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Development of a small wind power generator using permanent magnet attractive type passive magnetic bearings

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Abstract

This study aims to develop a magnetically levitated vertical axis wind turbine capable of achieving stable power generation performance. By adopting a vertical axis design and implementing a magnetic levitation mechanism—wherein the rotor is suspended through the application of electric current to the top-mounted coil—the constraints associated with installation locations can be significantly reduced, offering greater flexibility compared to conventional horizontal axis wind turbines.

Keywords : Attractive type passive magnetic bearing, Wind power generator, Permanent magnet, Coil sensor

1. Introduction

Conventional power generation depends heavily on fossil fuels, which cause major environmental harm. These resources are limited–natural gas and oil may run out in about 50 years, and coal and uranium might last up to 130 years. Therefore, we urgently need to develop new and sustainable energy technologies. In this regard, renewable energy has become increasingly important, with wind power emerging as a key solution for sustainable energy supply. Conventional horizontal axis wind turbines typically employ mechanical bearings and gearboxes, which can lead to reduced power generation efficiency and potential mechanical failures under low wind conditions due to friction. To address these issues, vertical axis wind turbines incorporating magnetic levitation technology have been investigated. This technology replaces mechanical bearings with magnetic bearings, eliminating physical contact and thereby reducing friction between the rotor and stator, enabling stable rotation even in low wind speeds. As a result, such turbines can operate more effectively in low-wind environments compared to traditional models.

Nevertheless, a key challenge remains: power generation efficiency and output decline as rotational speed decreases. Particularly for small-scale wind turbines intended for cost-effective and simplified applications, further improvements are necessary to achieve commercial viability. Mahmoud et al., 2020 developed a vertical axis wind turbine featuring an innovative passive magnetic bearing, successfully achieving stable suspension across various air gaps while avoiding resonance. This experiment will further employ a vertical axis wind turbine to achieve levitation and generate electricity, aiming to validate the practicality of the device.

2. Experimental device

The structure and photographs of an experimental equipment are shown in Figures 1 and 2. A passive magnetic bearing (PMB) consists of a cylindrical permanent magnet (PM) and an iron shaft . Due to the magnetic attractive force, the radial direction is passively stable, but the axial direction is unstable. The end of the shaft is tapered to improve the radial stiffness. Two PMBs are installed at the top and bottom of the rotor shaft. A cylindrical neodymium magnet with a magnetic flux density of 0.48 T was used in the experiment. The permanent magnet (PM) measures 10 mm in diameter and 10 mm in height. The shaft is made of soft magnetic iron, has a diameter of 8 mm, and a tip angle at tip of 120 degrees. The rotor, depicted in Figure 3, has a height of 350 mm and weighs 660 g.

A control coil (Coil diameter: 52mm, number of turns: 300, resistance: 1Ω) is placed around the top PM to change

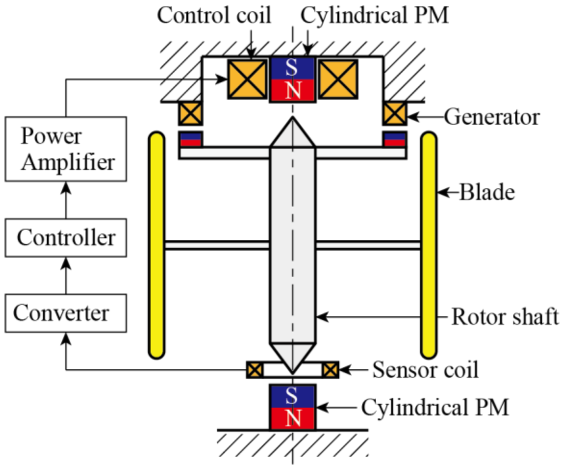

Fig. 1 Cross-section of a magnetically levitated vertical axis windmill.

Fig. 2 Maglev vertical axis windmill.

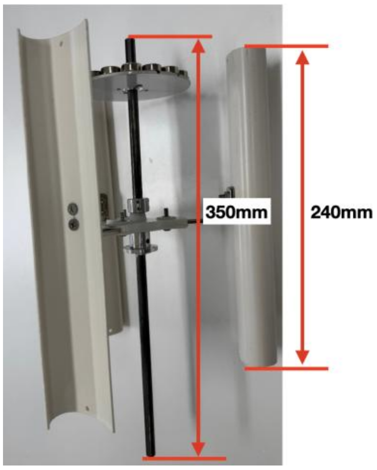

Fig. 3 Rotor structure.

