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# Desisgn and Fabrication of Permanent Magnetic Bearings for Small Wind Turbines

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***Abstract***

This study aims to propose a design of thrust bearing for rural area electricity generation wind turbines which require low maintenance because of the lack of maintenance skills and tools. Moreover, wind turbines installed in off-grid areas in Thailand are always exposed to the natural elements, therefore typical thrust ball bearings are likely to require more frequent maintenances which defeats the purpose of such turbines. Using passive magnetic thrust bearing could overcome this issue because it operation is contactless. However, passive magnetic bearings are currently not commercially available in Thailand. This work proposes a prototype of passive magnetic bearing for a Savonius type vertical axis wind turbine whose mass is under 30kg and a power rating below 30W. The design used in this study consists of two parts, the flange and the housing. Permanent magnets are aligned in circular pattern in four rings, one in the flange, one in the housing and the other two use to lock the first two layers in place. The magnetic bearing performance is evaluated by comparing the wind turbine mechanical power output between when the system is with and without the magnetic bearing. A field test is conducted in Samutsakorn province near Tha Chin estuary near a shrimp farm with no tall trees and buildings within 300m. The mean wind speed is approximately 5 m/s. The passive magnetic bearing is able to stably levitate the wind turbine at high rotational speed and there is no contact between rotational parts and stationary parts so it is likely to require less frequent maintenance. The wind turbine without magnetic bearing is superior to the wind turbine with magnetic bearing in all tests. This is because axial vibration occur due to varying repulsive force from discrete magnet configuration. In order to improve the design, continuous magnet configuration may be used since it produces constant repulsive force.

***Keywords:*** Thrust Bearing, Magnetic levitation, wind turbine

## 1. Introduction

From previous research "Design and Fabrication of Small Savonius Wind Turbine for Illumination Applications" [1] whose objective is to utilize a Savonius wind turbine for off-grid area electricity generation. The turbines must be light, efficient and require low maintenance because transportation is difficult and people lack maintenance skills and tools. Moreover, wind turbines installed in off-grid areas in Thailand are always exposed to the natural elements [1], therefore typical thrust ball bearings are likely to require more frequent maintenances which defeats the purpose of such turbines. Using magnetic thrust bearing could overcome this issue because magnetic bearing operation is contactless; there is no friction and wear.

Magnetic bearing uses magnetic levitation. Objects can be levitated by magnetic force, however a stable levitation cannot be achieved with only static magnetic force and gravitational force according to Earnshaw's theorem [2]. There are many known methods to stabilize the levitation. One of them is through mechanical constraint or pseudo-levitation which is highly suitable for the wind turbine application. This is because pseudo-levitation is the simplest among the other methods and the levitation from permanent magnets does not require any electricity. Magnetic bearings which are stabilized without electricity are called *passive magnetic bearing*.

Passive magnetic bearings are currently not commercially available in Thailand. This work proposes a prototype of passive magnetic bearing for a Savonius type vertical axis wind turbine whose mass is under 30kg and a power rating below 30W. The bearing is fabricated using neodymium magnets. Magnetic bearing performances are evaluated through the turbine power outputs when different types of bearings are installed, i.e. mechanical power output of wind turbine with a magnetic thrust bearing is measured against the power output of wind turbine with a typical thrust ball bearing. Another design criteria is during levitation, the rotational part must not be in contact with any stationary part.

## 2. Methodology

### 2.1 Passive Magnetic Bearing Design

The design used in this study is based on Kristoffer Zeuthen's bearing [3] as shown in Fig. 1 and Fig. 2. The bearing consists of two parts, the flange and the housing. The flange is a shaft merged with a large disc with a number of slots to attach permanent magnets on. Permanent magnets are aligned in circular pattern in two rings, where each ring is placed over and under of the disc. This is because magnets will repel each other and push the neighbouring magnets out of position even if the magnets are placed in the slots, so it is not possible to align them in only one circle. The housing is a disc fixed to the external casing with slots for permanent magnet placement aligned with the ring of magnets on the flange. An additional ring of permanent magnets is placed outside the box to lock the other layer in place. The advantages of this design lie in its simplicity since small magnets are easily available and the machining process for the flange is much simpler than the bucky ball design [3] and electromagnetic design [4]. The proposed design is also more cost effective than designs in Ref. [5, 6] because of the use of large ring-shaped magnets.

