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**MechEng**  
Mechanical Engineering



Vietnamese-German University

# CONCEPTUAL DESIGN AND PROTOTYPE DEVELOPMENT OF A THREE-BLADED, SEMI-ROTATING VERTICAL AXIS WIND TURBINE

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# CONCEPTUAL DESIGN AND PROTOTYPE DEVELOPMENT OF A THREE-BLADED, SEMI-ROTATING VERTICAL AXIS WIND TURBINE

A Thesis Presented

by

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TURBINE



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## ABSTRACT

From the sails which help our ancestors cruising and discovering new lands to the giant wind turbines that power thousands of homes, wind has accompanied the development and evolution of the humankind thousands of years to present days. Wind energy is no longer stranger to mankind, nonetheless, until 2021, this power resource has accounted less than 7% of the global electricity generation. This is the impetus to develop this topic. This thesis focuses on developing and examining a prototype for small three-bladed semi-rotating vertical axis wind turbine.

This design is inspired by sailing vessels, where veteran seafarer has mastered to adjust the windsails relative to the wind to steer the ship forward, even against the wind direction. This wind turbine has the same characteristics as available vertical axis wind turbine, with enhanced features, proposed to have some advantages regards to efficiency over the previous types. Experiments and conclusions will also be discussed in this paper.



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I hereby declare in lieu of an oath that I have produced the aforementioned thesis independently and without any other means except the aids listed. Any thoughts directly or indirectly taken from somebody else's sources are made discernible as such.

To date, the thesis has not been submitted to any other board of examiners in the same or a similar format and has not been published yet.



Thu Dau Mot city, April 29<sup>th</sup>, 2023

Signature

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## ABBREVIATIONS

F	Force of wind act on blade, N
$p_d$	Dynamic pressure, Pa
A	Area, $m^2$
v	Wind speed, m/s
$\rho$	Air density, $kg/m^3$
$\alpha$	Angle, rad
$v_t$	Wind speed at the tangential direction of the blade, m/s
$v_n$	Wind speed at the normal direction of the blade, m/s
r	Radius of the turbine arm, m
$v_b$	Velocity at normal direction of any point on the blade, m/s
$\omega$	Angular velocity of the turbine, rad/s
l	Length, m
$v_{rel}$	Relative velocity, m/s
T	Torque or bending moment, Nm
h	Height of the blade, m
b	Width of the blade, m
P	Power, W
$L_B$	Length of the GT2 belt, mm
$d_p$	Distance between 2 center of pulley, equal radius of the turbine, mm
$d_1$	Diameter of the GT2 30teeth pulley wheel, mm
$d_2$	Diameter of the GT2 60teeth pulley wheel, mm
rpm	Rotation speed, rounds/minute

# CHAPTER 1 – INTRODUCTION

## 1.1. BACKGROUND

Mankind has always been fascinated by the power of wind. Back in the old days, besides using wind power for sailing ships, people also harvested this resource to grind wheat or pump water by building traditional windmills. These windmills, whose designs were getting more and more sophisticated, continued to be spread and multiplied over continents until later, in the late nineteenth century, the first windmill for generating electricity was constructed. It was a 12kW direct current generator invented by an American engineer, Charles Brush [1],[2]. It is more correct to refer modern wind machines as wind turbines as they can be used for a variety of applications, such as generating electricity.

Nowadays, wind turbine technology is developing at a fast rate, making them capable of generating a great amount of energy. There is no doubt that wind power is establishing itself as one of the most affordable alternative sources of clean energy since its inexhaustibility and environmental friendliness offer a sustainable option to reduce the reliance on fossil fuels.

The basic working principle of every wind turbine, regardless of its type, is the same. When the wind blows, the turbine catches the wind with its blades. The low-pressure component of the air forms on one side of the blade and pulls the blade toward it while there is a wind's force against the front side of the blade. Different air resistance on the front and back of the wind turbine's rotor section causes it to rotate. In short, wind turbines capture atmospheric energy, convert it to kinetic energy and extract for useful mechanical or electrical energy [3].

Almost wind turbines can be separated of two fundamental class: “Horizontal-Axis Wind Turbine (HAWT)” and “Vertical-Axis Wind Turbine (VAWT)”. As their names suggest, these wind turbines are classified based on the orientation of the shaft and rotational axis. Each has their own characteristics due to difference in rotor

design. HAWTs have their rotational axes parallel to the direction of the wind. VAWTs' rotational axes are perpendicular to the wind stream [3].

This project focuses on Small Vertical Axis Wind Turbine as contrary to the large-scale wind turbines often seen at wind farms. These are suitable for residential use because they are easy to install; work with both off-grid and grid-connected; and generate only little noise [4]. However, their aerodynamic efficiency is considerably low, thus produce less power compared to the horizontally oriented ones. This proposed design attempts to overcome this shortcoming.

VAWTs produce the highest power when the blade surface is perpendicular to the blowing wind direction. The basic idea behind this proposed design is to optimize the blade angle in such a manner that it is continuously directly face the incoming wind while following a circular path. This said principle can be performed by utilizing half rotating method for three blades of the wind turbine, thus it is called Three-Bladed, Semi-Rotating Vertical Axis Wind Turbine.



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## **1.2. LITERATURE REVIEW**

When it comes to VAWTs, Savonius or Darrieus turbines are the most common, so numerous studies have been done on these two types [5], [6]. Contrastively, very little research has been done on this type of Three-Bladed, Semi-Rotating VAWT [7]. Some inventors from different countries have independently come up with the design of this turbine at various times, such as Cooper, Dieudonné, and Zhang Yuhua. This makes this turbine not have an official name, such as "VAWTs with relative rotating blades" by Bayeul-Lainé or "双叶片立轴风力机" meaning "Two-Leaf Semi-rotary VAWT" by Zhang Yuhua [7], [8]. Along with the name, these turbines also have different models. However, all of these turbines' designs are based on the same working principle, in which each blade combines the movement of rotation around the center axis of the turbine and around its own axis at half speed. Because of this combination, when the turbine makes one full revolution, the leading

edge of the blade becomes the following edge; therefore, the blade requires two symmetrical planes.

Contradictory to conventional VAWTs, this type of wind turbine requires to be pointed in the direction of the wind like HAWTs. This, combined with the spinning of straight or elliptic blades, produces an exceedingly valuable performance and is superior to the conventional one at 0 to 15 degrees of starting blade stagger. It was demonstrated that each blade's behavior has less of an impact on the power output and the flow stream surrounding the next blade. Approximately 38% is the maximum mean numerical coefficient [7]. Additionally, it is more capable of starting on its own. Furthermore, thanks to features like straightforward design, simple installation, and ease of maintenance, it is acutely suited for mountainous locations, off-grid power supplies, or even on roofs or in the gardens of households. However, the structural stability of the blades for big models and in strong winds is still an unsolved problem [7], [9].

There has been some research to develop this Three-Bladed, Semi-Rotating VAWT. The technical design of this type of turbine with two blades and how the system works were described in [10], [11]. The "proportional-integral-derivative controller" or PID approach based on the "Radial basic function network" is applied to simulate the mathematical design of this turbine design on the "Matrix Laboratory (MATLAB)" software. And finally, in [7], two shapes of blades, straight and elliptic, are compared to find the best performance using CFD simulation.

### **1.3. OBJECTIVES OF DESIGN**

Following criteria are to be taken into consideration when designing the prototype:

#### **1.3.1 MECHANICAL ASPECTS**

- The system is able to stand steadily under various windy weather conditions due to its firm base with low center of gravity.
- System's parts and connections are securely attached for proper operating.

- Spur gear system is arranged and installed in such a manner that allows it to run smoothly without hindrance.
- The direction of transmission of worm gear system is not reversible under any circumstances.
- Turbine wind blades' rotation and position is manageable.

### 1.3.2. CONTROLLING ASPECTS

- Wind vane's data is accurate and is timely reported back to the controller.
- Optimizations are made where possible, such as determining the shortest distance for stepper motor to rotate.
- The controller is able to correctly track the wind turbine's rotation speed.
- Accurately display system data via LCD module – wind direction, turbine direction and speed.
- Make the model readily portable by utilizing set of batteries.

## 1.4. REPORT CONTENT



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The thesis report comprises of following contents:

- **Chapter 1** is used for introduction, where the problem statement is defined along with a brief overview of the thesis structure.
- **Chapter 2** constructs a theoretical framework as foundation of the mechanical design process.
- **Chapter 3** discusses the electrical design of the project, covering the proposed hardware components and the programming code.
- **Chapter 4** describes the implementation of the previously constructed model and the experimental results.
- **Chapter 5** rebuilds the drive system to make the blade rotate at the right speed and test the prototype according to the new design.
- **Chapter 6** concludes what has been done in this work and considers the feasibility of further improvement.

## CHAPTER 2 - MECHANICAL DESIGN OF THE THREE-BLADED, SEMI-ROTATING VAWT

This chapter presents the mathematical approach to design the proposed three-bladed, semi-rotating VAWT. In order to design and build a conceptual prototype of a wind turbine, the aerodynamic principle needs to be learned and understood to serve as the foundation. Then a mathematical model is to be properly constructed to test the feasibility of the idea. However, numerical analysis of such model is considered quite difficult and complicated due to the complexity of power electronics and the uncertainty of aerodynamics. Additionally, unlike the horizontal type, whose design is mostly standardized and development method is uniform, VAWT's design can come in a vast variety of shapes and configurations, depending on the wind flow conditions of the specific determined location, hence, more constraints need to be put into consideration.

### 2.1. WIND TURBINE AERODYNAMIC MODEL

Savonius and Darrieus are so typical that they represent their classification when mentioning VAWTs. The difference of this design compared to those well-known types mainly lies in the mobility of its three blades. While Savonius and Darrieus wind turbines have their blades fixed to the arm and limit their movement around the center shaft, this VAWT's three blades add more freedom of rotation by allowing them to be able to self-rotation around the arms 'ends besides the main rotation of the wind turbine. With this design, the angle of attack is changeable in a favorable manner depending on the wind direction. Specifically, it helps maximize the wind force when the turbine's direction is in unison with the wind direction and vice versa, reduce the wind drag when their directions are different. In short, this will optimize the turbine performance. *Figure 2.1* shows the top-view of the simplified design to explain the discussed idea.

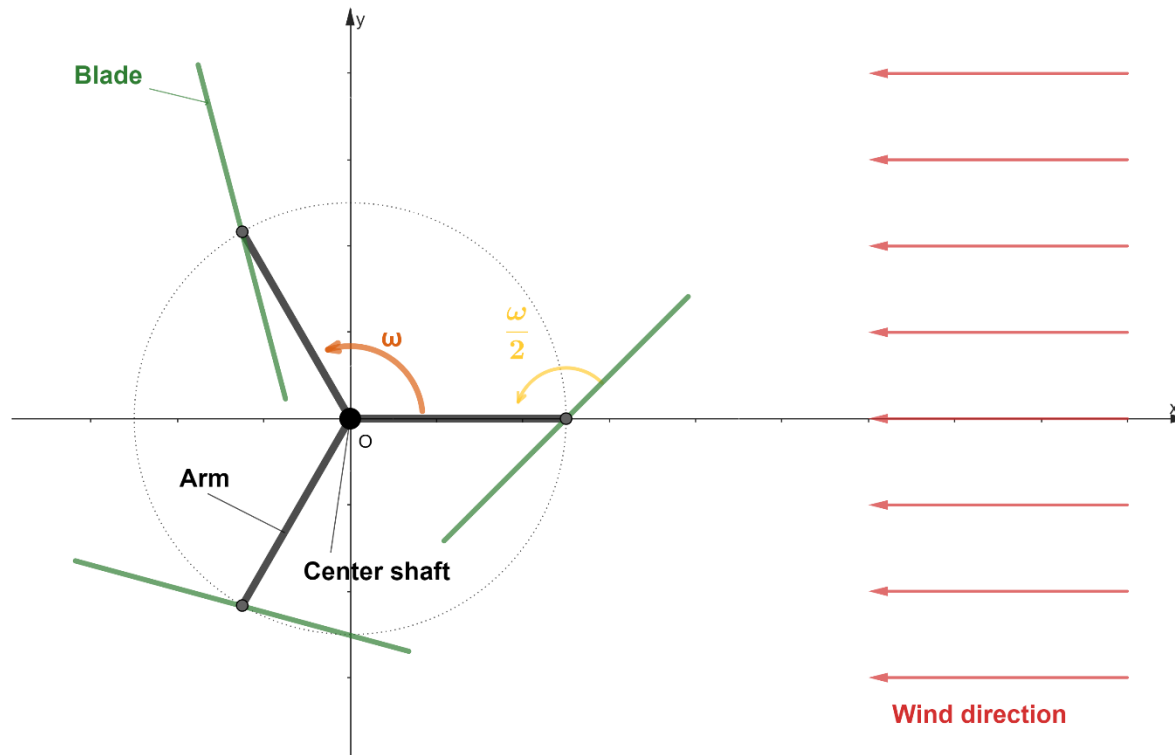


Figure 2.1: Basic structure of the wind turbine's blades

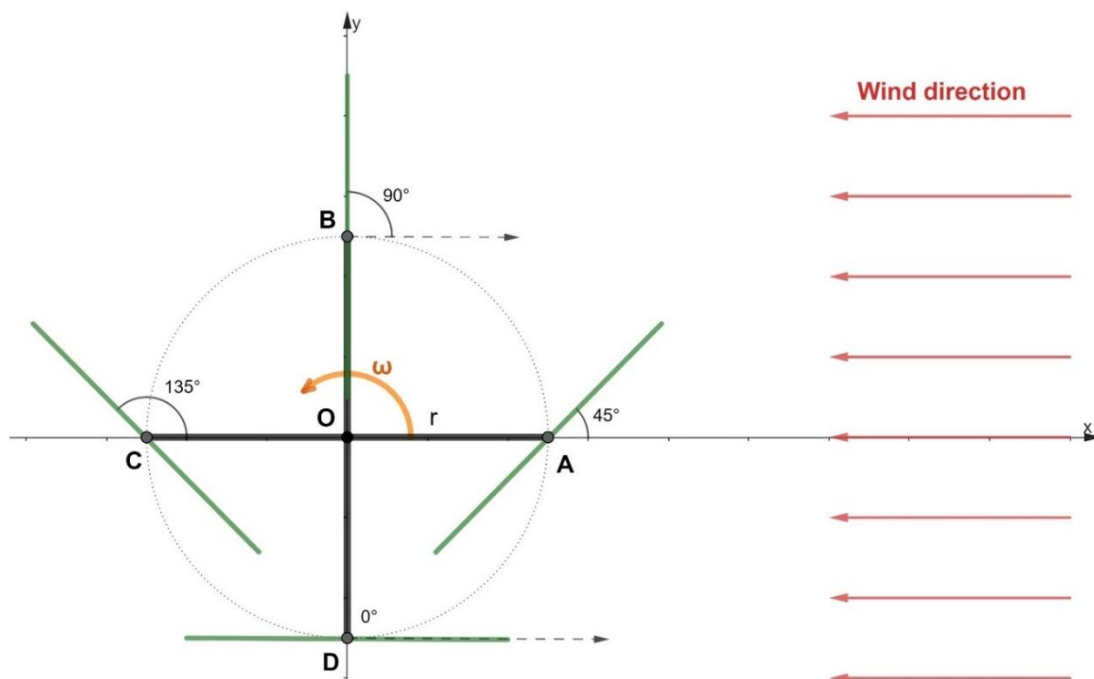
The wind turbine is composed of three blades for wind capturing. They are hinged to the end of the arms in such a manner that they are able to spin around their own axes which are perpendicular to the ground. The distances between these arms are equally distributed, which is 120 degrees apart. The three blades have identical design and are symmetrically located with a phase difference of 60 degrees.

The turbine rotates anticlockwise with a speed  $\omega$ , causing the wind blade to rotate about its radial axis and pick up a speed of half value of the turbine's speed, which is  $\omega/2$ . This deviation causes a variable movement of the blades due to uneven air pressure, which in turn prompts the turbine to rotate as the wind blows. This design implements both lift and drag forces for its operation and thus, belongs to a mixed type of lift-drag wind turbine. This combination is proposed to have some beneficial characteristics that may overcome the limitations of each type of VAWT alone. However, it is categorized as a resistance-type wind turbine because of the overweighing drag force.

