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Relation between Minimal Speed and Rotational Inertia of Stable PM Maglev Bearing Rotator

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Abstract: The authors' former works demonstrated that a passive magnetic (PM) rotator supported merely by PM bearings has a minimal speed, above which it can stabilize its equilibrium, under the function of a so-called Gyro-effect. It is unclear, however, by which factors is this minimal speed determined. To investigate the effect of rotor inertia on minimal speed, three same rotors made of different materials were manufactured: rotor A was made of plastic and its rotary inertia is 6.293×10^{-5} ($kg\cdot m^2$); rotor B was made of aluminum and its inertia is 1.074×10^{-4} ($kg\cdot m^2$); rotor C was made of steel and its inertia is 2.081×10^{-4} ($kg\cdot m^2$).The rotors were tested in a model with PM bearings and the maximal eccentric distance of the rotors was measured. In case the maximal eccentric distance of the rotor was smaller than the gap between the rotor and the stator, the rotor could be considered being suspended. In such way the minimal speed for stable levitation of the rotor A, B and C was obtained to be 4597, 3030 and 2222 rpm respectively. It concluded that the minimal speed increases with the square of decreasing inertia according to a formula: [$y=1/(a+bx+cx^2)$, here y: minimal speed, with unit rad/s; x: rotational inertia, with unit $kg\cdot m^2$; a, b, c are constants: $a=3.5367\times10^{-5}$， $b= 39.1012$， $c=-8.8726\times10^{4}$].

Keywords: PM Bearing, Rotational Inertia, Minimal Stable Speed, Eccentric Distance

Introduction

In 1839, an English scientist named Earnshaw proved theoretically that any permanent magnets in static passive magnetic fields couldn't achieve stable suspension in all of the 6 degree of freedom [1]. In order to achieve stability, non-static PM force, such as hydraulic pressure, friction or electromagnetic force, should act in at least one degree of freedom [2,3].

The authors' former works demonstrated that a PM rotator supported merely by PM bearings has a minimal speed, above which it can stabilize its equilibrium, under the function of a so-called Gyro-effect [4]. It is unclear, however, by which factors is this minimal speed determined. In this paper, the effect of rotator's inertia on minimal stabile speed has been investigated. Experimental results indicated that the minimal speed of stable suspension decreased along with the square of increasing rotating inertia.

Materials and Methods

PM Bearings and Permanent Maglev Turbine. The authors developed a novel PM bearing shown in Fig. 1(right), which has two PM rings with different outer and inner diameters but same thickness; the smaller ring is located beside the bigger ring concentrically and both are magnetized same in axial direction [5].

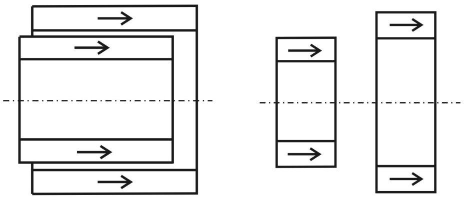


Figure 1. The traditional PM Bearing A (left) and the novel PM bearing B (right). Comparatively, the bearing B needs smaller axial occupation but has bigger axial bearing force; more importantly, the bearing B has better stability than bearing A.

With the novel bearing B, the authors designed a permanent maglev turbine, whose schematic drawing was shown in Fig. 2(left): The arrows represent magnetized direction of the rings. The PM rings in the stator can provide the rotor axial and radial restore force, and prevent the rotor from tilting. The stator and rotor would contact in radial direction when stationary because of Earshaw's theory. In accordance with the schematic drawing, a physical turbine model shown in Fig. 2(right) was manufactured. If the rotor eccentricity is less than the gap between the rotor and the stator (0.5mm) when rotating, it can be considered that the rotor is fully suspended.

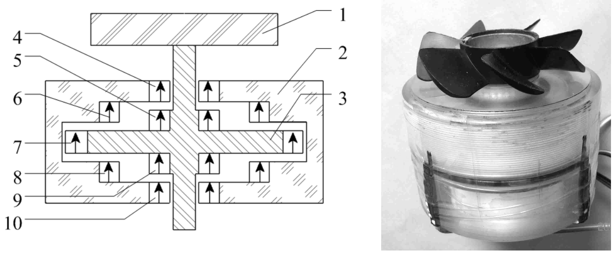


Fig.2 The schematic drawing of the turbine model(left): 1. Turbine's impeller; 2. Stator; 3. Rotor; 4,5 and 9,10. PM rings, attracting separatively each other and providing radial bearing force; 6,7and 7,8. PM rings, repelling respectively each other, providing axial bearing force; Right of Fig.2: the prototype of the turbine.The impeller fixed on the top of the rotor was driven by high-pressure air.

To investigate the effect of rotor's rotational inertia on minimal speed, three rotors of same size but made of different materials were manufactured: rotor A was made of plastic; rotor B was made of aluminum; rotor C was made of steel. These rotors were tested in a model stator with PM bearings one after another (shown in Figure 2). The gap between the stator and the rotors is 0.5mm. The eccentric distance of the rotors was measured by 4 Hall sensors (Fig.4), and the rotating speed was tested by speed sensors.