Fig. 1 Passive Magnetic Bearing showing flange and housing with rings of circular slots for magnets

This magnetic thrust bearing is designed to work together with a typical thrust ball bearing and typical radial ball bearings. The magnetic bearing levitates the shaft and rotor blades during operation while the radial ball bearing provides constraint to lateral movements of the wind turbine shaft, hence, stabilizes the levitation. However when the turbine stops, the turbine weight is supported by both the magnetic bearing and the thrust ball bearing.

The most crucial design process is the magnet specifications, consisting the dimension, shape and number of magnets in each ring. This is because these parameters dictate the designs of other parts such as slot dimension, flange shape and housing shape. Button shape magnets with 20mm diameter and 5mm thickness are selected in this work because they are commercial available and circular slots are easier to make than rectangular shape.

The number of magnets required in the flange and the housing is determined by its repulsive force characteristic. Fig. 3, an experiment is conducted to measure the repulsive force of the 20mm diameter and 5mm thick button shaped neodymium magnets by use digital weighing scale and plastic magnet holder. Results of the experiment are presented in Fig 4. The repulsive force reduces with distance and the closest distance that the force can be measured is 1mm. Magnetic bearing is designed to lift the flange 2mm above the housing disc, therefore the number of magnets in one circumference alignment is 14 and the entire magnetic bearing is 56. Others parameters are shown in table 1.

Fig. 2 Passive Magnetic Bearing exploded view showing the arrangement of four rings of magnets

Fig. 3 Permanent magnet repulsive force experiment apparatus set up showing a plastic magnet holder and a digital weighing scale

### 2.2 Passive Magnetic Bearing Performance Test

The magnetic bearing performance is evaluated by comparing the wind turbine mechanical power output between when the system is with and without the magnetic bearing. A field test is conducted in Samutsakorn province near Tha Chin estuary near a shrimp farm with no tall trees and buildings within 300m. The mean wind speed is approximately 5 m/s. The mechanical power of the turbine is measured using the rope brake dynamometer and a tachometer while the wind speed is measured by hand-held digital anemometer. Fig. 5 show the turbine and apparatuses.

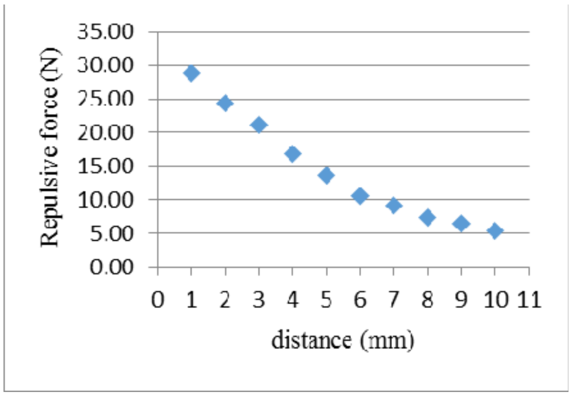


Fig. 4 Repulsive force VS distance of 20 mm in diameter and 5 mm thick button neodymium magnet

Table. 1 Others parameters in millimeter and material

| | |
|---|---|
| Flange | |
| Shaft Diameter | 25 |
| Shaft Length | 70 |
| Disc Diameter | 150 |
| Disc Thickness | 9 |
| Flange Material | Polycaprolactam |
| Housing | |
| Disc Diameter | 155 |
| Disc Thickness | 6.5 |
| Disc Material | Polycaprolactam |
| Box Width | 165 |
| Box Height | 55 |
| Box Thickness | 5 |
| Box Material | Poly (methyl methacrylate) |
| Slots | |
| diameter | 22 |
| depth | 5 |
| distance between center of the slot | 25 |