The number of blades is one of the most significant factors that determine the performance of a wind turbine. Even though fewer blades have the advantage of less drag force, two-bladed turbines come with a major drawback of imbalanced vibration when directly facing the wind. The reason behind this behavior is the changing angular momentum in the vertical axis against the resistance to motion change in the blades. A three-bladed wind turbine solves this issue with a relatively balanced system constructed by three blades evenly positioned apart, so when one blade is up, the other two are pointing at an angle, keeping the angular momentum at a constant value [12].

### 2.1.1. WIND FORCE ANALYSIS ON A SINGLE BLADE

For simplification purpose, structural analysis is conducted on a representative blade when it transports to 4 main points. The set-up approximation is illustrated in *Figure 2.2*: the origin  $O$  is the wind turbine's center shaft; the incoming wind direction is established along the axis- $Ox$  and is pointing towards the axis- $Oy$ . The 4 points of observation lie on two orthogonal axes- $Ox$  and  $-Oy$ , namely  $A(r,0)$ ;  $B(0,r)$ ;  $C(-r,0)$  and  $D(0,-r)$ .



**Figure 2.2:** Top view of a single blade operation at 4 observation points A, B, C, D



At  $A(r,0)$  and  $C(-r,0)$ , the wind blade forms an angle of 45 degrees and 135 degrees with respect to the axis- $Ox$ , respectively.

At  $B(0,r)$ , the blade forms an angle of 90 degrees with the axis- $Ox$ . According to the setup, this means it is directly perpendicular to the wind the direction, yielding the maximum moment of force to the turbine.

In contrast, at  $D(0, -r)$ , the blade's axis is aligned with axis- $Ox$  and also with the wind direction. In this case, no aerodynamic forces or moments are produced by the wind force, which makes it the most unfavorable position.

According to the momentum theory, the incoming airflow creates a pressure difference between the front and back area of the blade surface. This pressure difference is referred to as dynamic pressure, which then is transformed into useful force to drive the blade moving forward. In practice, more complex forces are involved in the transformation process due to existence of drag and other effects [13]. Therefore, to simplify the analysis, the blade thickness is assumed to be zero and ignorable, thus, the calculations are merely based on the case where dynamic energy of wind is totally transformed into dynamic pressure.

Generally, force and pressure are related as:

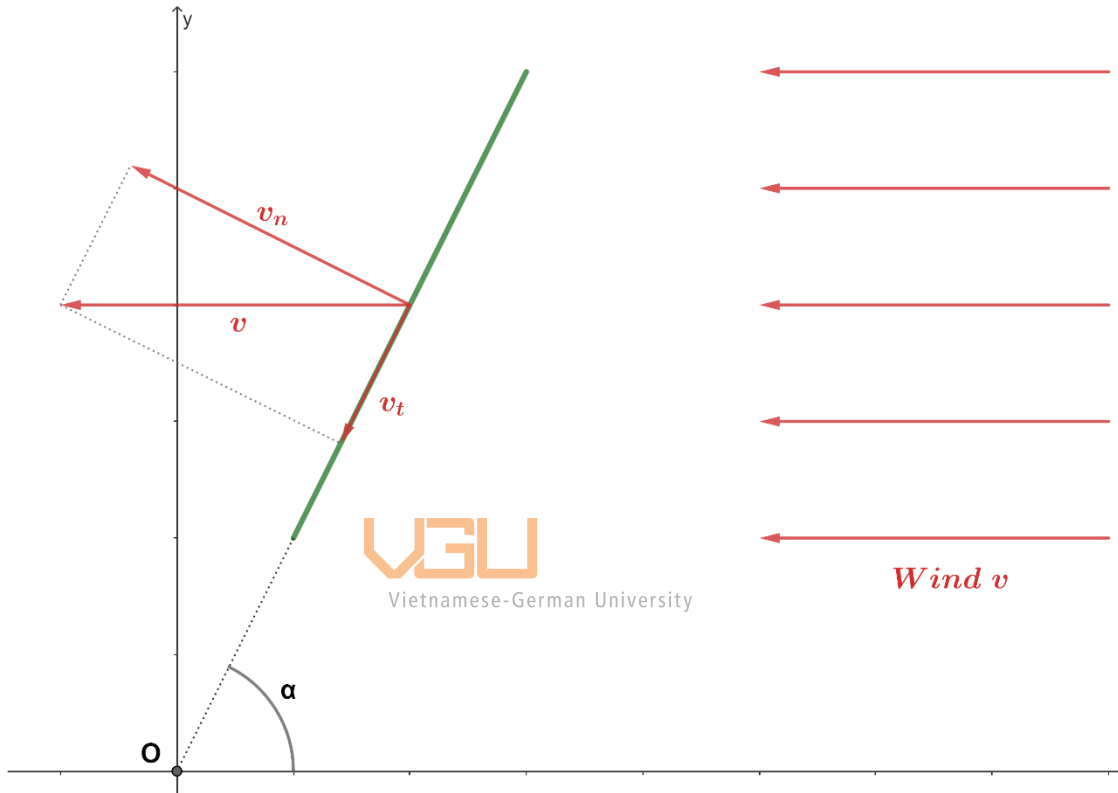
$$F = p_d A = \frac{1}{2} \rho v A, \text{ where } p_d \text{ is dynamic pressure and } v \text{ is wind speed.} \quad (2.1)$$

Note that the above wind speed  $v$  is applicable only for object whose surface is put perpendicular to the wind surface. As a matter of fact, the moving turbine blade's angle varies from 0 to 180 degrees with respect to the wind direction. Therefore, the resultant wind velocity vector is resolved into two perpendicular components: one parallel to the blade spanwise and the other is orthogonal to the blade plane. The parallel component contributes no effect on the blade and therefore is left out of the calculation:

$$v_t = v \cos \alpha \quad (2.2)$$

The normal wind component  $v_n$  at an arbitrary angle  $\alpha$  is taken into consideration, together with geometric arrangement as in *Figure 2.3*, yields:

$$v_n = v \sin \alpha \quad (2.3)$$



**Figure 2.3:** Wind force velocity components

The force acting on the turbine blade is then expressed as:

$$F = p_d A = \frac{1}{2} \rho v_n^2 A \quad (2.4)$$

*Figure 2.4* is served for the calculation of the turbine torque of the mentioned blade. All details in consideration are illustrated and may be described as:  $O$  is the center shaft,  $OE$  is equal to the rotation radius  $r$ ,  $T$  is an arbitrary point. The orientation of the blade is aligned with axis- $l$ ,  $E$  represents the origin of axis- $l$ , distance between  $E$  and  $T$  is  $l$ .  $D$  is the intersection point between the axis- $l$  and the circle. Semi-

rotating characteristics yield that by constructing in such a way that the blade rotates about origin  $O$  has an angular velocity that is twice as much as the blade rotates around the fixed point  $D$  [10].

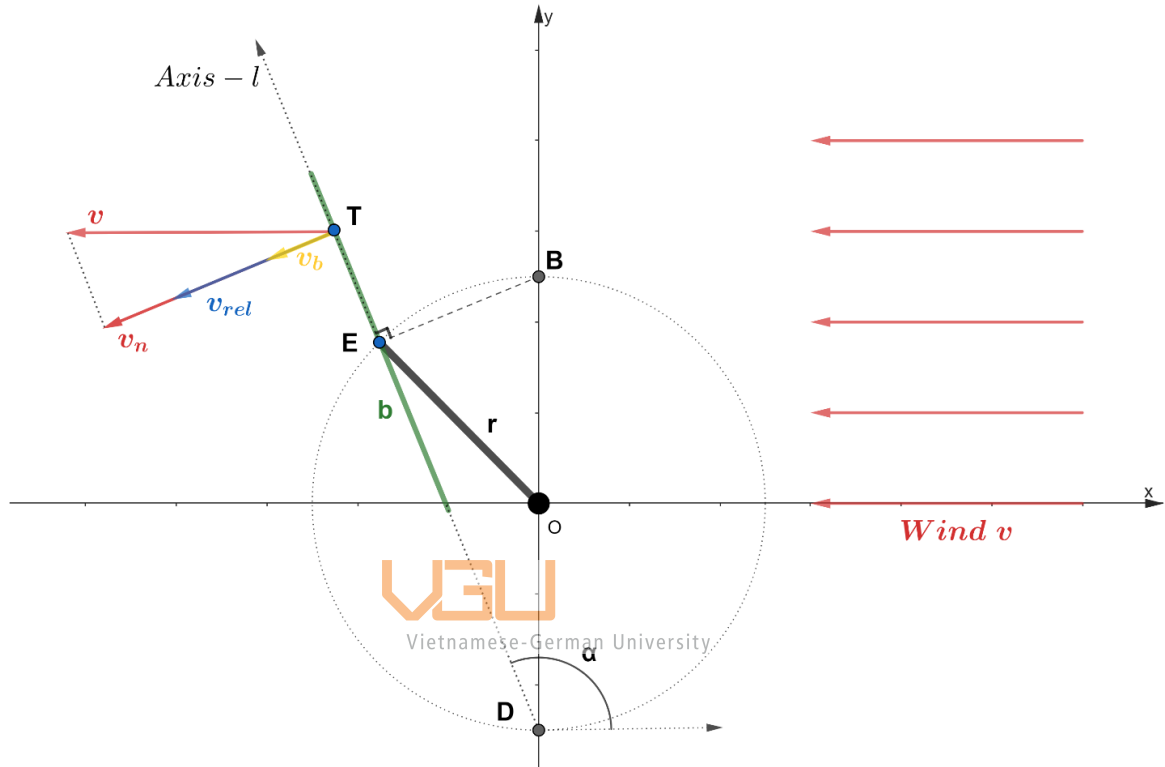


Figure 2.4: Top view construction to calculate the turbine torque (a)

Let the blade width is  $b$ , blade's angular velocity is  $\omega$ . Speed of point  $T$  in normal direction with respect to the blade can be expressed as:

$$v_b = \frac{\omega}{2} \times DT = \frac{\omega}{2} \times \left[ 2r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] \quad (2.5)$$

Where,

$$DT = DE + ET = 2r \cos\left(\alpha - \frac{\pi}{2}\right) + l \quad (2.6)$$

This is achieved based on the geometric characteristic: the triangle  $BDE$  has a right angle at  $E$ . Therefore,

$$DE = DB \cos\left(\alpha - \frac{\pi}{2}\right) = 2r \cos\left(\alpha - \frac{\pi}{2}\right) \quad (2.7)$$

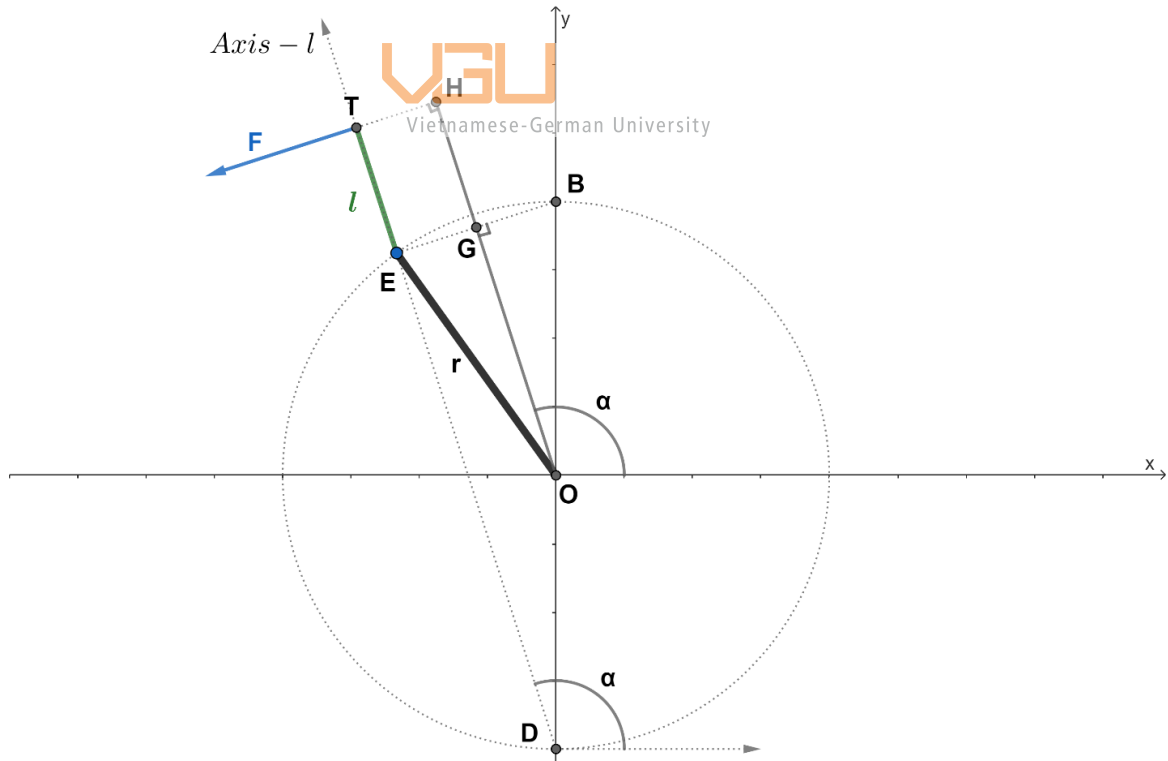
At the blade's normal direction, the relative velocity of the wind is:

$$v_{rel} = v_n - v_b \quad (2.8)$$

From (2.4), the force acting on point  $T$  is then expressed as:

$$F = \frac{1}{2} \rho A \left\{ v \sin \alpha - \frac{\omega}{2} x \left[ 2r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] \right\}^2 \quad (2.9)$$

Torque is defined as the product of the magnitude of the perpendicular component of the force vector and the length of the moment arm.



**Figure 2.5:** Top view construction to calculate the turbine torque (b)

Figure 2.5 shows that the torque arm is the line  $OH$  which is perpendicular to the direction of force vector  $F$ . By geometry,  $OH$  yields:

$$OH = OG + HG = OB \cos\left(\alpha - \frac{\pi}{2}\right) + ET = r \cos\left(\alpha - \frac{\pi}{2}\right) + l \quad (2.10)$$

Together with (2.9), the torque that the wind turbine gained at any point  $T$  can be calculated as:

$$dT = \frac{1}{2} \rho h \left\{ v \sin \alpha - \frac{\varpi}{2} \times \left[ 2r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] \right\}^2 \times \left[ r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] dl \quad (2.11)$$

where  $h$  is the height of the blade.

The average blade torque when the blade revolves a full revolution now can be expressed as:

$$\bar{T} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \int_{-\frac{b}{2}}^{\frac{b}{2}} \frac{1}{2} \rho h \left\{ v \sin \alpha - \frac{\varpi}{2} \times \left[ 2r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] \right\}^2 \times \left[ r \cos\left(\alpha - \frac{\pi}{2}\right) + l \right] dl d\alpha \quad (2.12)$$

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$$\bar{T} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \frac{1}{2} \rho h \left[ rb(v - r\omega)^2 \cos^2\left(\alpha - \frac{\pi}{2}\right) + \frac{b^3}{12} \left( \frac{5r\omega^2}{4} - v\omega \right) \right] \cos\left(\alpha - \frac{\pi}{2}\right) d\alpha \quad (2.13)$$

$$\bar{T} = \frac{2\rho hrb}{3\pi} (v - r\omega)^2 + \underbrace{\frac{\rho h b^3}{12\pi} \left( \frac{5r\omega^2}{4} - v\omega \right)}_{\text{ignorable}} \quad (2.14)$$

The latter section of the summation is relatively small and thus, can be eliminated from the calculation [11]. Equation (2.14) can be reduced into:

$$\bar{T} = \frac{2\rho hrb}{3\pi} (v - r\omega)^2 \quad (2.15)$$

Assuming that the influence of the blades on each other can be ignored due to small values, then the total torque of three blades is:

$$\bar{T}_{total} = 3\bar{T} = \frac{2\rho r h b}{\pi} (v - r\omega)^2, \text{ with } \omega < \frac{v}{r} \quad (2.16)$$

So, the power of the wind turbine is:

$$P = \bar{T}_{total} \times \omega = \frac{2\rho r h b}{\pi} (v - r\omega)^2 \omega \quad (2.17)$$

## 2.2. MECHANICAL DESIGN OF PARTS AND COMPONENTS

The design of wind turbine consists of three main parts: turbine base (I), turbine upper part (II) and turbine lower part (III). These 3 parts would be designed and assembled separately to be comprehensive, then they would be assembled together in the final. Below are the components of this wind turbine.

