Gyro-effect Extends Earnshaw's Theorem for Permanent Maglev Stability from Static to Dynamic Equilibrium

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Abstract

Earnshaw's theorem(1839) stated that no stationary object made of magnets in a fixed configuration can be held in stable equilibrium by any combination of static magnetic or gravitational forces. What happens by a moving body like a rotating passive magnetic levitator? Nobody has given an answer until now.

The author applied a self-made passive magnetic bearing to radial pump and turbine machine, and found that if the rotating speed could be higher than a critical value, 3250rpm by pump and 1800rpm by turbine, the rotors would be disaffiliated from stators and keep the rotation stable. It seems that the fast rotating levitator has a so-called "Gyro-effect" which makes the passive maglev rotator stable.

These results have extended Earnshaw's theorem from static to dynamic equilibrium: In static state or by a speed lower than critical value, the passive maglev rotator cannot keep rotation stable; if the rotating speed is higher than critical speed, the passive magnetic levitator will have Gyro-effect and thereby stabilize its rotation.

Keywords

passive magnetic bearing; permanent maglev; equilibrium stability; Gyro-effect

I. Introduction

In 1893, an English scientist named Earnshaw proved theoretically that a magnetic body cannot be supported in a stable manner in the field produced by any combination of mere passive magnetic poles [1]. That means, it is impossible for a pure permanent maglev to achieve a stable equilibrium, because the force of attraction (or repulsion) between two magnetized bodies is inversely proportional to the square of their separation (distance). In more precise words, there is no point of equilibrium between two magnets; they will attract or repel each other until they are attached together or separate indefinitely far away from each other. From viewpoint of energy, the magnetic power in passive magnetic field has no minimal value point, at which any magnetic body changes its position needs energy increase.

Things will be changed if the magnetic body moves. A rotating magnetic object, for example, has not only passive magnetic energy but also dynamic energy. Could a passive maglev rotator achieve stable rotation? The author applied a patented novel passive magnetic bearing [2] in rotary pump and turbine machine, and found that the rotors of these devices could be levitated in a stable manner if the rotating speed were high enough.

This paper presents the permanent maglev pump and permanent maglev turbine model, demonstrates the stable levitation of the rotors and discusses the mechanism why passive maglev can be stable in dynamic equilibrium.

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II. Passive magnetic bearings

The author's bearing is shown in Fig.1(Bearing B), which has two passive magnetic 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. Compared with the available passive magnetic bearing(Bearing A in fig.1), which consists of two passive magnetic cylinders with same length but different outer and inner diameters and the smaller cylinder is located within the bigger one and both are magnetized same in axial direction [3], the Bearing B needs smaller axial occupation and has bigger axial magnetic bearing force; besides, the Bearing B has better stability than Bearing A, that means the rotor with Bearing B has smaller vibration amplitude than that with Bearing A under same conditions [4].

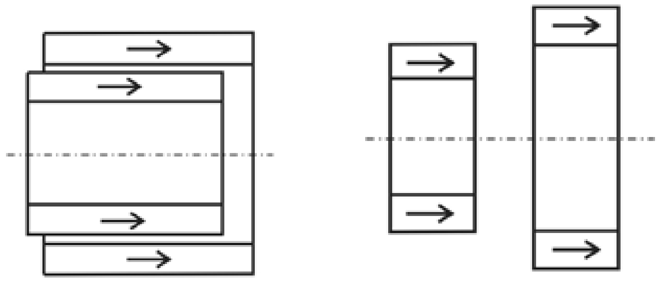

Fig.1: The available passive magnetic Bearing A (left) and the novel passive magnetic bearing B (right). Comparatively, the bearing B needs smaller axial occupation but has bigger axial bearing force; more importantly, the bearing B has better stability than bearing A.