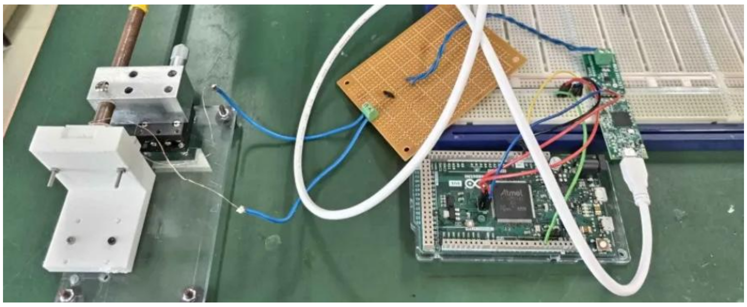

Fig. 4 Coil sensor.

the magnetic attractive force. The coil current is calculated by a DSP and supplied by a power amplifier (Junus JSP-090-10). Another cylindrical coil is installed at the bottom and is used as a sensor to measure the axial displacement. The measurement principle is to read changes in the resonant frequency of an LC circuit.

Blades and generator are mounted on the shaft. A three-phase axial gap generator is installed. The iron core of the stator has been removed to eliminate the unbalance pull force between the stator core and the permanent magnet on the rotor. Commercial wind turbine blades are used.

3. Control system

As illustrated in Fig. 4, the resonant frequency of the coil and capacitor is measured using the Texas Instruments LDC1101EVM, and the definitions of the resonant frequency and the coil's self-conductance are provided.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$L = \frac{\mu N^2 |S|}{l} \tag{2}$$

Here, f denotes the resonant frequency, L represents the inductance, C stands for the capacitance, μ indicates the magnetic permeability of the coil core, N is the number of turns in the coil, l refers to the coil length, and S denotes the cross-sectional area of the coil. The variation in the coil's self-inductance depends solely on the magnetic permeability

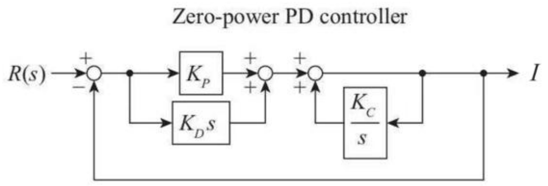

Fig. 5 Block diagram of the closed-loop system of the MAGLEV system.

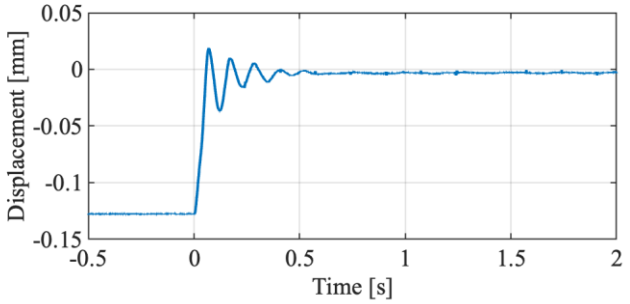

Fig. 6 Start-up response.

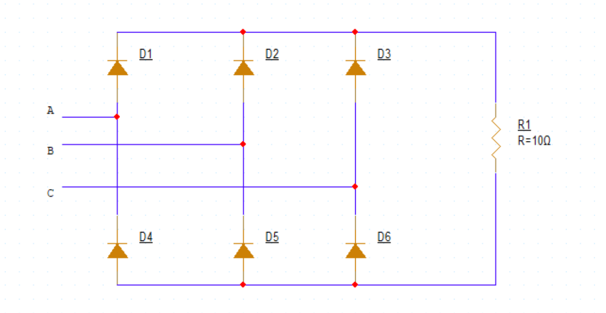

Fig. 7 Generator circuit diagram.

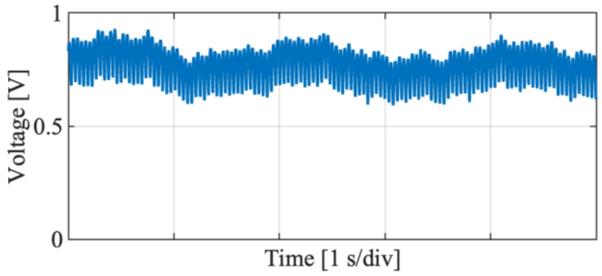

Fig. 8 Voltage measurement with generator connected.

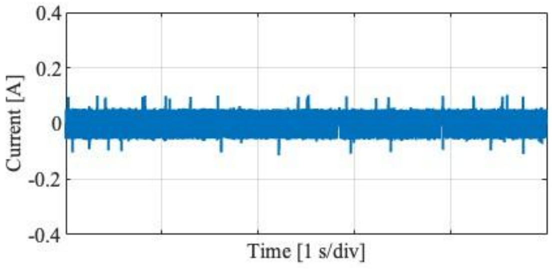

Fig. 9 Current measurement.