No.	Turbine parts	Quantity	Material
1	Base disc	1	Steel
2	Base arm	2	Steel
3	Base arm drill	1	Steel
4	Base lower hexagon	1	Steel
5	Base upper hexagon	1	Steel
6	Stepper motor Nema 17 mount	1	Steel
7	Worm of worm gear system	1	Copper
8	Gear of worm gear system	1	Aluminum
9	Turbine center and control shaft	1	Steel
10	Encoder mounting bar	1	PMMA clear
11	Encoder V2	1	Standard
12	M6 x 25mm stainless steel bolt	3	Standard
13	M6 stainless steel nut	9	Standard
14	6901-2RS Ball Bearing 12x24x6mm	2	Standard
15	M4 x 15mm stainless steel bolt	8	Standard

16	M4 stainless steel nut	8	Standard
17	M3 x 6mm stainless steel bolt	4	Standard
18	Stepper motor Nema 17	1	Standard
19	Turbine blade	3	PE foam
20	Arm of turbine	3	PMMA clear
21	Sun spur gear with 15 teeth	1	PMMA clear
22	Planet spur gear with 30 teeth	3	PMMA clear
23	Bearing and arm fixing on shaft	3	PVC
24	Arm support	3	PVC
25	Upper blade mounting shaft	3	ABS
26	Lower blade mounting shaft	3	ABS
27	Blade mounting shaft fixing	3	PVC
28	Turbine upper shaft	1	PVC
29	Arm seal bearing	18	PMMA clear
30	Planet spur gear fixing	3	PVC
31	6801-2RS Ball Bearing 12x21x5mm	12	Standard
32	M3 x 15mm stainless steel bolt	4	Standard
33	M3 stainless steel nut	4	Standard
34	Turbine lower shaft	1	PVC
35	Encoder disc	1	PMMA black
36	Copper ring 12x16x2mm	3	Copper
37	Shaft fixing ring	8	Steel
38	Screw Stainless Steel A2 Socket Head Hexagon Recess Hexagon Socket 2 M4X5 Cone Point	11	Standard

**Table 2.1:** List of components of the Semi-rotating Three-blade VAWT

### 2.2.1. MECHANICAL DESIGN OF TURBINE BASE (I)

To make the wind turbine stand stable in the wind flow, the design of it has to have a large base and low center of gravity. Thus, the turbine base is made mainly from steel and has a large base disc.

2.2.1.1. Base disc

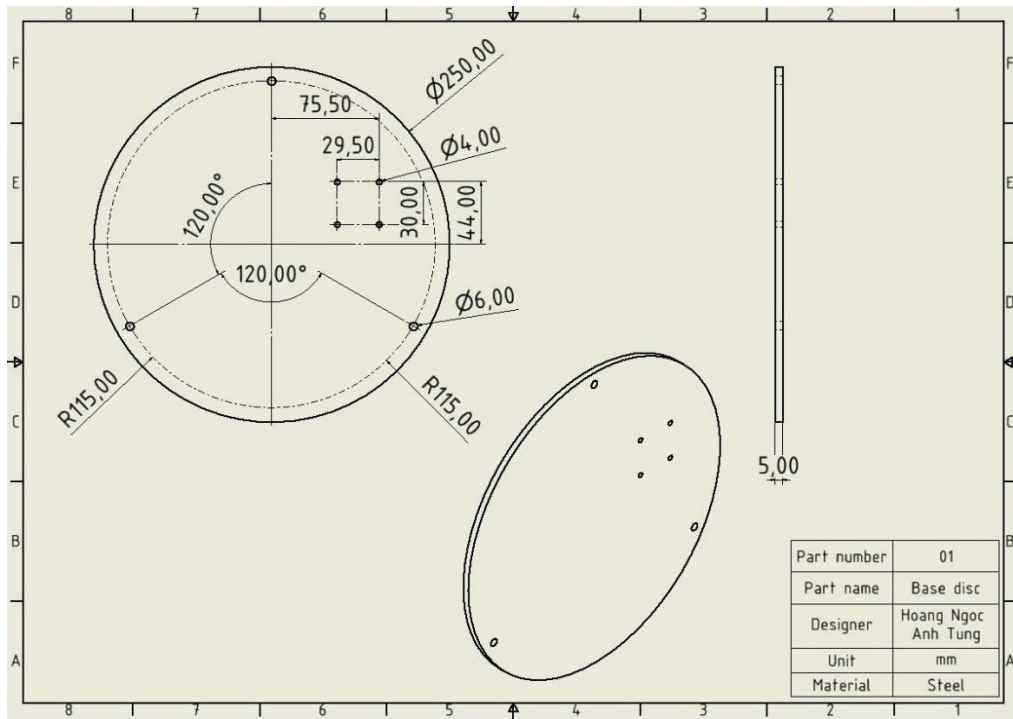


Figure 2.6: Part 01-Base disc



2.2.1.2. Base arm

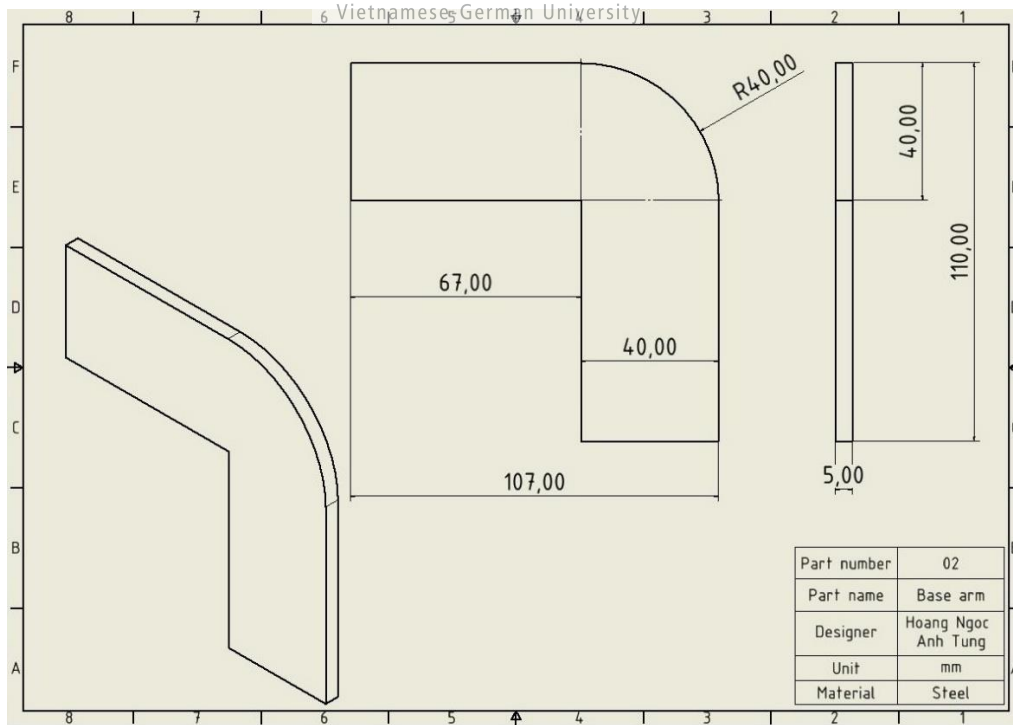


Figure 2.7: Part 02-Base arm



2.2.1.3. Base arm drill

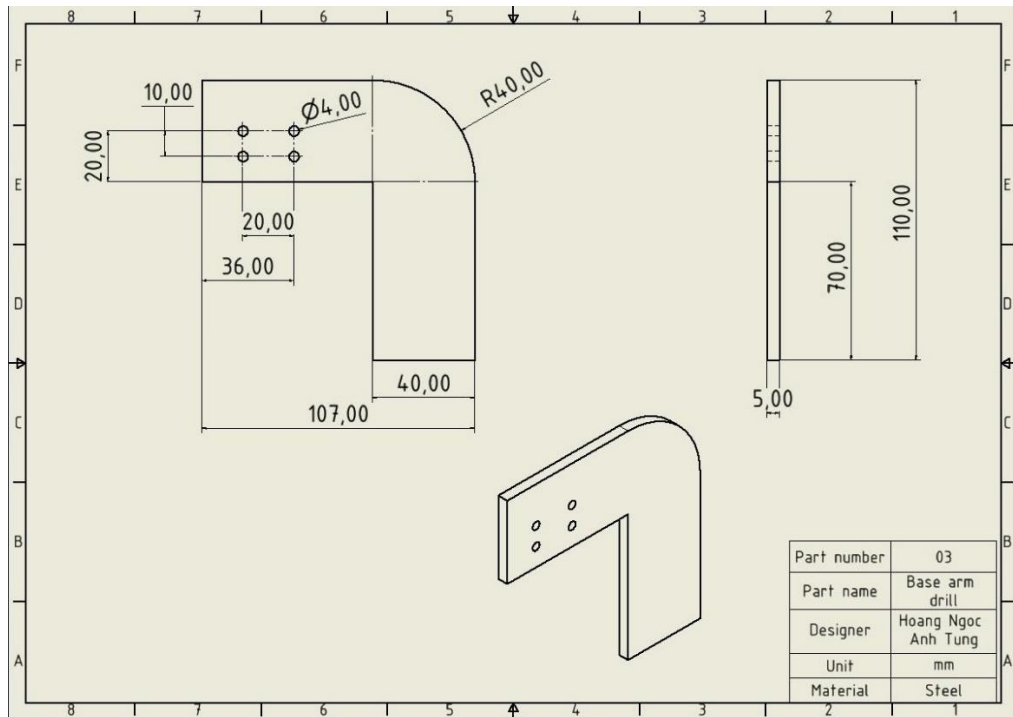


Figure 2.8: Part 03-Base arm drill



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2.2.1.4. Base lower hexagon

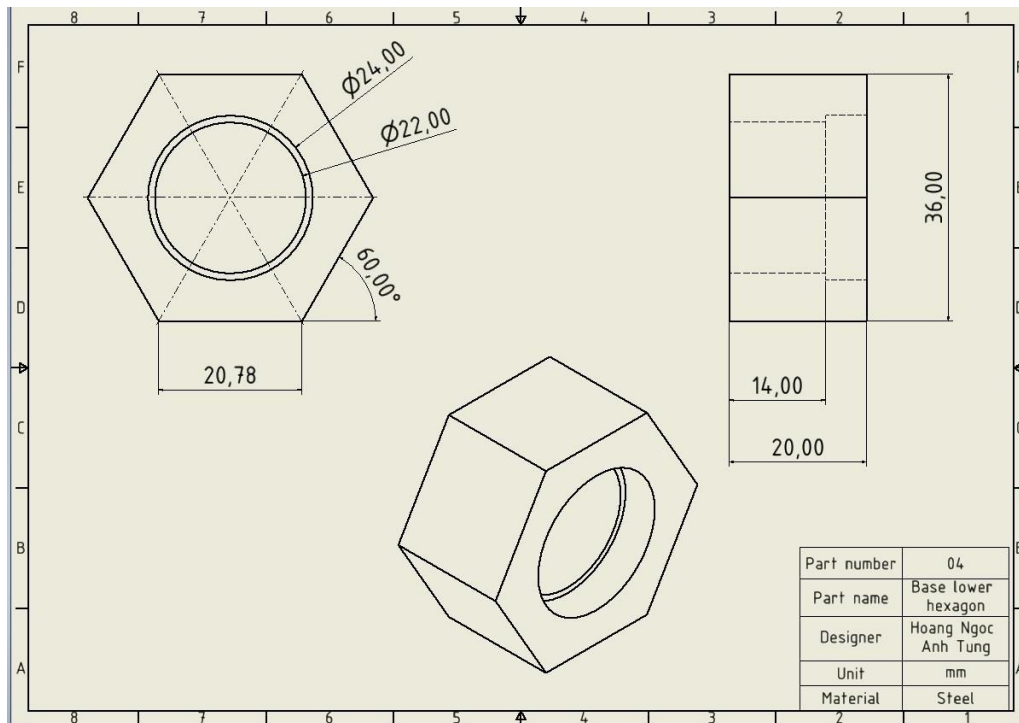


Figure 2.9: Part 04-Base lower hexagon

### 2.2.1.5. Base upper hexagon

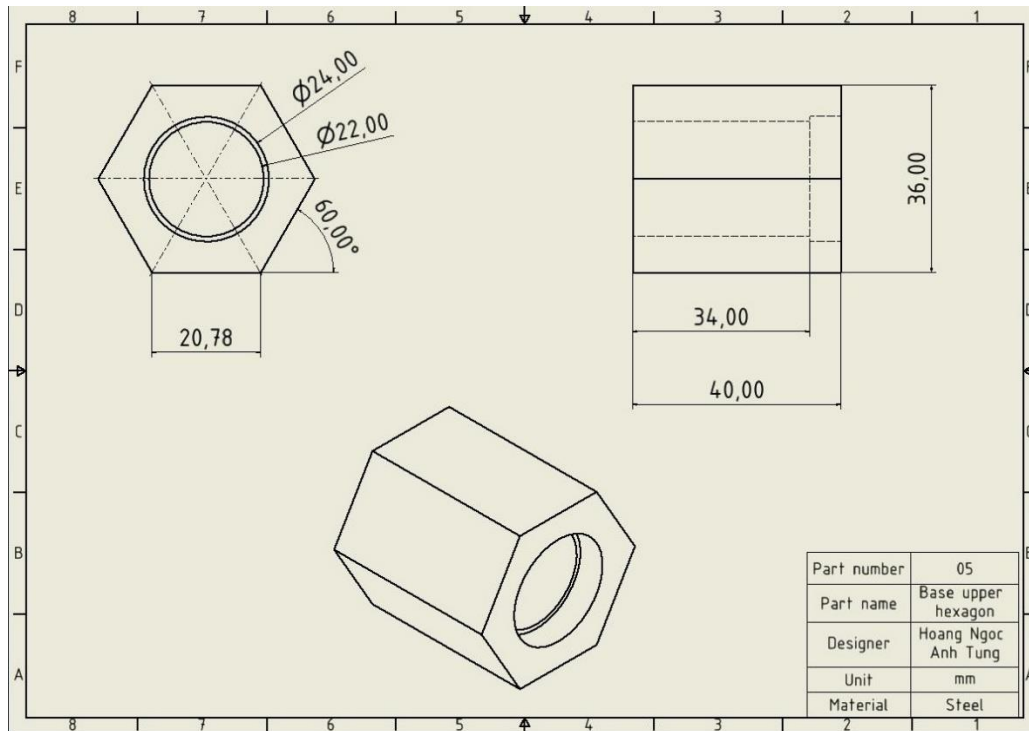


Figure 2.10: Part 05-Base upper hexagon



### 2.2.1.6. Stepper motor Nema 17 mount

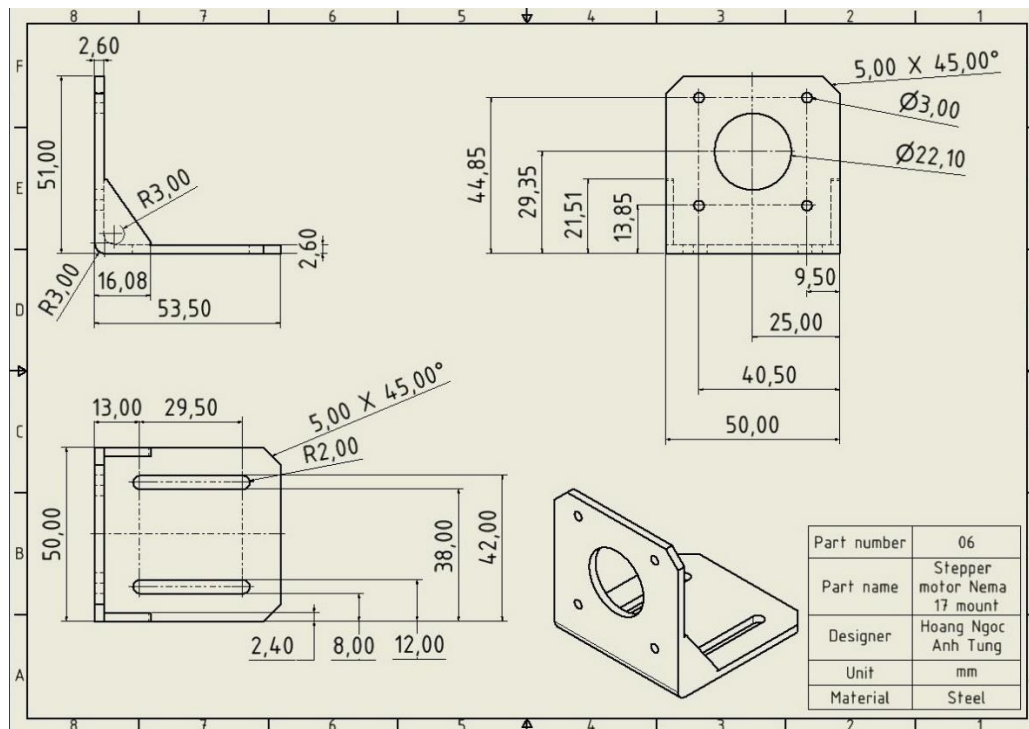


Figure 2.11: Part 06-Stepper motor Nema 17 mount

### 2.2.1.7. Worm gear system

To transmit power from the stepper motor to the center control shaft, a worm gear system is used. A worm gear system consists of a driving worm, which is a shaft with a spiral thread, and a driven gear which is like the spur gear. However, worm gear is the oldest type in one of six gear systems, it still has many advantages to use as a control system, especially in this wind turbine prototype. The most suitable feature of worm gear is the inability to reverse the direction of power [14]. Because of the worm's and gear's friction, it is impossible for the control shaft when being applied force to move the motor, hence, keep the turbine direction fixed and protect the motor.