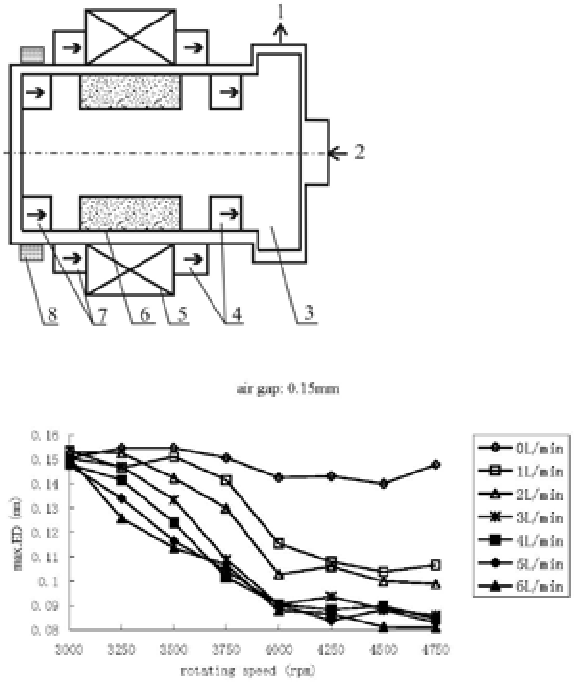

Fig.2: Schematic drawing (left) of radially driven centrifugal pump. 1-Outlet; 2-Inlet; 3-Impeller; 4-Bearing B; 5-Motor coil; 6-Rotor magnets; 7-Bearing B; 8-Hall sensors. The right picture showed the rotor maximal eccentric distances (max. ED, ordinate) by different rotating speed (abscissa). It's clear, the max. ED will go down to less than 0,15mm when rpm is larger than3250, that

means the rotor has no contact with stator because the gap between rotor and stator is 0,15mm.

III. Permanent maglev pump

A radially driven centrifugal pump used a pair of Bearing B is illustrated in fig.2. It is composed of a motor coil and an assemble of rotor magnets, the pump impeller is fixed onto the rotor. To verify whether the rotor was levitated in the stator, 4 Hall-sensors are devised at the end of the stator evenly in periphery. The distances between the rotor and the sensors are detected by voltage differences in the sensors. Then the maximal eccentric distance (max. ED) and vibration amplitude of the rotor are calculated. The results indicates that these eccentric distances and vibration amplitudes by use of Bearing B would be under 0,07mm and 0,05mm respectively, smaller than the gap between the rotor and the stator (0,15mm), if the rotating speed increased to over 3250RPM [4]. That means the rotor had no contact with the stator, namely, was suspended in the stator.

IV. Permanent maglev turbine

The author's permanent maglev pump was doubted by some people who insisted that the levitation in the pump was due to hydrodynamic forces rather than passive magnetic force. Therefore, a passive maglev turbine model was manufactured (Fig. 3).

The device has the same levitation structure as passive maglev pump, but its dimension is 4 times larger than the pump. The rotor position is detected by 4-Hall sensors. The propeller (at the top of the device) is driven to rotate by a compressor. Then the rotating speed is gradually decreased. Results demonstrate that the max. ED will be smaller than the gap between the rotor and the stator if rpm is larger than 1800, indicating the rotor has no contact with the stator; if rpm is smaller than 1800, the max. ED will reach 0,15 mm, that means the levitation has been broken.