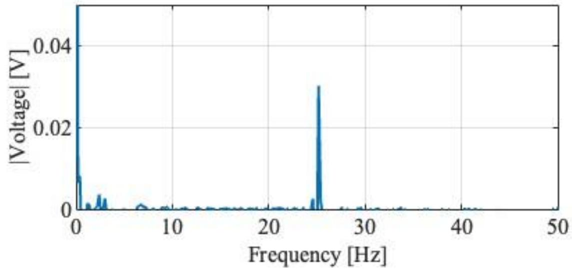

Fig. 10 FFT analysis of connected generators.

of the coil core. This relationship between the shaft displacement through the coil and the resulting change in resonant frequency is utilized as a sensing mechanism.

The block diagram is shown in Fig. 5, where K_P, K_D and K_C denote the proportional gain, derivative gain, and local integral feedback gain, respectively, and R(s) represents the reference position signal. The sampling time is set to 0.0001 s. During control implementation, K_P, and K_D are typically configured as 35 and 0.02, respectively.

To reduce power consumption, a zero-power control strategy is employed. This method achieves an effective balance between the attractive force produced by the permanent magnets and the gravitational weight of the levitated object, thereby enabling the control current to asymptotically approach zero.

4. Levitation and power generation experiments

First, a levitation test was performed. Figure 6 shows the start-up response of the rotor displacement. Stable levitation was achieved.

Next, a rotation and power generation test was conducted. The rotor was rotated by the wind blowing from the side. The shaft remained stable even when the wind blew from the side. As shown in Figure 7, a 10 Ω resister was connected to the generator. A, B, and C represent the three input phases of the three-phase full-wave bridge rectifier circuit. At a wind speed of 3.1 m/s, the resistor voltage waveform is shown in Figure 8. The average voltage is about 0.75 V and the power generation was about 7.5 W. The current in the coil, as shown in Figure 9, remains nearly zero. The result is

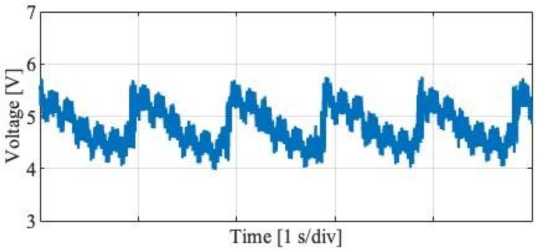

Fig. 11 Voltage measurement without generator connected.

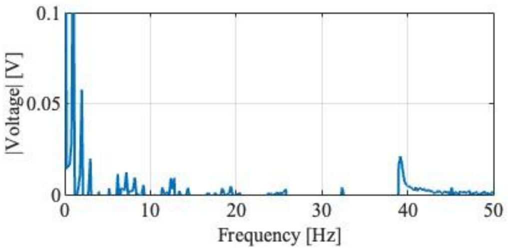

Fig. 12 FFT analysis without generator connected.

presented in Figure 9 after undergoing Fast Fourier Transform (FFT) analysis. As shown in Figure 10, the resonant frequency is 25Hz. Given that the power generation section of the device contains 16 permanent magnets, the rotational speed can be calculated as 19.63 rad/s. We also conducted the experiment without connecting the generator, and the voltage waveform is illustrated in Figure 11. The waveform after the fast Fourier transform is illustrated in Figure 12. As shown in the figure, the rotational speed reached 29.85 rad/s without the generator connected, and the noise level generated at this high speed was significantly increased.

Through vibration experiments, we determined that the critical rotational speeds in the horizontal direction are 3.77 rad/s and 25.13 rad/s, respectively. This also explains why the vibrations increase in magnitude when the rotor speed approaches the dangerous speed with the generator disconnected. We also evaluated the shedding effect through direct measurement. However, the precession angular velocity was only 0.000183 rad/s, significantly lower than the actual rotational speed. Consequently, the influence of the gyroscopic effect was neglected in this experiment.

5. Conclusion

This study designed and tested a magnetically levitated vertical axis wind turbine. By employing coil sensors, the system achieved stable levitation with a gap of 0.12 mm and rotational speed of 19.63 rad/s, generating approximately 7 W of power. With the generator disconnected, the rotor speed increased to 29.85 rad/s, resulting in significantly greater vibration. According to actual measurements, the dangerous speeds of the rotor in the horizontal direction are 3.77 rad/s and 25.13 rad/s. Future improvements are planned to enhance power output.

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