Figure 2.12: Worm gear system

In this system, the gear has 64 teeth, so to make the gear rotate 1 full revolution, the worm has to rotate 64 revolutions. It implies that when the motor rotates 1 revolution, the gear will rotate 1 tooth or  $5.625^\circ$ . Below are the designs of gear and worm:

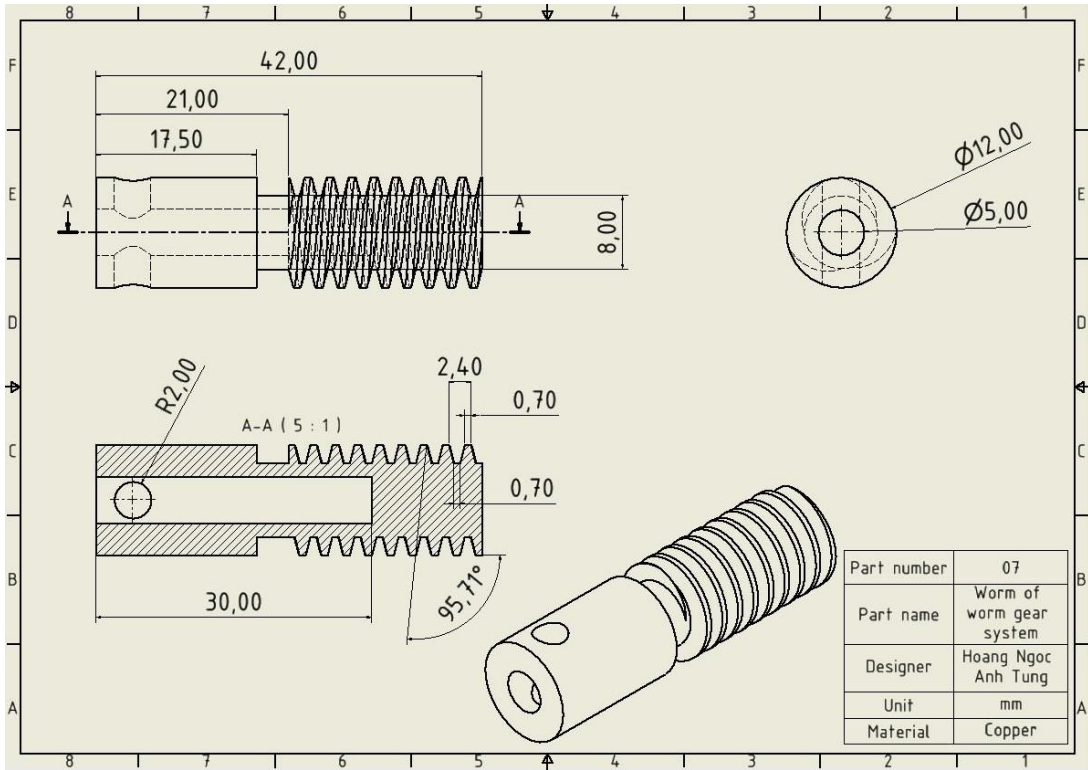


Figure 2.13: Part 07-Worm of worm gear system

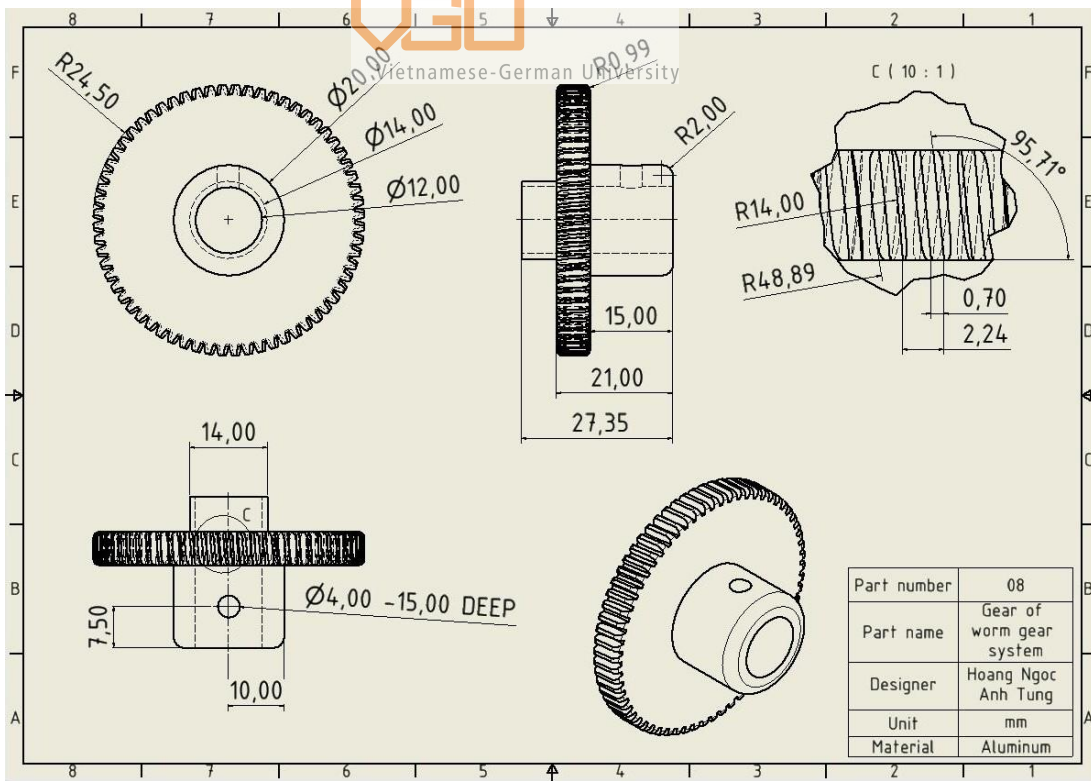


Figure 2.14: Part 08-Gear with 64 teeth of worm gear system

2.2.1.8. Turbine center and control shaft

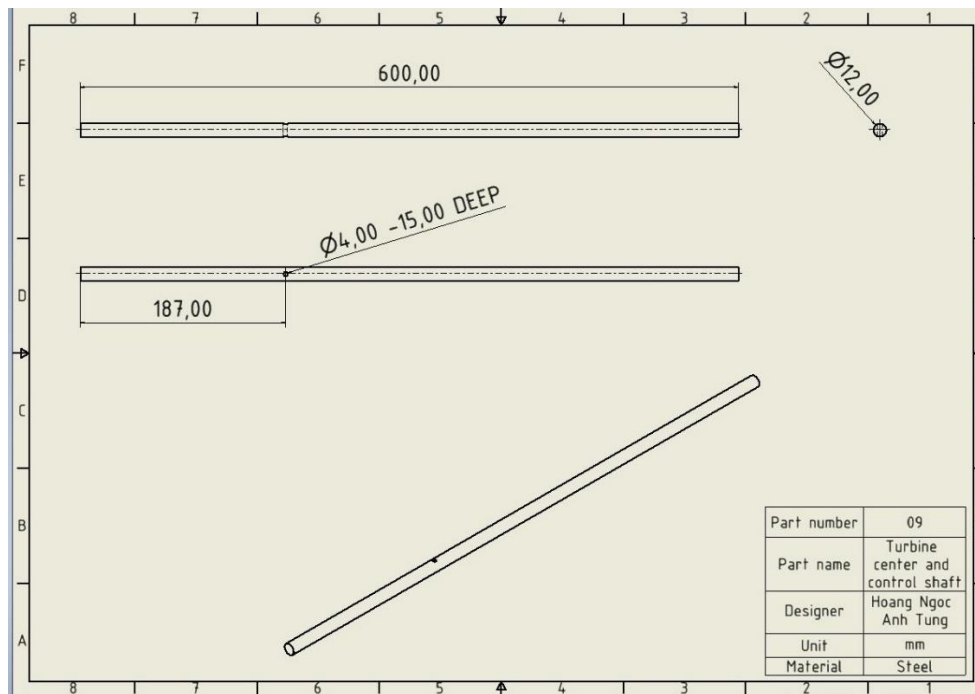


Figure 2.15: Part 09-Turbine center and control shaft



2.2.1.9. Encoder V2 mounting bar

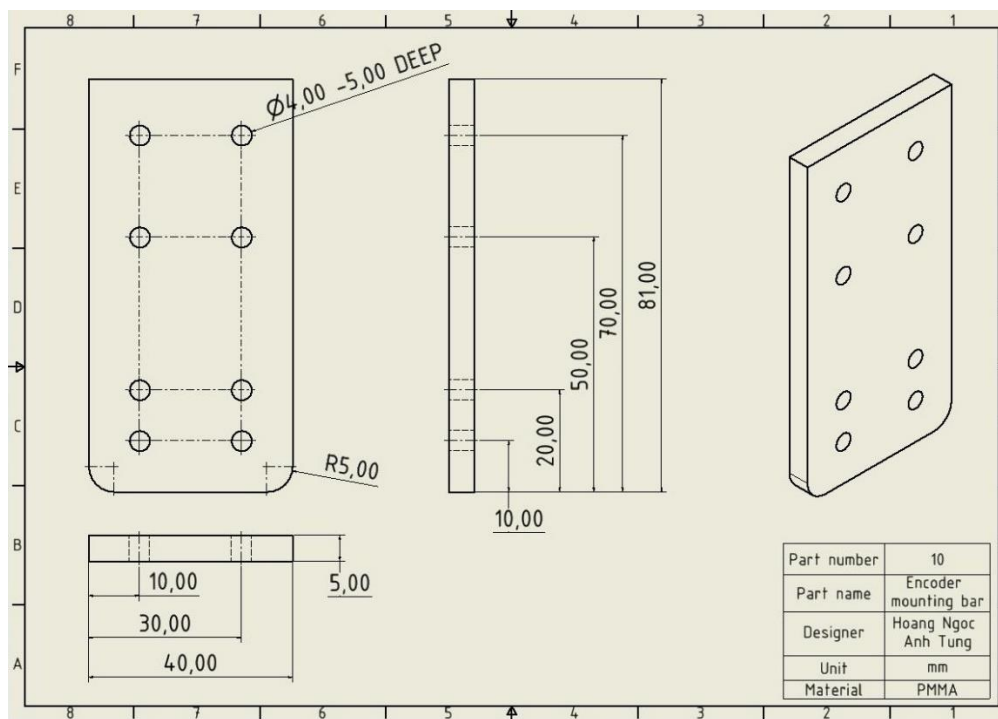


Figure 2.16: Part 10-Encoder V2 mounting bar

2.2.1.10. Assembly the turbine base

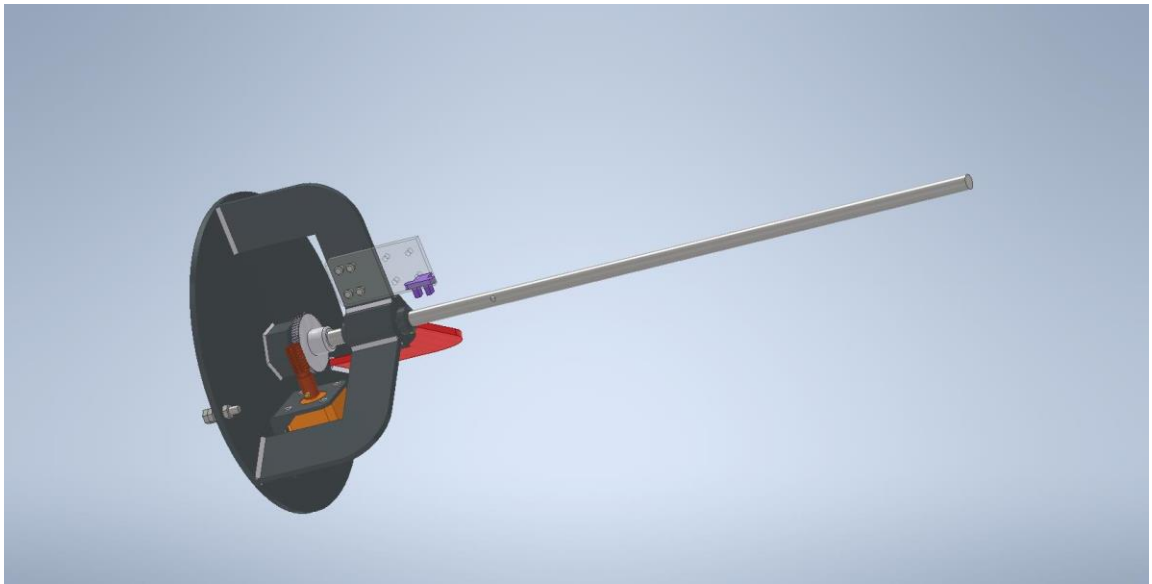


Figure 2.17(a): Assembly the turbine base

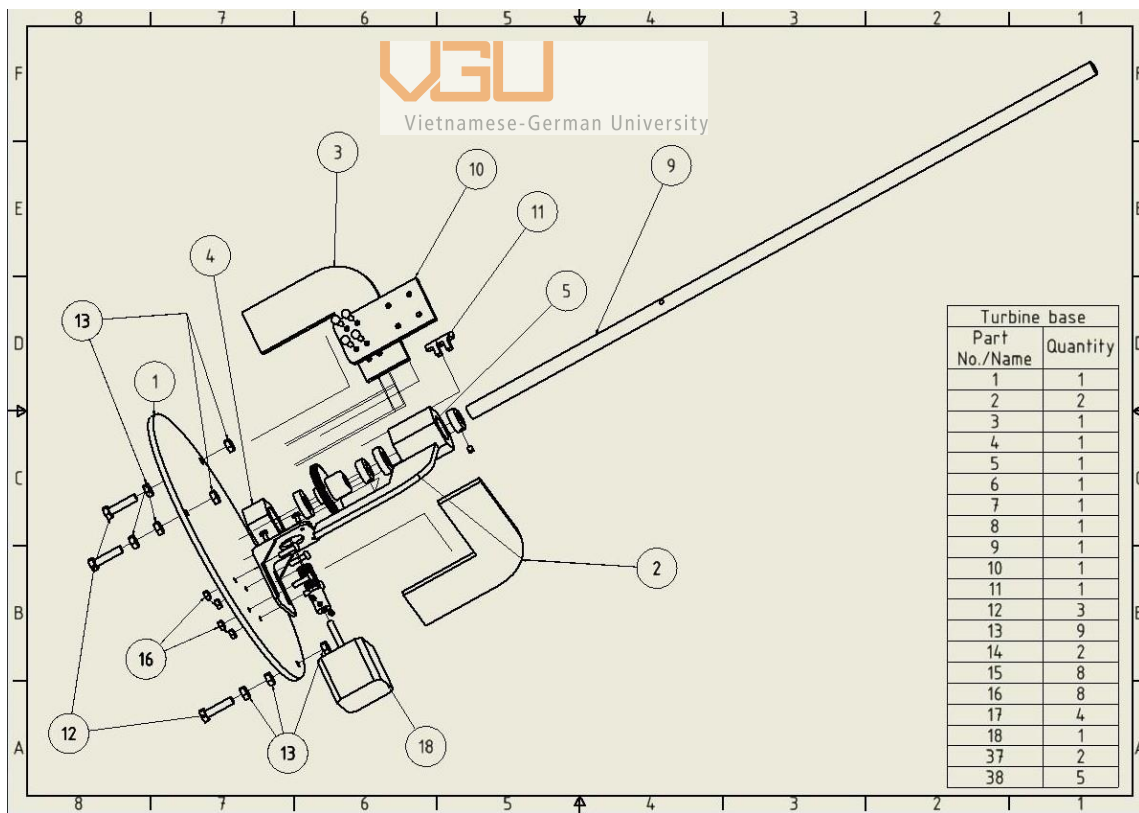


Figure 2.17(b): Assembly the turbine base presentation 1

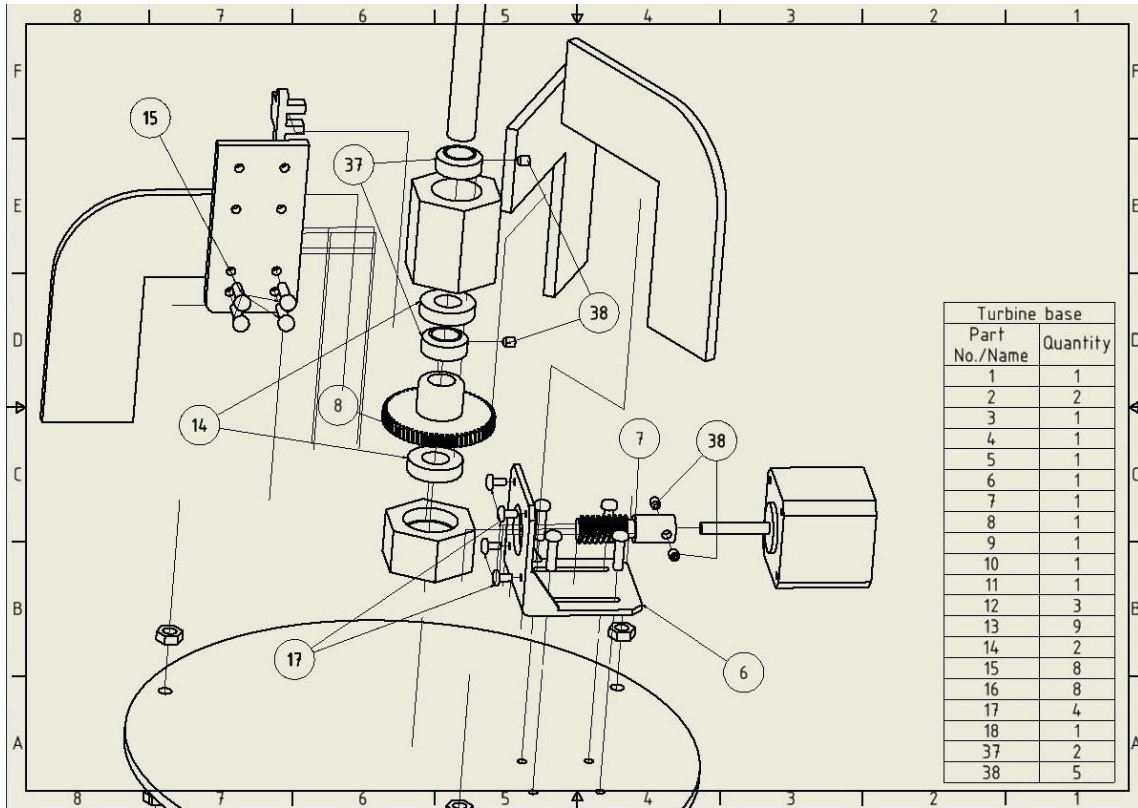


Figure 2.17(c): Assembly the turbine base presentation 2

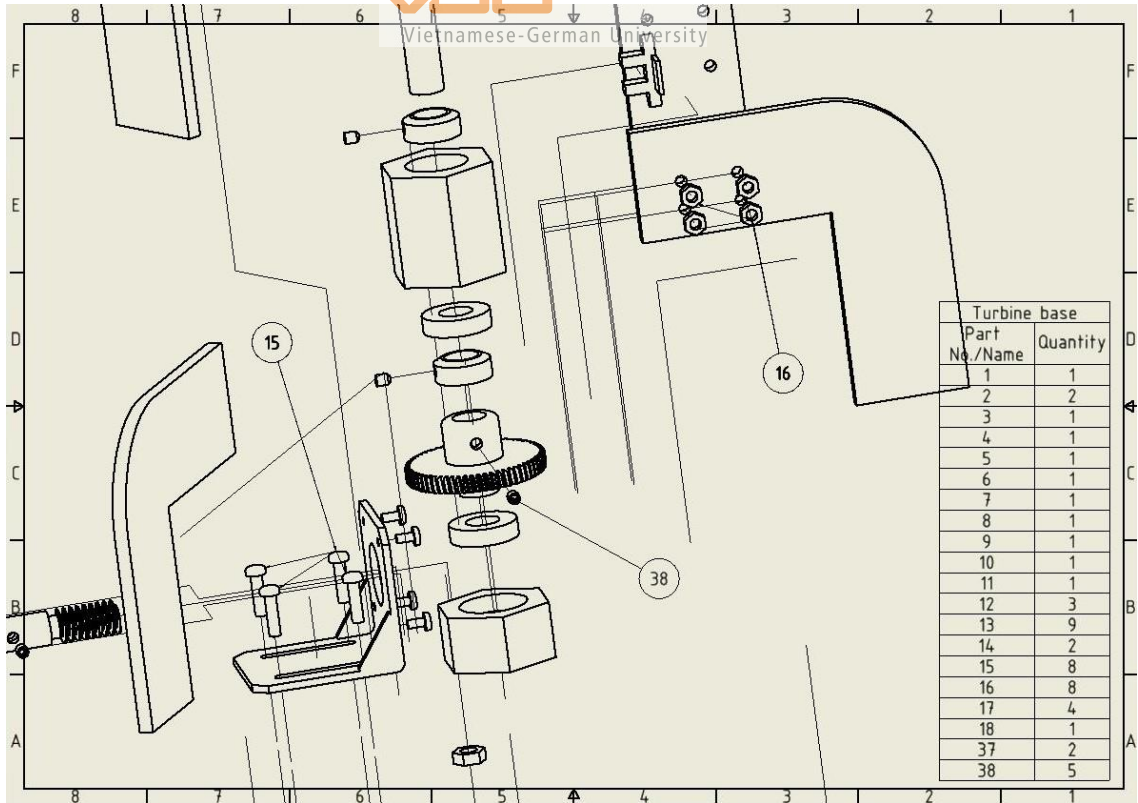


Figure 2.17(d): Assembly the turbine base presentation 3

### 2.2.2. MECHANICAL DESIGN OF TURBINE UPPER PART (II)

Apart from the base, almost others part of the turbine is made from many kinds of plastic such as PVC, Polymethylmethacrylate, and PE foam. The main reason plastic used to make this turbine is similar at the industrial wind turbine. Plastic is the strong, but light weight material, when turbine blade making from plastic, it can spin with faster speed, hence increase the total efficient [15].

