today's high-speed, lightweight machine applications.

Surface area x input pressure = grounding force [2].

Surface area x input pressure x efficiency = load capacity [2].

Design and Analysis

In process of researching and manufacturing the machine, it is achieved some technical requirements:

- Remove mechanical contact as much as possible.
- Air bearing must be bored by radial force. Standardized moment is 200Nm (If distance d=0.5m then load M=400N).
- 5 degrees of freedom are constrained and the rest one rotates.
- Requiring its stiffness highly to avoid changing air clearance and ensuring tolerance.
- Low cost under the circumstances in Vietnam.

The machine contains air bearings that were composited on the shaft consistently as shown in Fig. 1:

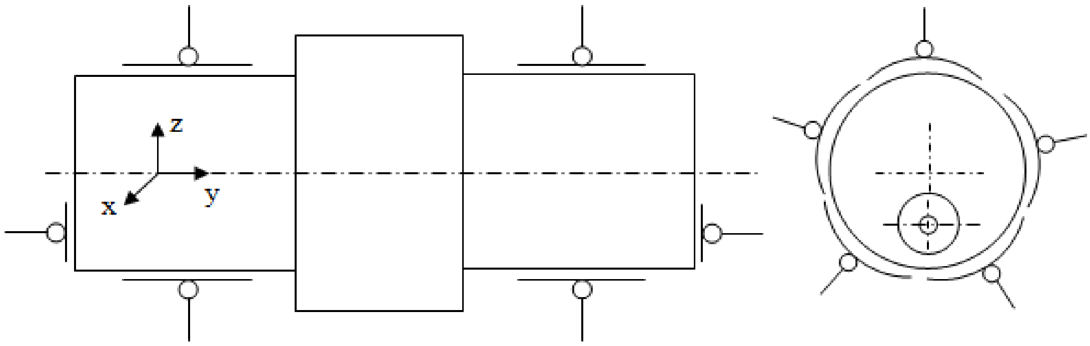

Fig. 1: Arrangement of air bearings on the shaft

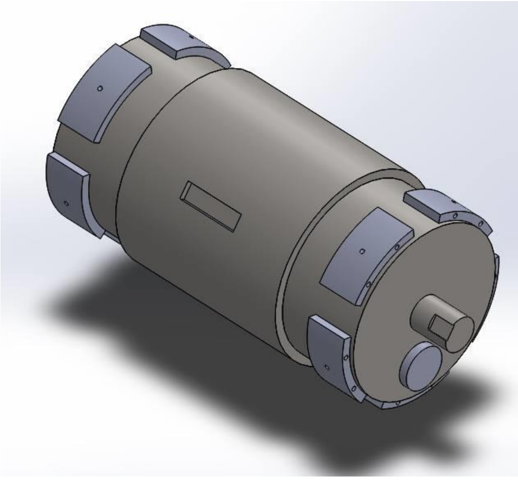

Fig. 2: 3-D of the shaft with air bearings around

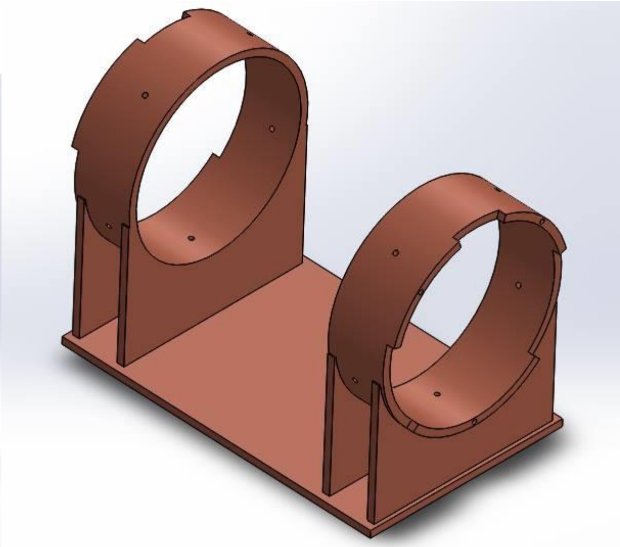

Fig. 3: The table of the machine.

Stiffness of the system is increased by supporting 5 curve air bearings on each side of the shaft. This purpose is to constrain 2 DOF (moving along x, z axis and rotating around these axes). Plus, 2 flat air bearings are put on 2 side surface which prevent moving along y axis. Therefore, there is 1 DOF which rotates around y axis.