### 3. Result and Discussion

At high rotational speed, the passive magnetic bearing is able to stably levitate the turbine and shaft as shown in Fig. 6. There is no contact between rotational parts and stationary parts. However, at rotational speed below 35RPM, vibrations in axial direction with 5mm amplitude can be observed but there is still no contact between the moving and stationary part. The vibration reduces with increasing rotational speed and becomes negligible when rotational speed exceeds 35 RPM. This vibration occurs because of discrete alignment of magnets, i.e. when magnets are off-phase, the turbine stays in the lowest position and when they are in-phase the turbine is lifted to the highest position. Vibration also produces noise throughout the operation.

Fig. 5 Photograph of the field test of the wind turbine with passive magnetic bearing and apparatuses

In comparison of the performance with the thrust ball bearing, as shown in Fig. 7, the power output of the wind turbine with permanent magnetic thrust bearing is clearly less superior to the system with a thrust ball bearing. The wind turbine with magnetic bearing averages the Power Coefficient around 7% while the wind turbine with ball bearing averages around 8-9%This is due to the friction loss between radial bearing inner surface and turbine shaft in the axial direction during the vibration; noise also contributes to the loss too.

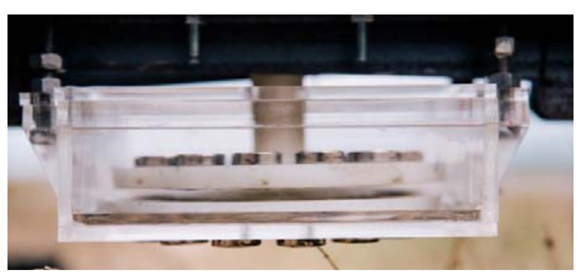

Fig. 6 Passive magnetic bearing operates without contact at high speed

power output. The design used in this paper is discrete so repulsive force in axial direction is not constant. This varying force cause axial vibration. With no axial vibration, friction loss between shaft and radial bearing will vanish and result in more power output.