#### 2.2.2.1. Turbine blade

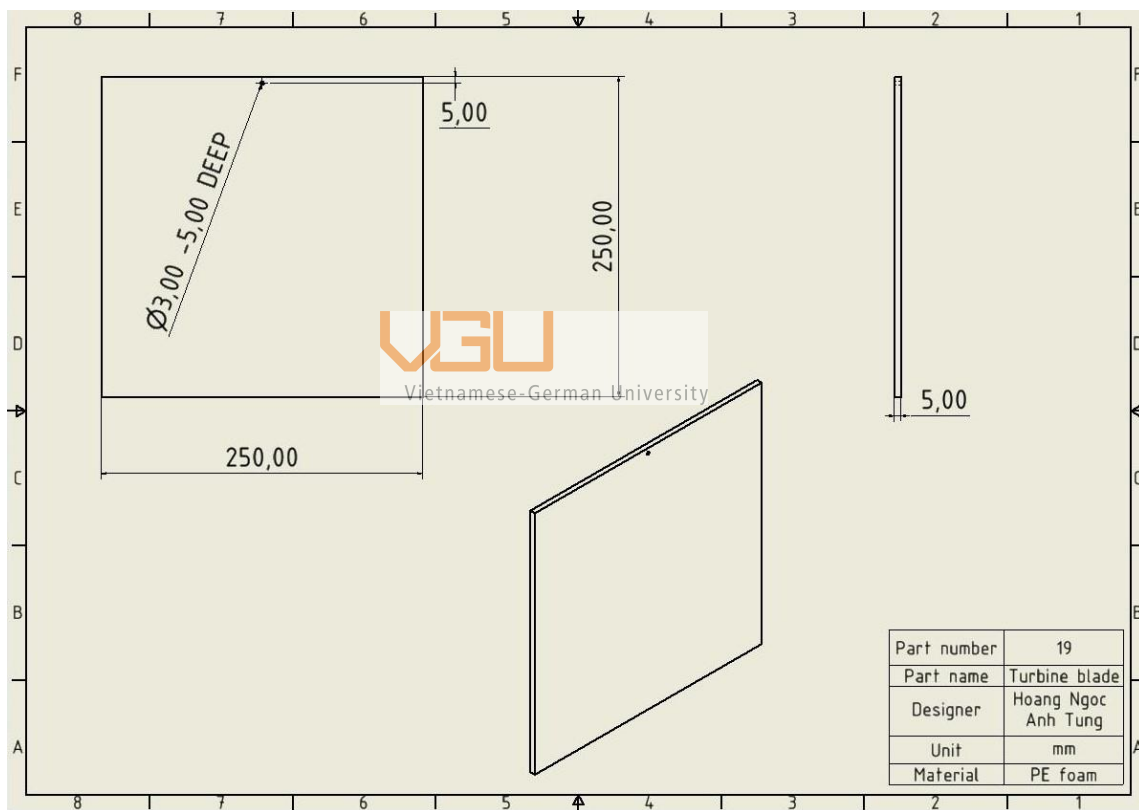


Figure 2.18: Part 19-Turbine blade



### 2.2.2.2. Arm of turbine

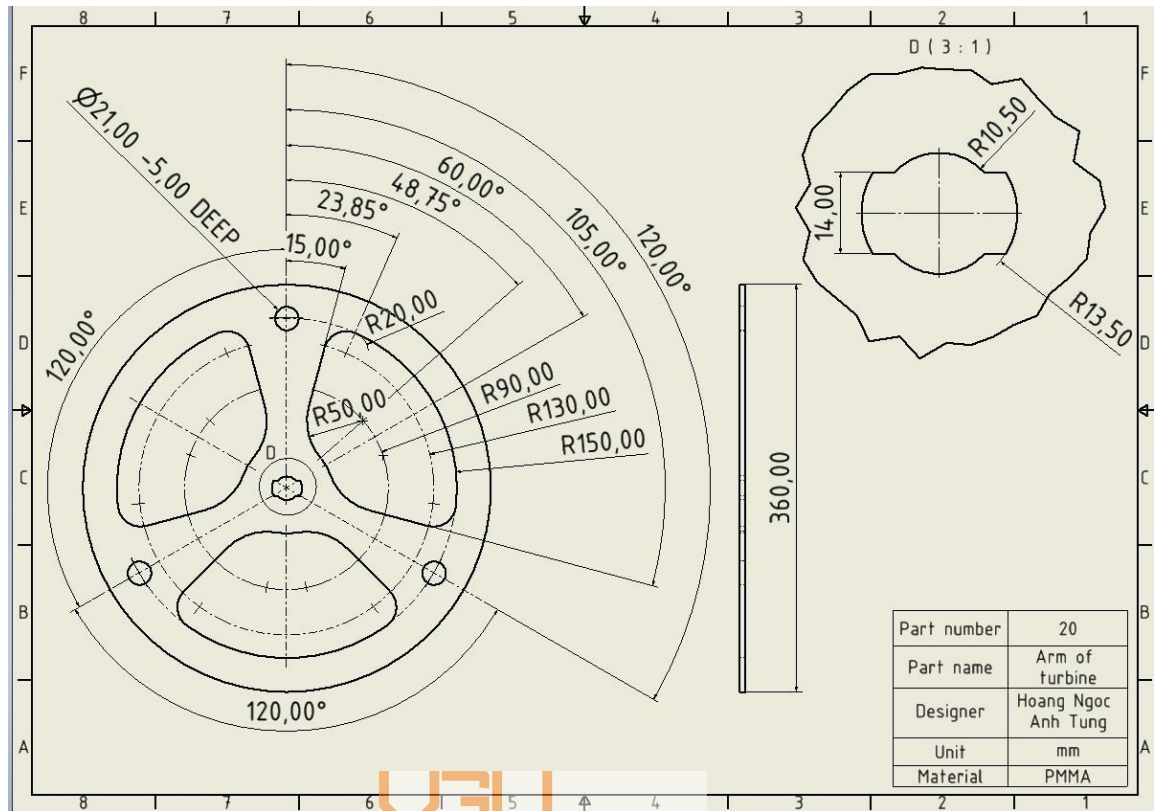


Figure 2.19: Part 20-Arm of turbine  
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### 2.2.2.3. Spur gear system

A spur gear system similar to the planetary spur gear system is accounted for making the blades rotate relatively to the wind turbine, the system consists of one small sun gear at the center fixing to control shaft and 3 planet gear with twice radius moving around the sun gear (Figure 2.20). This setup results in making the planet gear semi-rotating relatively with the turbine spinning.

To construct gear system, Design Accelerator of Inventor program is utilized. This function produces parts using calculations in the Engineer's Handbook in order to propose standards-based geometry. Additionally, Design Accelerator instructions automate choices and geometry development, so simplify the design process [16]. The Figure 2.21 below shows the window of design acceleration of spur gear system.

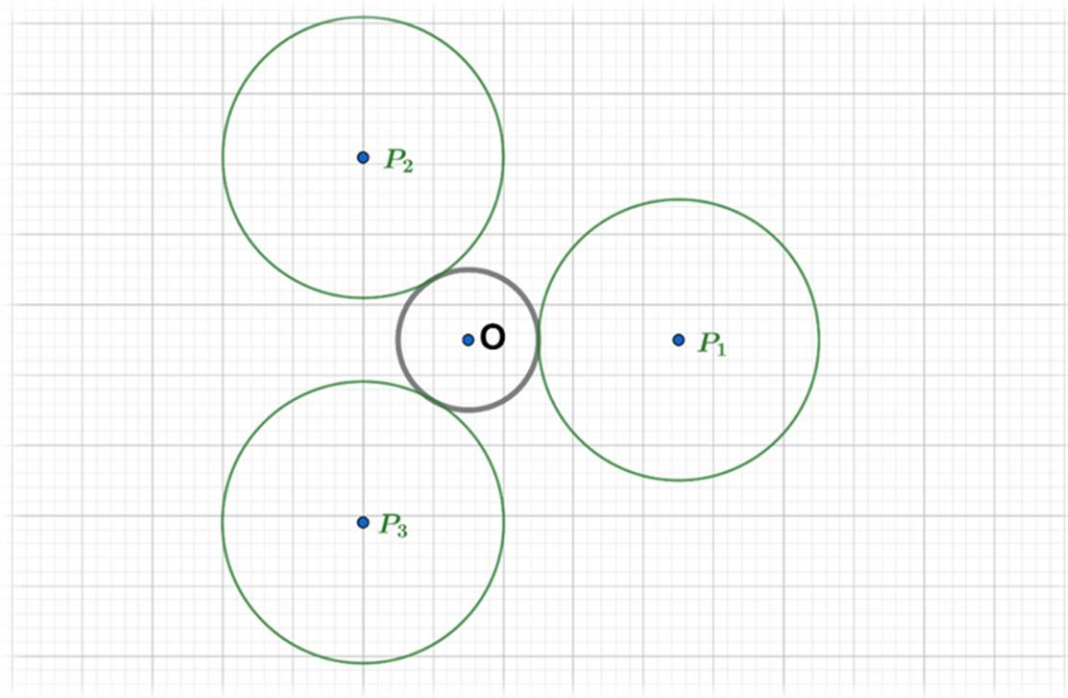


Figure 2.20: Spur gear model

Spur Gears Component Generator

Design **Calculation**

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**Common**

Design Guide: Total Unit Correction

Pressure Angle: 20.0000 deg

Helix Angle: 0.0000 deg

Desired Gear Ratio: 2.0000 ul

Unit Corrections Guide: In Gear Ratio

Module: 6.6 mm

Center Distance: 149.000 mm

Total Unit Correction: 0.0767 ul

Preview...