Under consideration, one curve air bearing is put on each row at the bottom exactly to take advantage of lift force through it.

Fig. 3 illustrates the structure of standard moment measurement machine table which designed at Laboratory of Department of Precise Mechanical and Optical Engineering. To enhance the stability of the entire system, two blocks of support is manufactured. Add to this, a pair of two upright supports was welded with a round support as shown below.

Based on technical requirements, some primary calculations are executed to find out air clearances and establish the diagram of lift force:

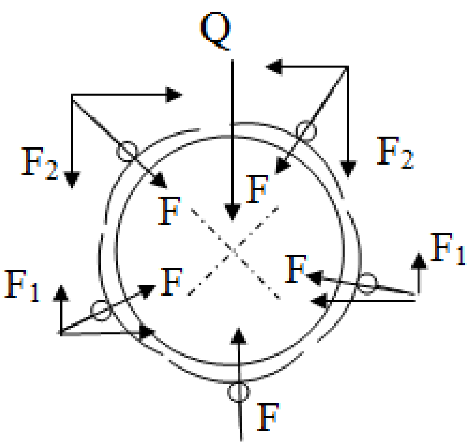

Fig. 4: Arrangement of curve air bearings on the cylinder

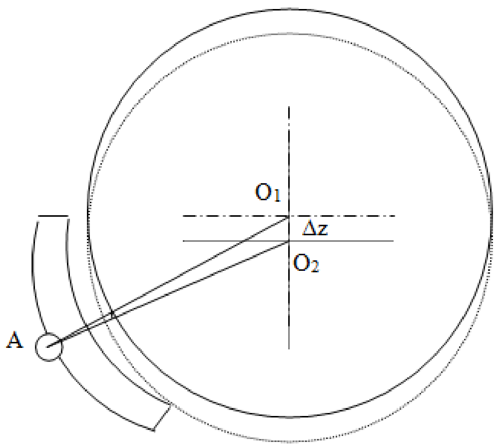

Fig. 5: Decreasing by Δz under load Q

Assume that gravity of rotary shaft is by zero, when load Q=0 then total forces in this case is zero.
When load Q≠0 (includes the load on shaft and gravity of rotary shaft):

+ Air clearance between the bottom air bearing and the shaft will decrease by Δz.

+ Air clearance between the neighboring air bearing and the shaft will be calculated as:

$$\Delta z_1 = AO_1 - \sqrt{AO_1^2 + \Delta z^2 - 2.AO_1.\Delta z.\cos 72^0} \tag{1}$$

With air clearance is 12µm, diameter of rotary shaft is 115mm, where: OA_1= 115.012mm

$$\Delta z_1 = 115.012 - \sqrt{\Delta z^2 - 71.081.\Delta z + 115.012^2} \tag{2}$$

Similarly, air clearance between the top air bearing and the shaft:

$$\Delta z_2 = \sqrt{\Delta z^2 + 186.093.\Delta z + 115.012^2} - 115.012 \tag{3}$$

The relationship between load Q and stiffness K is calculated by equation:

$$Q = f(K, \Delta z) = K(\Delta z + 2.\Delta z_1.\cos(360/5) + 2.\Delta z_2.\cos(360/10)) \tag{4}$$

Total force of the shaft (400N) and the load (400N) is distributed equally on two sides of the spindle, therefore, each is 400N. With the maximum of air clearance decrease to ensure non-mechanical contact Δz=10µm (Δz_1=3µm; Δz_2=8µm), stiffness is required: K=400N/24.8µm=16N/µm≅1.6kg/µm.

Thus, the minimum of stiffness in design is required by 1.6kg/µm.

Fig 6 shows the rotary air-bearing which is expanded to equivalent with flat air-bearing. The air-bearing has a rectangle groove and orifice in the center. The ratio of the distance from the orifice center to groove and the distance from the orifice center to side is 0.5÷0.7 that the lift force of air bearing is highest, shown in fig.7 [1].