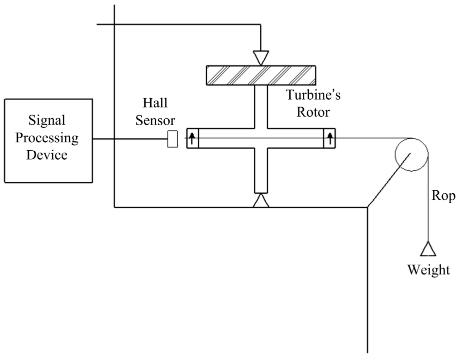


Fig.3 The device for measurement of inertia

The Measurement of Rotational Inertia. The three rotors’ rotational inertia was measured by use of a device shown in Fig.3. Each rotor was placed between two triangular fulcrums, and can rotate when driven by a rope tying a weight. Because the rotor is equipped with magnetic rings, rotor’s rotation will cause changes of the output voltage of Hall sensors near the rotor. By each rotation of the rotor, the sensor’s output voltage will appear a maximum and a minimum. The rotor’s angular acceleration β can be thus calculated by using the sensor’s output when the rotor is rotating. If two weights with mass m_1 and m_2 are tested respectively in experiment, the angular acceleration β_1 and β_2 can be obtained. Then the rotor’s inertia J was:

$$J = \frac{(m_2 - m_1)gr - (m_2\beta_2 - m_1\beta_1)r^2}{\beta_2 - \beta_1}$$

where g is gravitational acceleration, and r is the radius of the rotor.

So the inertia J can be calculated easily. Finally, the inertia of rotor A, B, C are 6.293×10^{-5} kg·m^2, 1.074×10^{-4} kg·m^2, 2.081×10^{-4} kg·m^2 respectively.

Experimental Program. The levitation of the turbine’s rotor was exhibited by measuring the rotor’s eccentricity when turbine was rotating. Four UGN3503U Hall sensors, fixed outside the turbine symmetrically, detected the magnetic flux density of the magnetic rings in the rotor (Fig.4).

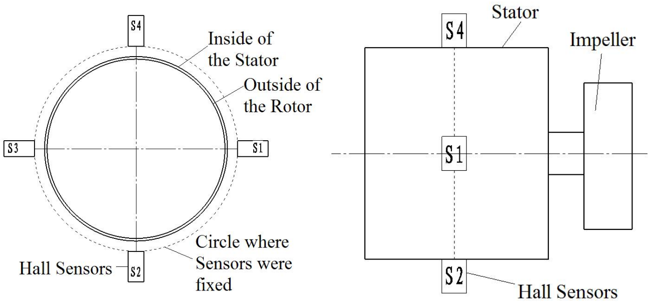


Fig.4 Hall sensors’ distribution on turbine.The output of four Hall sensors was computed to the distance between the rotor and the stator in four positions, thus the eccentricity of the rotor in the stator could be calculated.

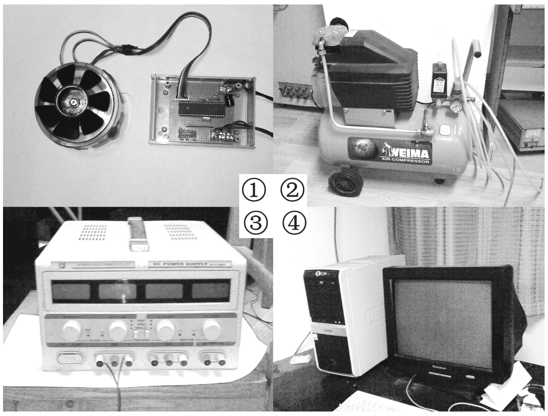


Fig.5 (1) Permanent magnetic levitation turbine and eccentricity detection device (2) Air compressor (3) DC Power Supply (4) Computer

Fig. 5 listed the equipments of the experiment: permanent maglev turbine model and eccentricity detection device, air compressor, DC power supply and computer.

The measuring process is shown in Fig.6: Air compressor produced high-pressure air of

810.4kpa, blowing the impeller and the rotor to rotate with a high speed. Then high-pressure air was removed, the detection device began to record the four Hall sensors' output and the rotating speed. When the rotor's speed decreased slowly to zero because of air resistance, the measuring system stopped recording data, and uploaded the data to computer. The eccentricity detection device recorded a set of data every 4 ms, which included four Hall sensors' output voltage and rotating speed.