**Gear 1**

Component: Cylindrical Face

Number of Teeth: 15 ul

Facewidth: 10.000 mm

Unit Correction: 0.0256 ul

**Gear 2**

Component: Cylindrical Face

Number of Teeth: 30 ul

Facewidth: 7.000 mm

Unit Correction: 0.0511 ul

**Results**

i	2.0000 ul
e	1.5440 ul
<b>Gear 1</b>	
d <sub>a</sub>	112.525 mm
d	99.000 mm
d <sub>f</sub>	82.838 mm
x <sub>z</sub>	0.6290 ul
x <sub>p</sub>	0.1532 ul
x <sub>d</sub>	-0.0185 ul
s <sub>a</sub>	0.6461 ul
b <sub>r</sub>	0.0707 ul
<b>Gear 2</b>	
d <sub>a</sub>	211.862 mm

09:56:20 PM Design: Gear 1: The Unit Correction (x) is less than the Unit Correction without Undercut (x<sub>p</sub>)

09:56:20 PM Design: Numbers of teeth are commensurable - shots of the same teeth are taken relatively regularly

09:56:20 PM Design: Gear 2: The Unit Correction (x) is less than the Unit Correction without Tapering (x<sub>z</sub>)

09:56:20 PM Calculation: Calculation indicates design compliance!

Calculate OK Cancel >>

Figure 2.21: Design acceleration of Inventor

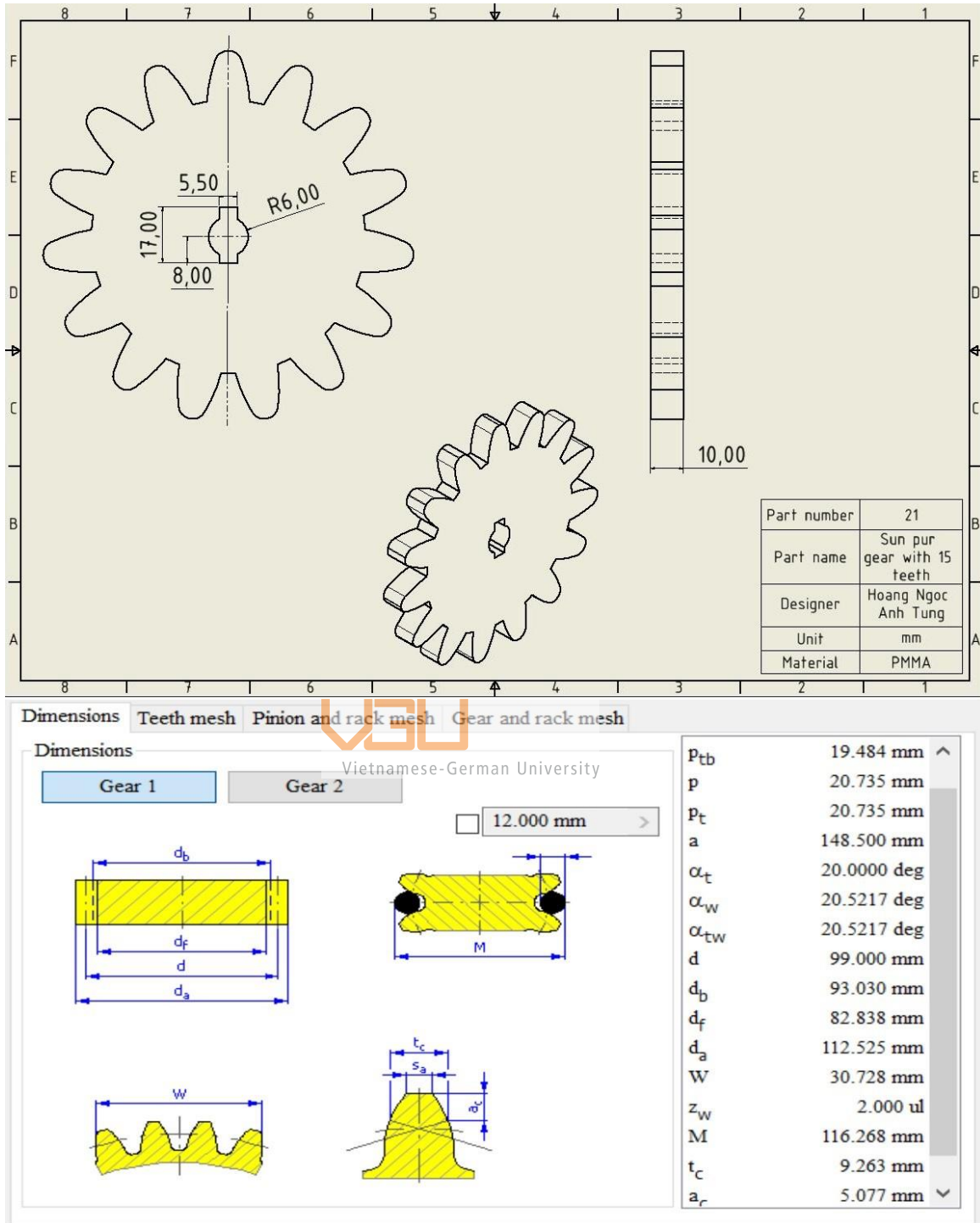


Figure 2.22: Part 21-Sun spur gear with 15 teeth

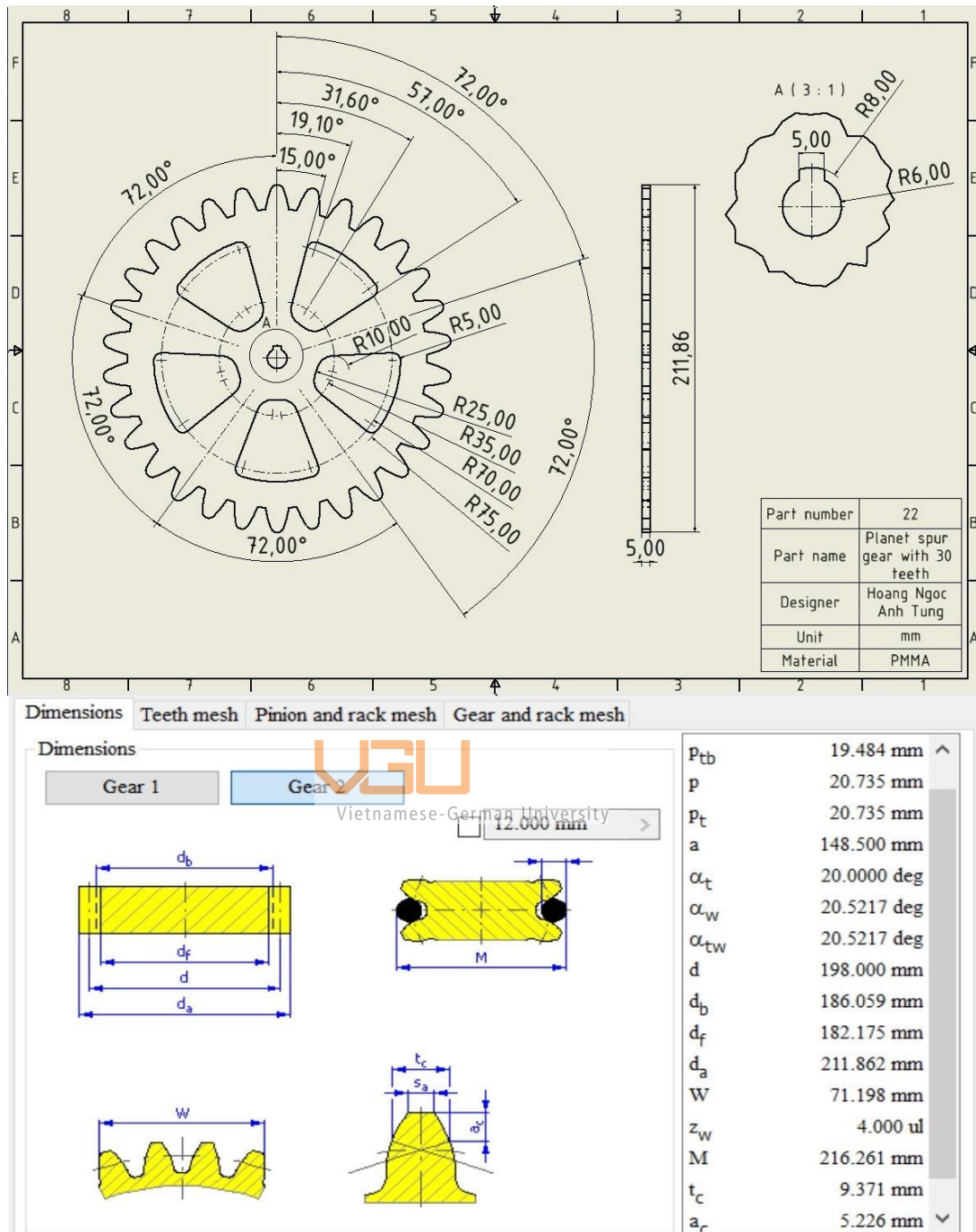


Figure 2.23: Part 22-Planet spur gear with 30 teeth

The material is chosen to make the gear and the arm is Polymethylmethacrylate (PMMA), because it has good impact resistance, outperforming both glass and polystyrene [17]. Moreover, PMMA is simple to precisely machine by laser cutting and accessible on the market. In addition, PMMA has a 92% of transparent, which is suitable for prototype as well as having clear observation when experiments.