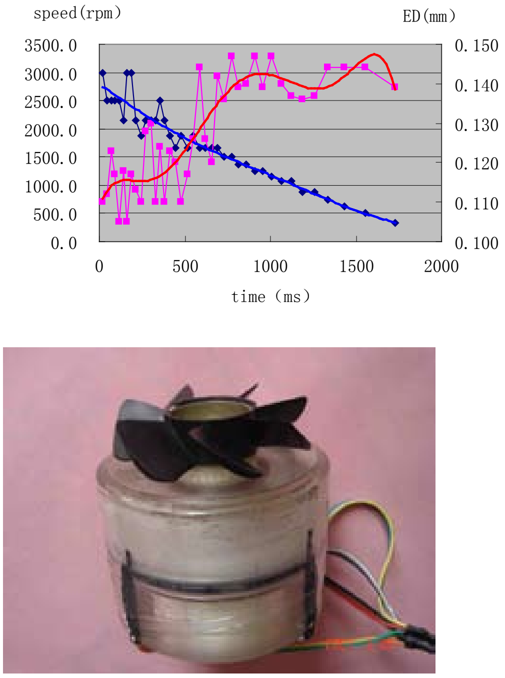

Fig.3: Passive maglev turbine model and its rotor position detection. The model has the same levitation structure as passive maglev pump, but 4- time larger dimension than the pump. 4 Hall sensors detect the position of the rotor. As the propeller is driven by a compressor to rotate, then the rotating speed will gradually decrease. It demonstrates the maximal ED is smaller than gap (0,15mm) when rpm is larger than 1800; and max. ED will reach 0,15mm if the rpm is smaller than 1800.

V. Discussion and Conclusion

Passive maglev rotary machines have advantages of simpler structure, lower costs and more reliability compared with other maglev devices [5]. The traditional concepts exclude the possibility of passive maglev because of Earnshaw's theorem. Actually, few of the people who disregard passive maglev know Earnshaw's theorem was deduced in static status. In dynamic status, it's impossible to have a field with pure passive magnetic forces. That is to say, Earnshaw's theorem is not valid for dynamic equilibrium of passive maglev. There should be another principle to answer the question whether a rotating passive magnetic levitator can achieve a stable equilibrium; and why if it can. In Fig.4 there is a gyro standing up a ball. It rotates stably when it has large enough speed; but it will go down the ball if the gyro rotates slowly or in standstill. Just like a Levitron [6] in Fig.4, the small ring can contact-less rotate above the large ring when its speed is large enough; by low speed, the small magnetic ring will fall over. The magnetized direction by Levitron is different from that in the author's bearing (fig.1), this is due to less axial occupation by later as mentioned. High speed rotating object has a so-called "Gyro-effect", which enables the object to maintain the rotation stable. Gyro-effect can be understood as a function of inertia like some thing following Newton's First Law, as simple as riding a bicycle: with certain high speed the rider can avoid to fall over though theoretically a two-wheel bicycle cannot achieve stable equilibrium. People may think a bicyclist can use the steering for control, but nobody can maintain a stable equilibrium of a bike in standstill.

The critical speed between unstable to stable equilibrium may change according to the rotating inertia of the system: with larger inertia the critical speed will be lower. More extensive study is desirable.

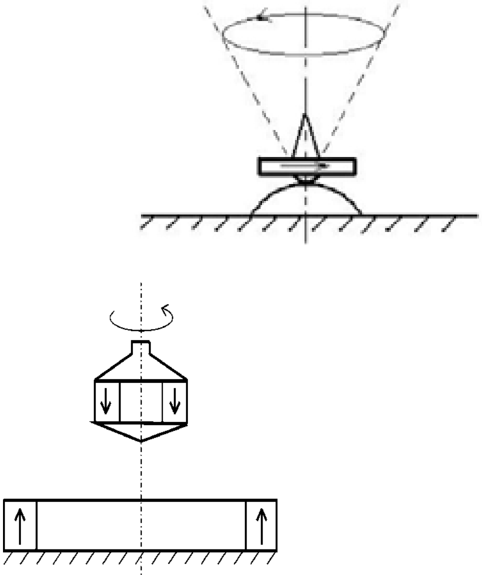

Fig.4: Illustration of Gyro-effect(left):a gyro can stand up a ball if its rotating speed is large enough, but will go down if it is in standstill or rotates not fast. The toy Levitron(right) has same property: the small magnetic ring can rotate above the large ring if the small ring has enough speed, but will fall off if its speed decreases to certain value [6].

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