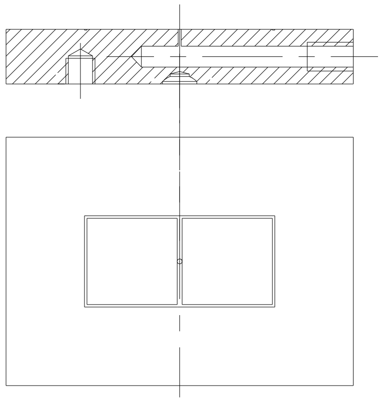

Fig 6: Design style of air bearing

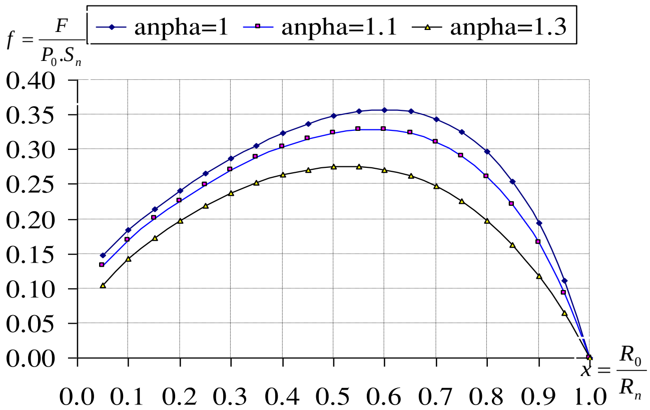

Fig 7: Relation between f=F/Po*Sn and Ro/Rn with z= 10µm; l = 1.5mm; y = 7.68

With the rotary shaft diameter of 200mm, cylindrical air -bearing is arranged as Fig.4 shown; each air bearing has 12cm of curve length and 7cm of width. Thus, the primary lift force is calculated:

$$F = f.P_0.S_n = 0.35 \text{ x } 40 \text{ x}12\text{x}7\text{x}10 = 1176\text{N} \tag{5}$$

Where input pressure P_0= 4bar≈40N/cm^2.

Experiment and results

To assess the relationship between air clearance and pressure without applying such load, the variation of air gap is measured by MITUTOYO indicator 0.001 turn-on-turns. After that, the data was recorded, implemented and illustrated as Fig. 8 shown.

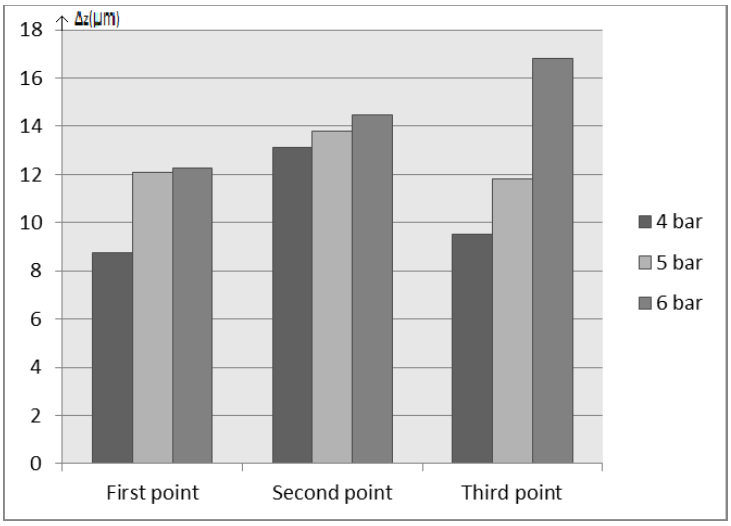

Fig. 8: The relationship between air clearance and pressure without applying load.

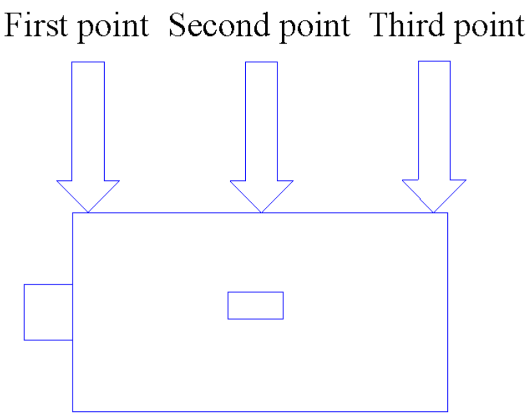

Fig. 9: The position of considered three points.

The results show: The range of air clearance is 8÷16µm. Air clearance between air bearings and the shaft depends on pressure. The higher pressure is supplied, the more air clearance is. At the second point, the value of air clearance is 13.1µm at 4bar, 13.8µm at 5bar and increase to 14.4µm at 6bar. It is similar to the remaining points.