#### 2.2.2.4. Bearing and arm fixing on shaft

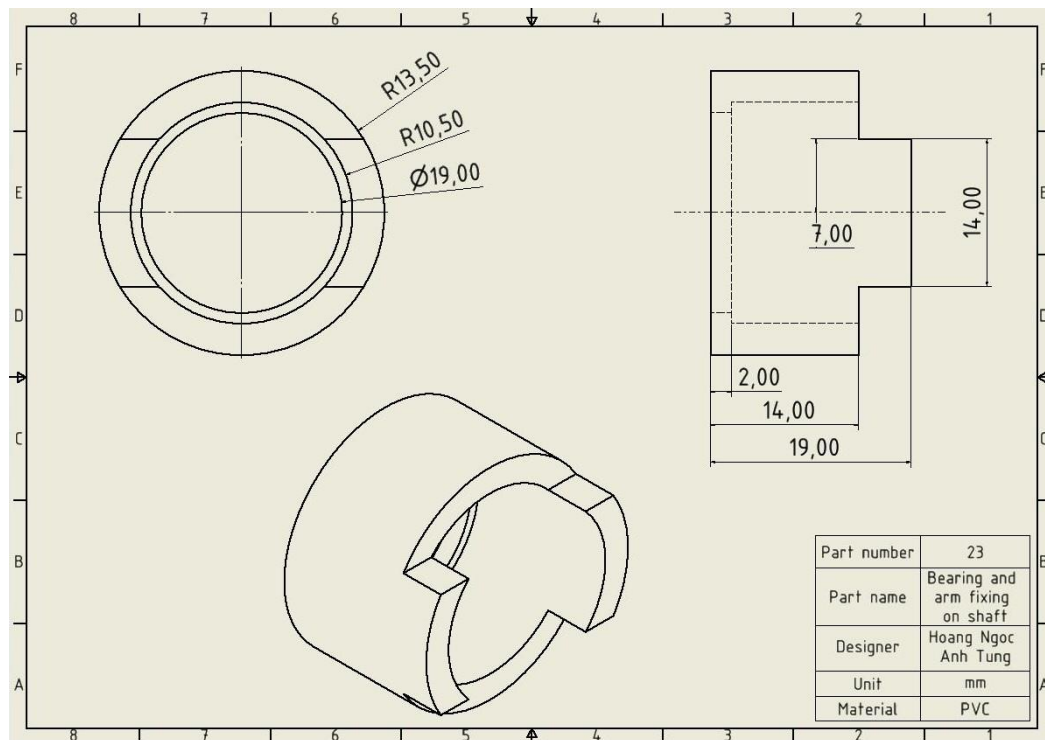


Figure 2.24: Part 23-Bearing and arm fixing on shaft



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#### 2.2.2.5. Arm support

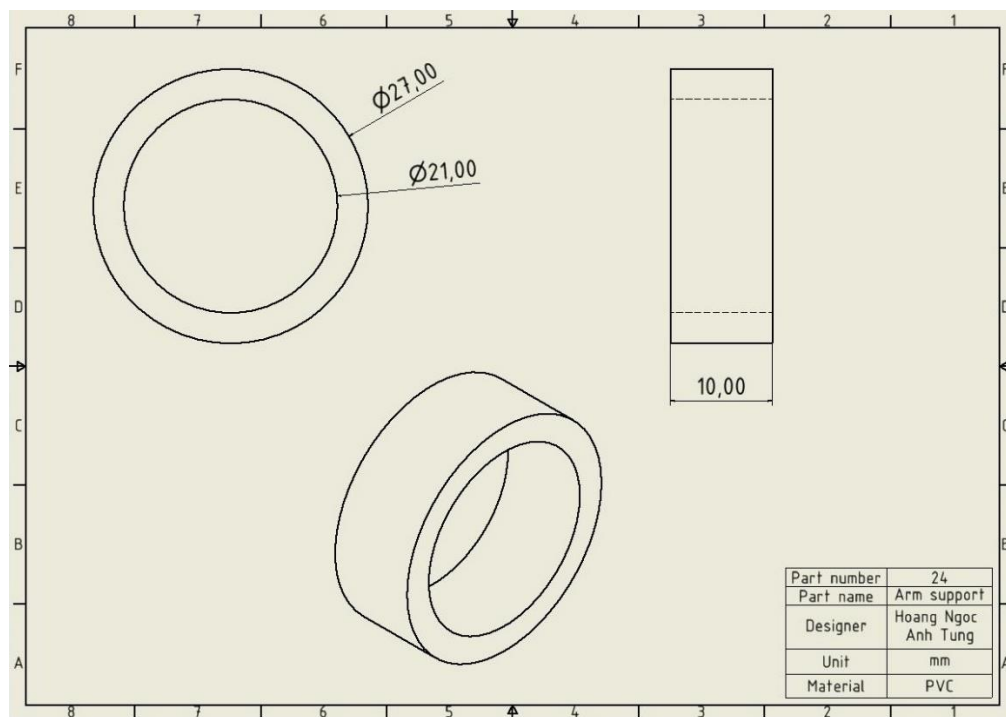


Figure 2.25: Part 24-Arm support

2.2.2.6. Upper blade mounting shaft

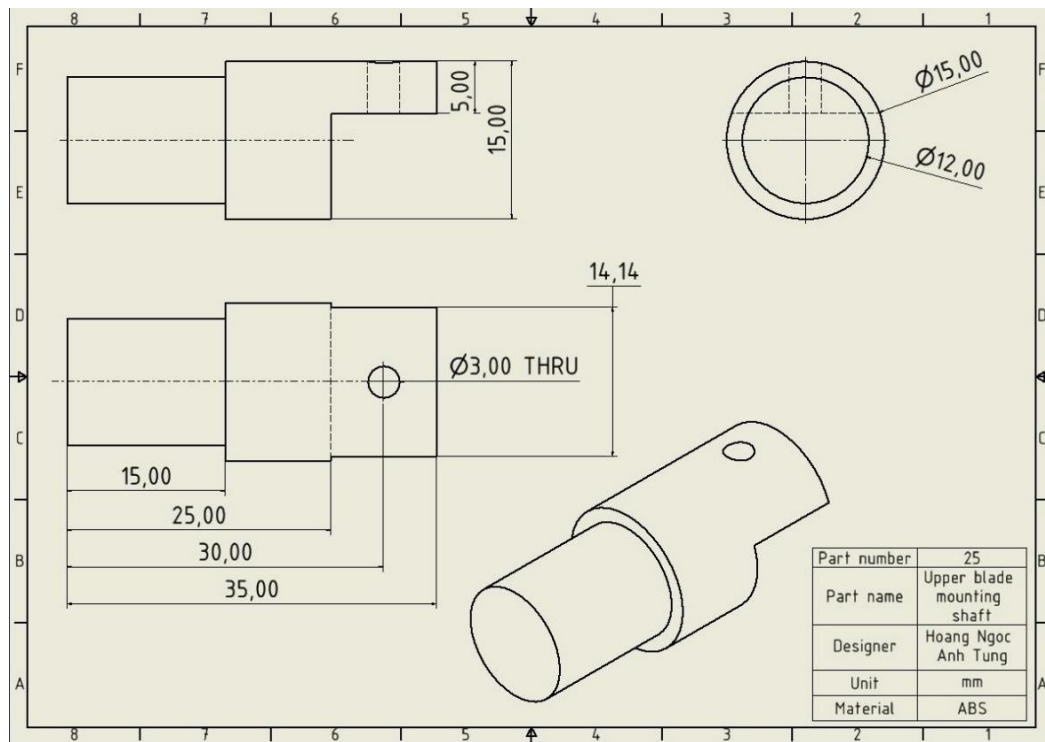


Figure 2.26: Part 25-Upper blade mounting shaft

2.2.2.7. Lower blade mounting shaft

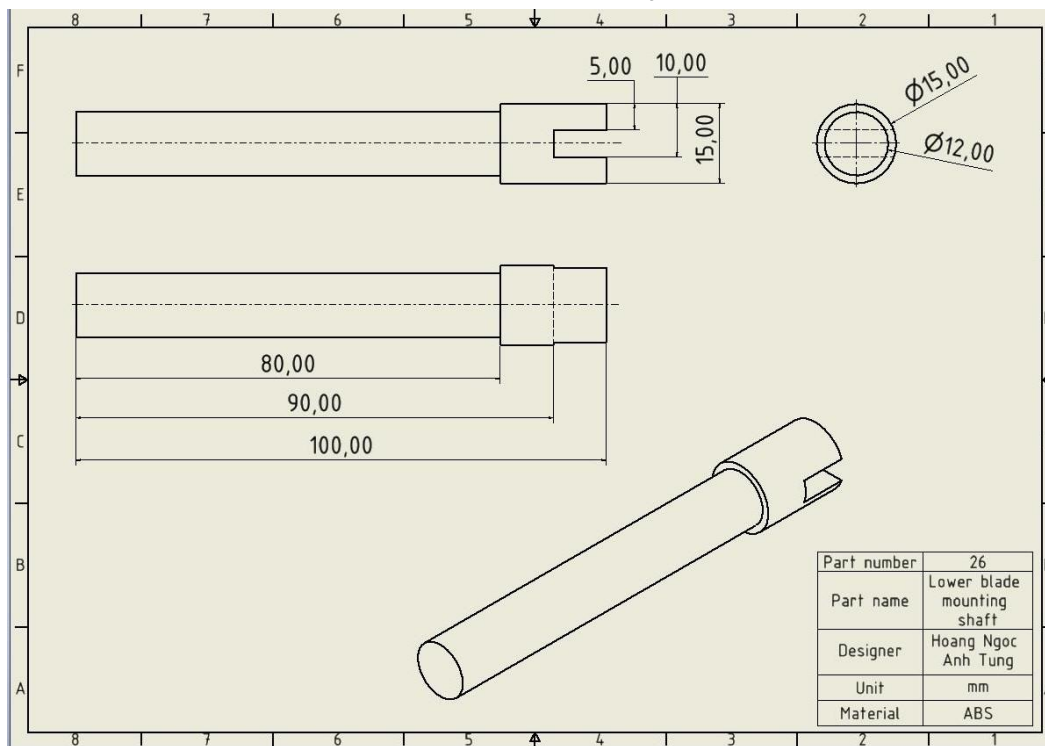


Figure 2.27: Part 26-Lower blade mounting shaft

2.2.2.8. Blade mounting shaft fixing

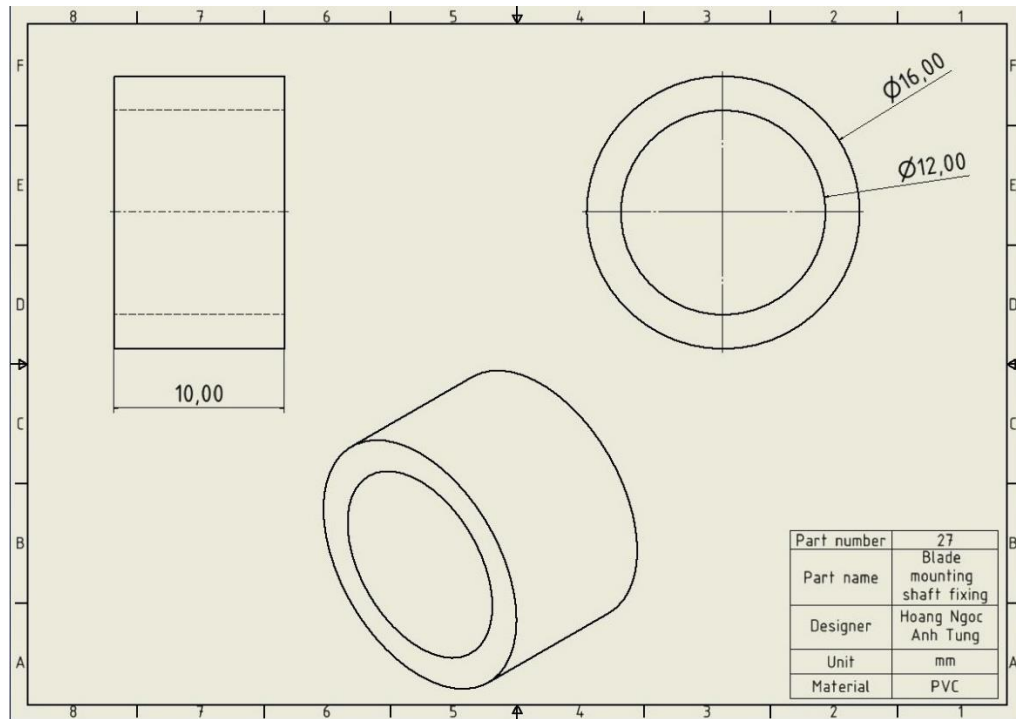


Figure 2.28: Part 27-Blade mounting shaft fixing



2.2.2.9. Turbine upper shaft

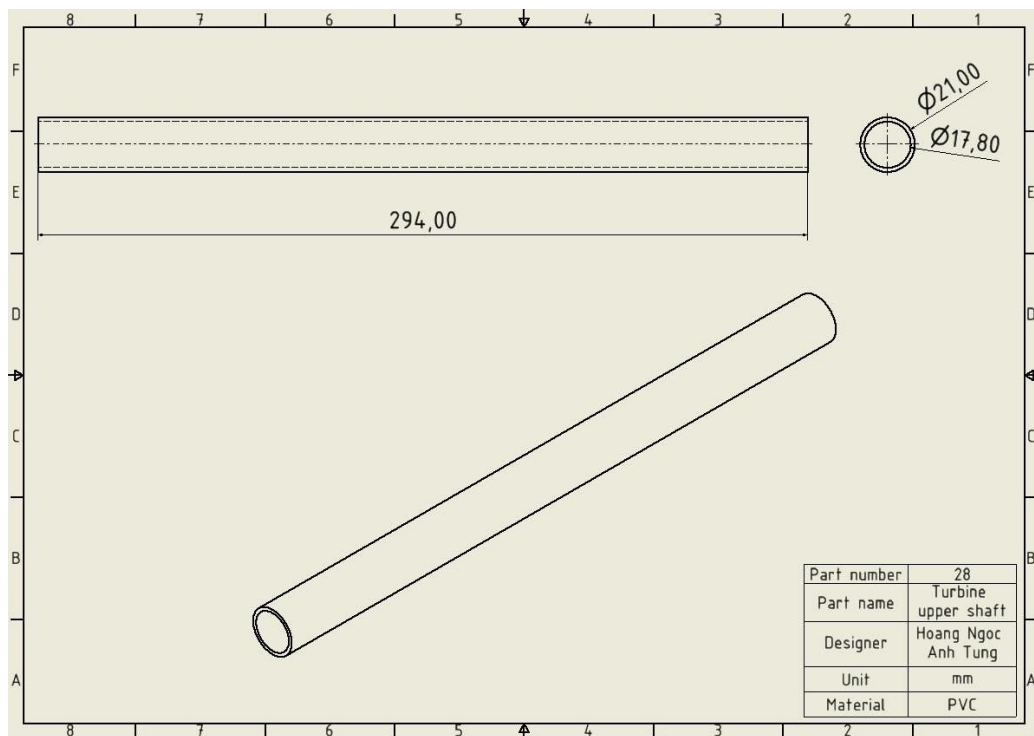


Figure 2.29: Part 28-Turbine upper shaft

2.2.2.10. Arm seal bearing

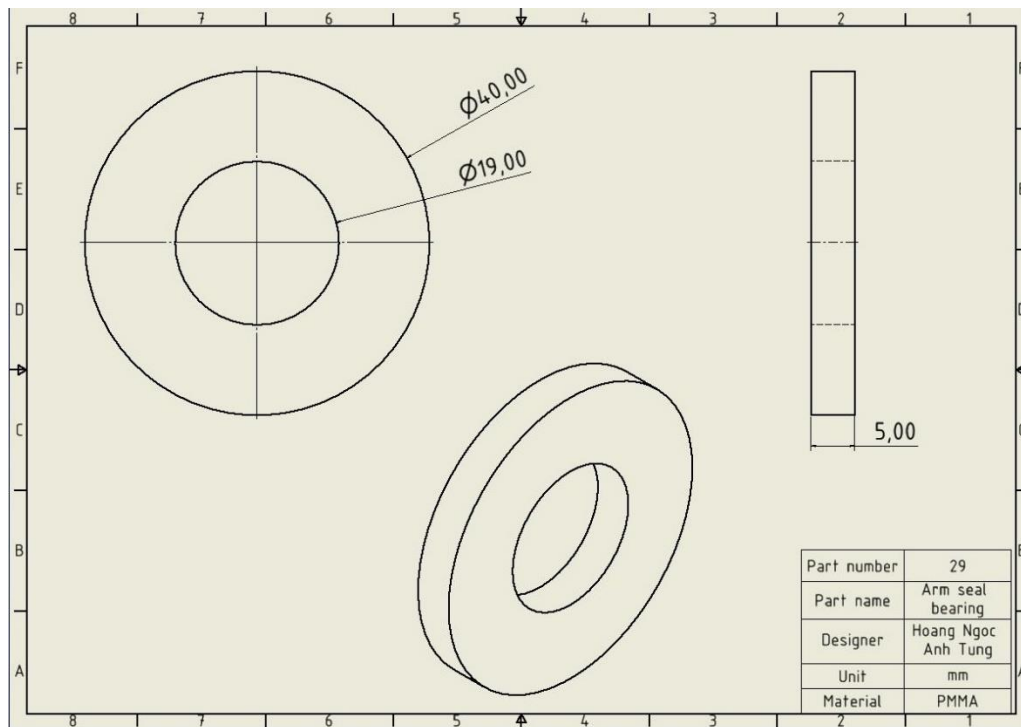


Figure 2.30: Part 29-Arm seal bearing



2.2.2.11. Planet spur gear fixing

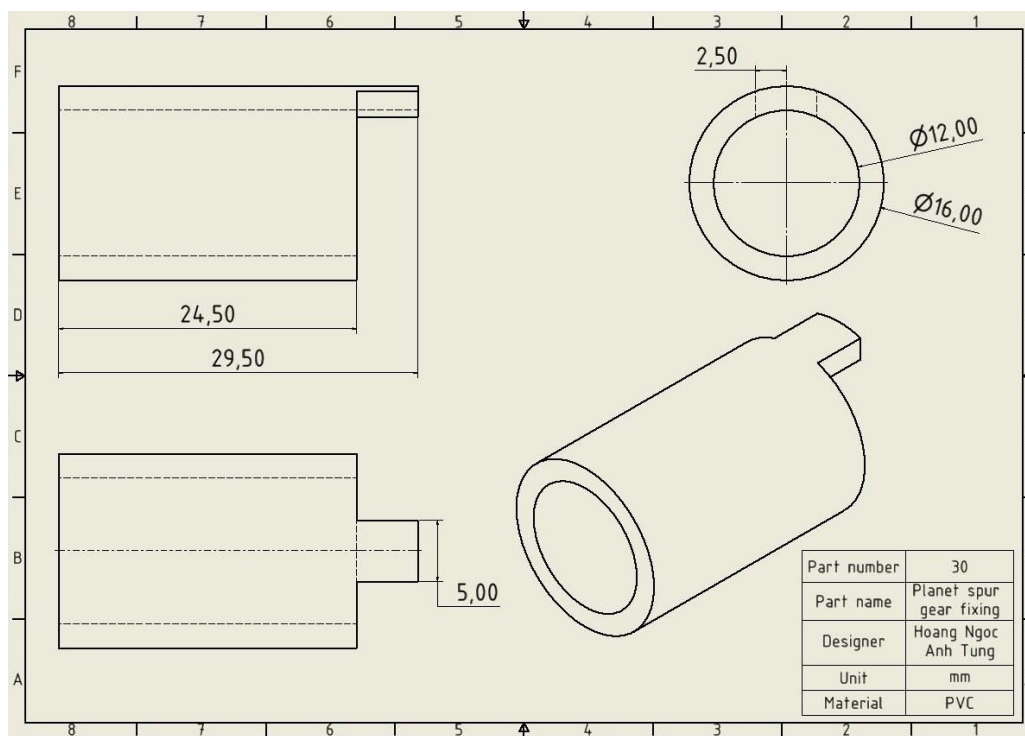
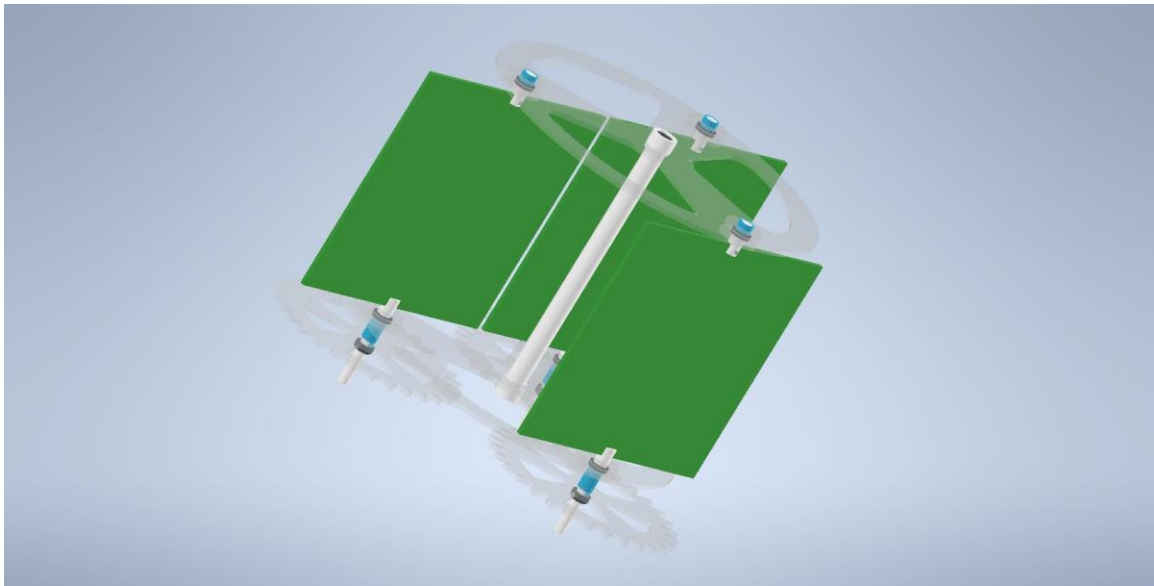