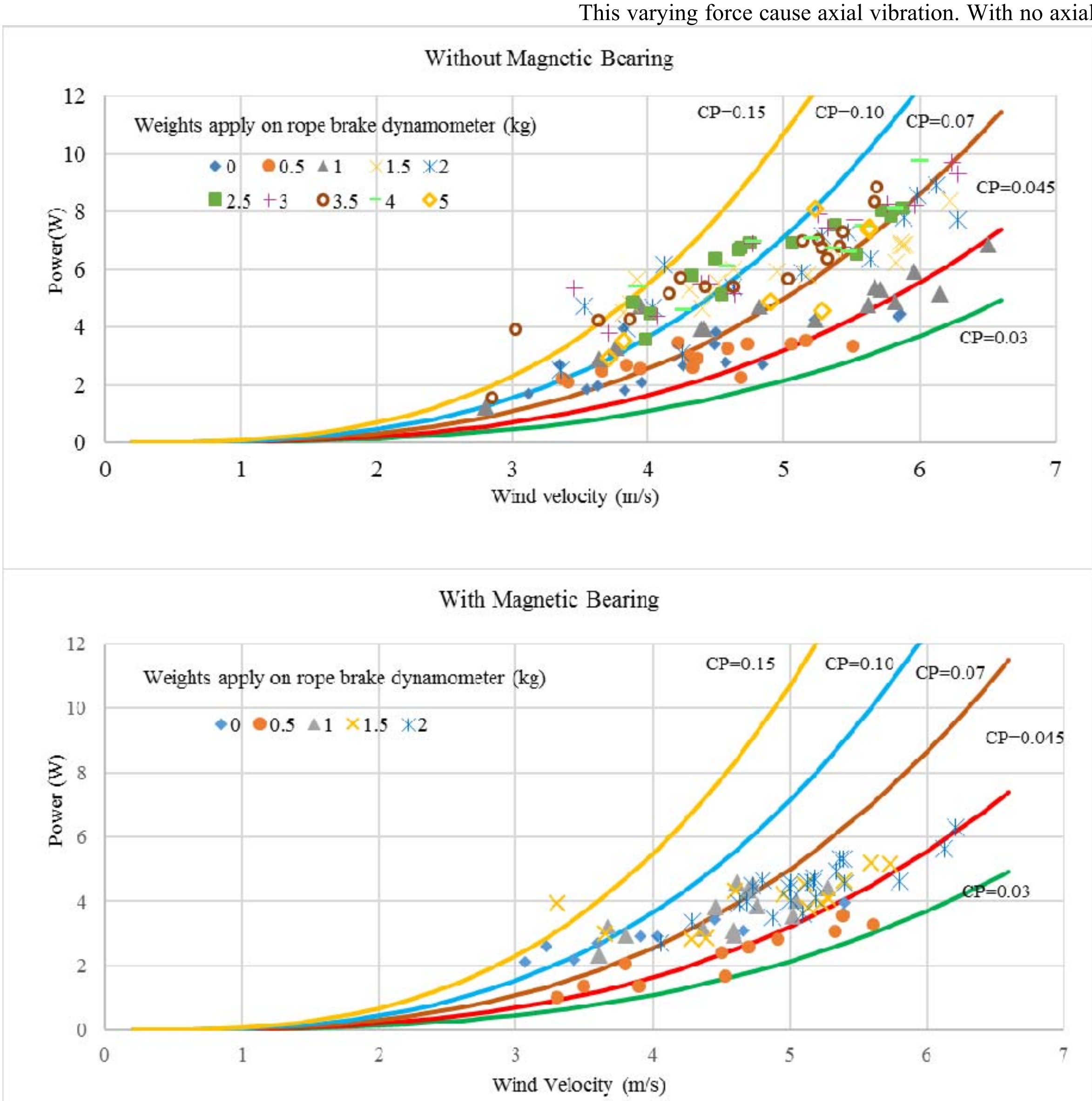


Fig. 7 Power output of the wind turbine with and without permanent magnetic thrust bearing

Fig. 7 also suggests that the wind turbine with permanent magnetic thrust bearing has a higher cut-in speed. This is because the turbine is in the lowest position when it is not in operation, as the magnets are off-phase, however when the turbine begins to rotate it must be lifted from the lowest position to highest position. This starting characteristic requires addition starting torque which is higher than under normal circumstances.

## 4. Suggestion

### 4.1 Magnet Configuration

Changing magnet alignment to continuous configuration will result in no vibration and more

### 4.2 Magnetic Shielding

Magnetic flux density above 0.5mT can harm pacemaker install patient [7]. Commercial version of passive magnetic bearing should be shielded with ferromagnetic material to reduce magnetic flux density outside the casing.

## 5. Conclusion

A prototype of passive magnetic bearing for a Savonius type vertical axis wind turbine whose mass is under 30kg and a power rating below 30W is fabricated. The passive magnetic bearing is able to stably levitate the wind turbine at high rotational speed and it is contactless between rotational parts and stationary parts so it is likely to require less frequent maintenance. However, tests have shown that the wind turbine without magnetic bearing is superior to the wind turbine with magnetic bearing in all cases. This is because axial vibration occurs during operation due to cyclic repulsive force from discrete magnet configuration. Continuous magnet configuration produces constant repulsive force which result in more power output compare to discrete configuration. The result also suggests that the wind turbine with permanent magnetic thrust bearing has a higher cut-in speed.

## 6. Acknowledgement

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