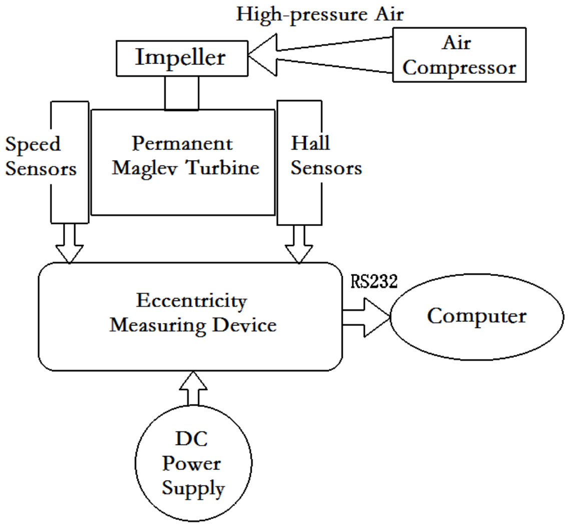


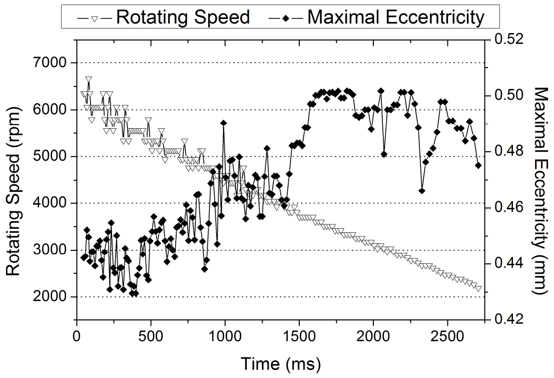
Fig.6 Block diagram of the eccentricity measurement system

Results

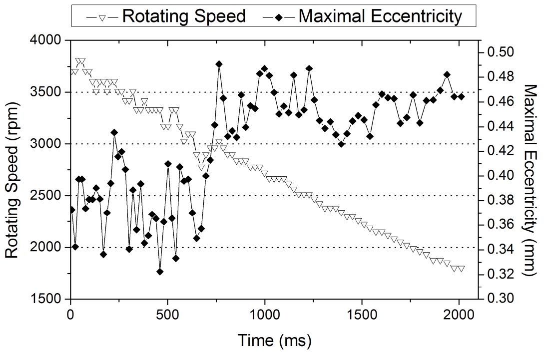
Using the Hall sensors' voltage, the rotor's eccentric distance was calculated. In case the maximal eccentric distance of the rotor is smaller than 0.5mm, the rotor could be considered being suspended.

To analyze the minimal speed, the relationship between rotating speed and the maximal eccentricity corresponding to this speed was established and exhibited in Fig. 7. The abscissa represented time; The left ordinate denoted the rotor's speed, and its unit was rpm; The right ordinate represented the maximal eccentricity(mm).

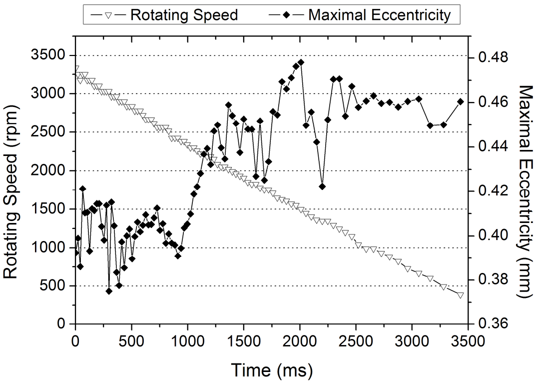
From the experimental results of each rotor shown in Figure 7, it can be seen that the maximal eccentric distance was smaller than 0.5mm when rotating speed was higher than a certain value, thereafter the rotor would touch the stator because the maximal eccentric distance reached 0.5mm. This value of speed was the minimal speed for stable levitation.



Rotor A made of plastic



Rotor B made of aluminum



Rotor C made of steel

Fig.7 Curves describing the three rotors' eccentric distance and rotating speed.

In such way the minimal speed for stable levitation of the rotor A, B and C was 4597, 3030 and 2222 rpm respectively.

It is concluded that the minimal speed for suspension increases with the decreasing inertia according to [$y=1/(a+bx+cx^2)$, y: minimal speed, with unit rad/s; x: rotational inertia, with unit kg·m^2; a,b,c are constants: $a=-3.5367\times10^{-5}$， $b= 39.1012$， $c=-8.8726\times10^{4}$] (Fig.8).

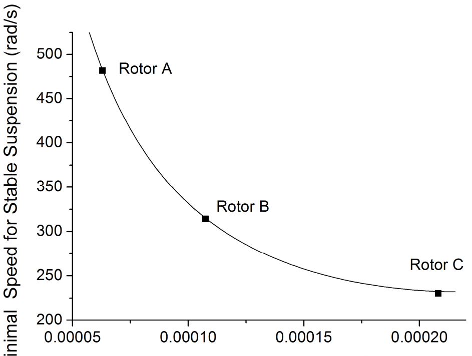


Fig.8: Relation between minimal speed and rotational inertia of stable PM bearing rotator

Conclusions

In this paper, three rotors with different inertia were made to study the relation between minimal speed and rotational inertia of stable permanent maglev rotator. From the experimental data, it is clear that the minimal stable speed decreases with the square of the increasing rotating inertia.

The relation between the minimal speed and the strength of the PM bearings is now in investigating.

References

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