In addition to this, there are different air clearances among pairs of air bearing and the shaft. The same is at 4bar; however, the air clearance is 8.7µm at first point, 13.1µm at second point and 9.5µm at third point. Various pressure values at different air bearings, errors in manufacturing and the decrease of pressure through pipes explain for this problem.

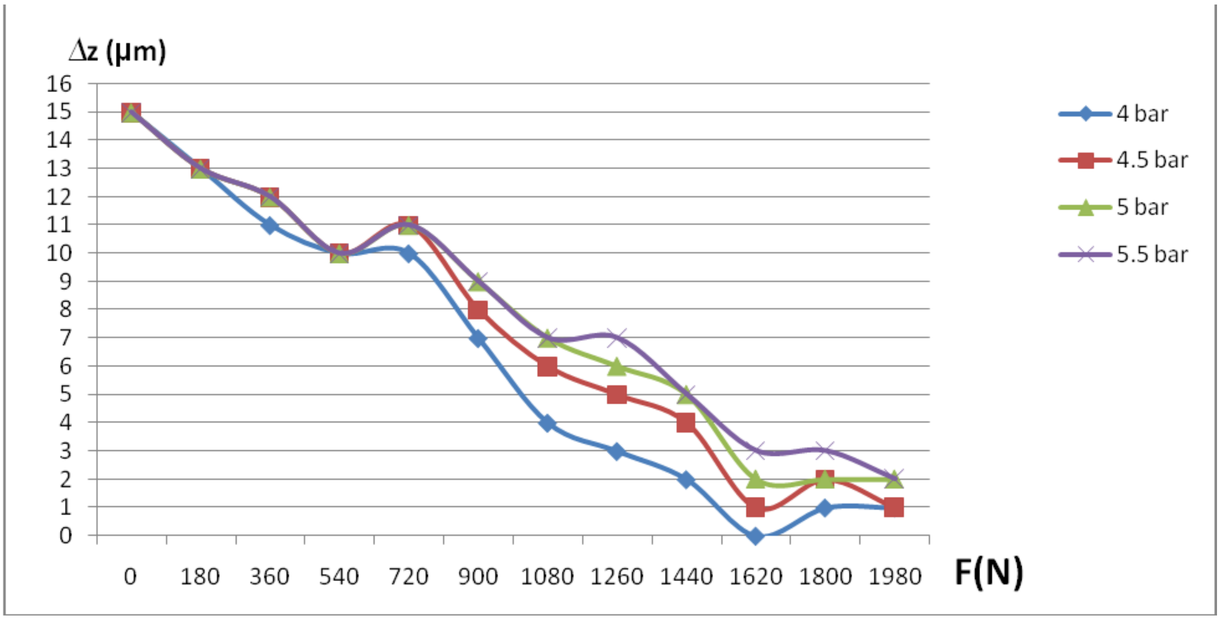

Fig. 10: The relationship between load capacity and pressure.

The results are obtained: Load capacity depends on pressure. In general, load capacity of the machine is about 1500N at 4 bar, 1650N at 4.5 bar and 5 bar, and greater than 2000N at 5.5 bar.

Moreover, the stiffness is inversely proportional to air clearance. The higher the stiffness is, the less the air clearance value is.

The machine gets the best stability at 5bar (Comparing to the base line, the line at 5bar is the most closest).

As the diagram of the relationship between load capacity and pressure shown, the stiffness of air rotary system $K= \Delta F/\Delta z$. At the different input air-pressures, the stiffness is not much different from each other, shown in Fig 10: P_0=4bar - K=108N/µm, P_0=4.5bar - K= 115 N/µm, P_0=5bar - K= 124 N/µm, P_0=5.5bar - K= 135 N/µm.

Summary

In this research, the standard torque machine was designed and manufactured, which can remove mechanical contact total. It operates to 2000N of load capacity and the range of air clearance is 8÷15µm.

Under consideration, it is offered and given some solutions for solving problems. Firstly, manufacturing welded table (instead of separate parts) is to increase the stability of the entire machine. Secondly, using 5 curve air bearings in each round improve its stiffness. Finally, the machine is replaced steel balls by porcelain balls to checking mechanical contact in each air bearing. After finishing of analysis problems and assembling the parts of machine totally, the experiments were built to determine the relationship between load capacity and pressure, air clearance and pressure, and run out.

These results have opened up the prospect of manufacturing the high accuracy standard torque machine in Vietnam.

References

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