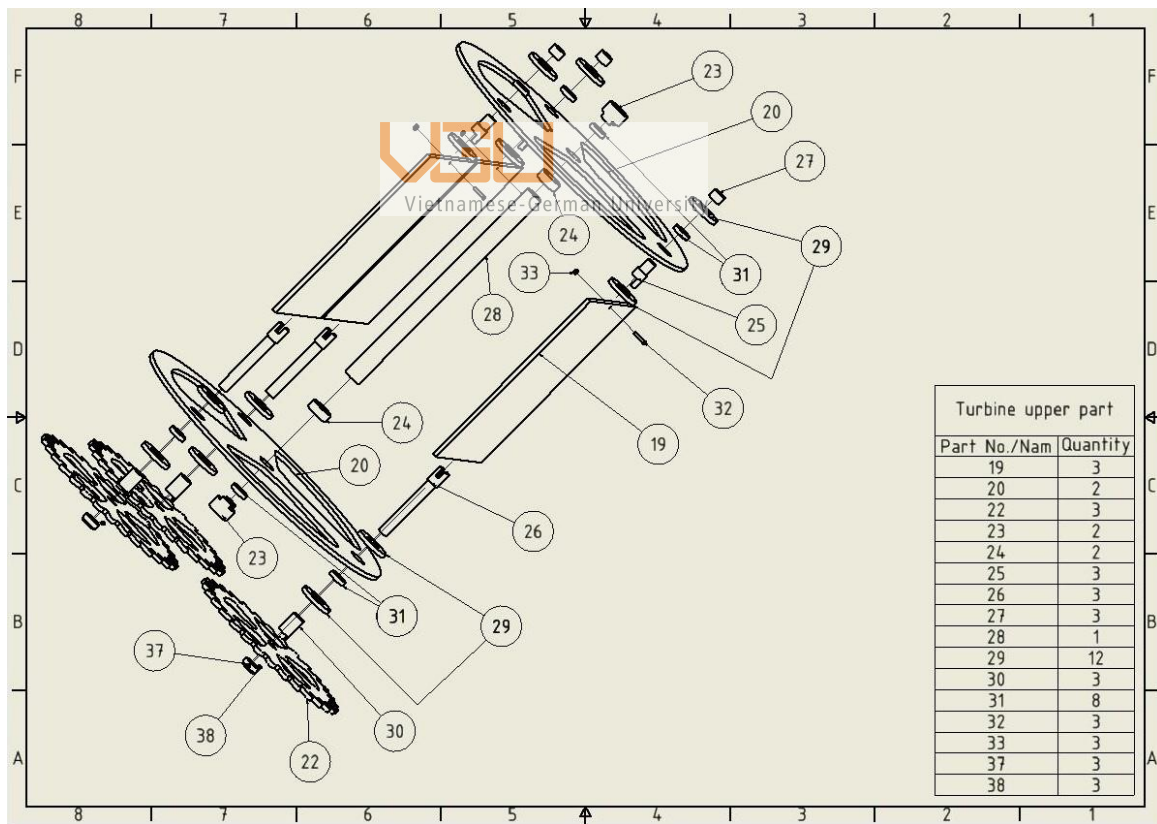
Figure 2.31: Part 30-Planet spur gear fixing



### 2.2.2.12. Turbine upper part assembly



**Figure 2.32(a):** Turbine upper part assembly



**Figure 2.32(b):** Turbine upper part assembly presentation

## 2.2.3. MECHANICAL DESIGN OF TURBINE LOWER PART (III)

### 2.2.3.1. Turbine lower shaft

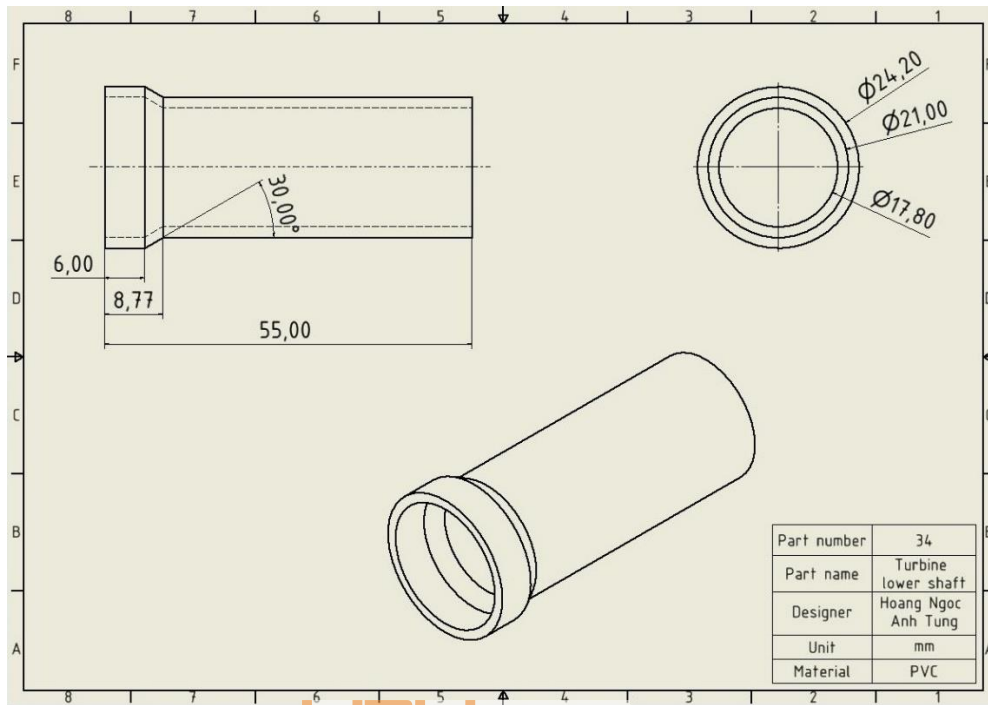


Figure 2.33: Part 34-Turbine lower shaft

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### 2.2.3.2. Encoder disc

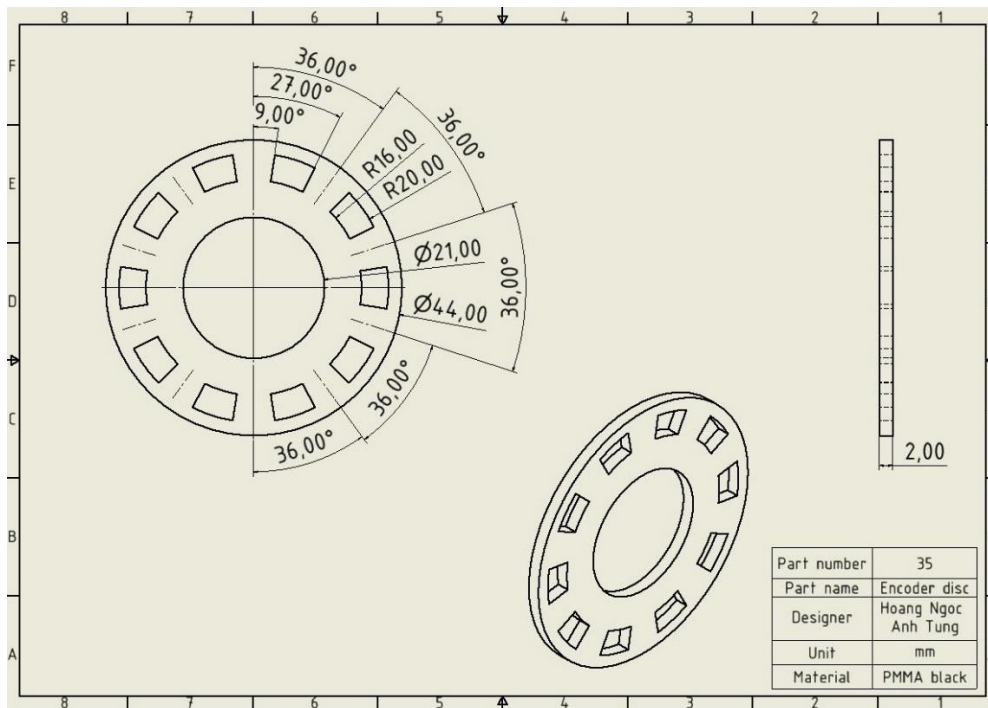


Figure 2.34: Part 35-Encoder disc

### 2.2.3.3. Turbine lower part assembly

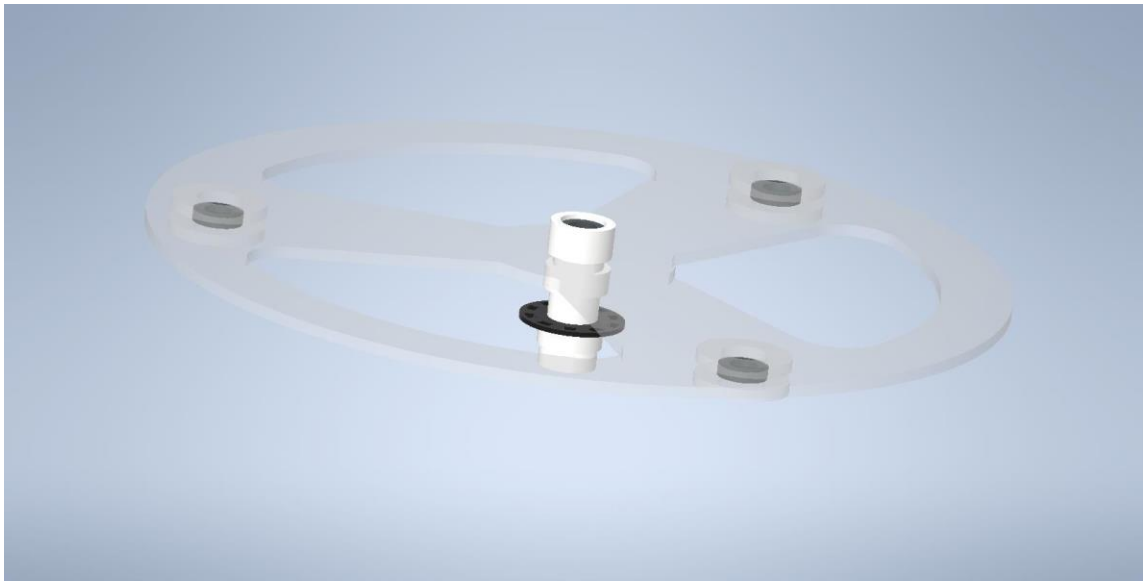


Figure 2.35(a): Turbine lower part assembly

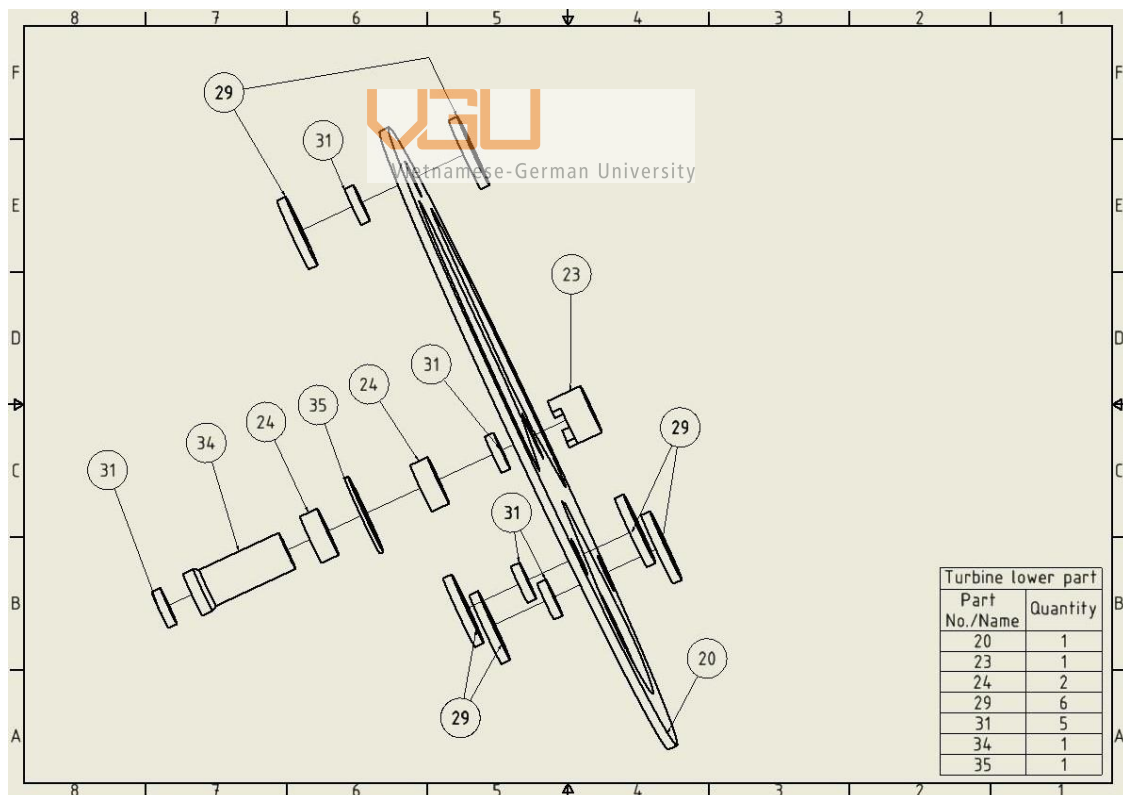


Figure 2.35(b): Turbine lower part assembly presentation

## 2.2.4. ASSEMBLY OF WIND TURBINE

### 2.2.4.1. Additional components need for assembly

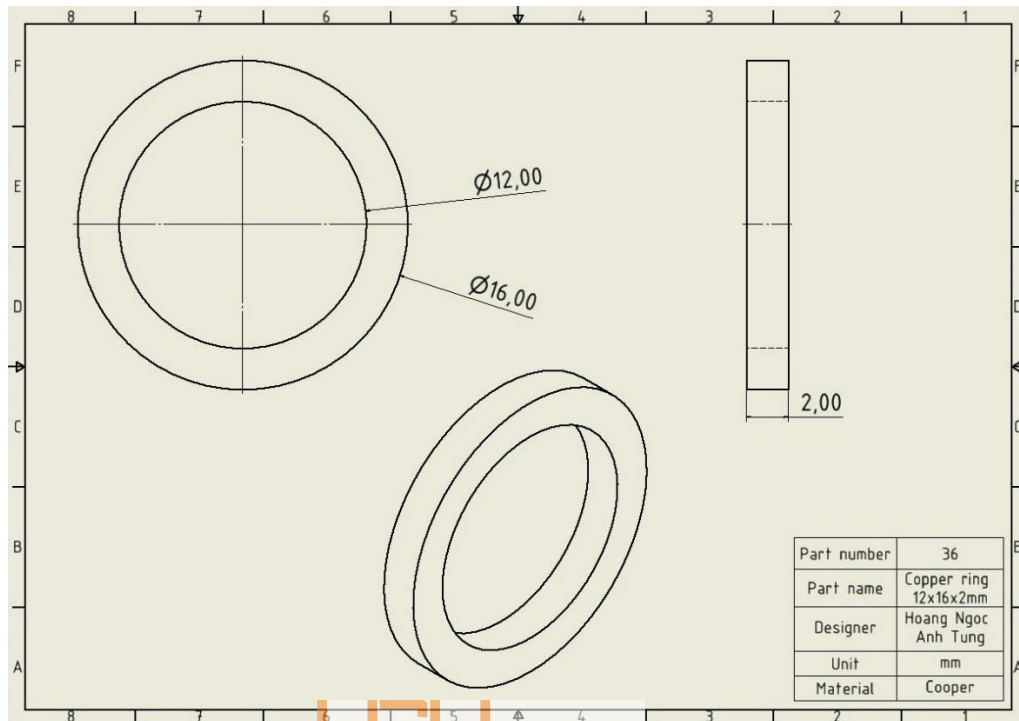


Figure 36: Part 36-Copper ring 12x16x2mm

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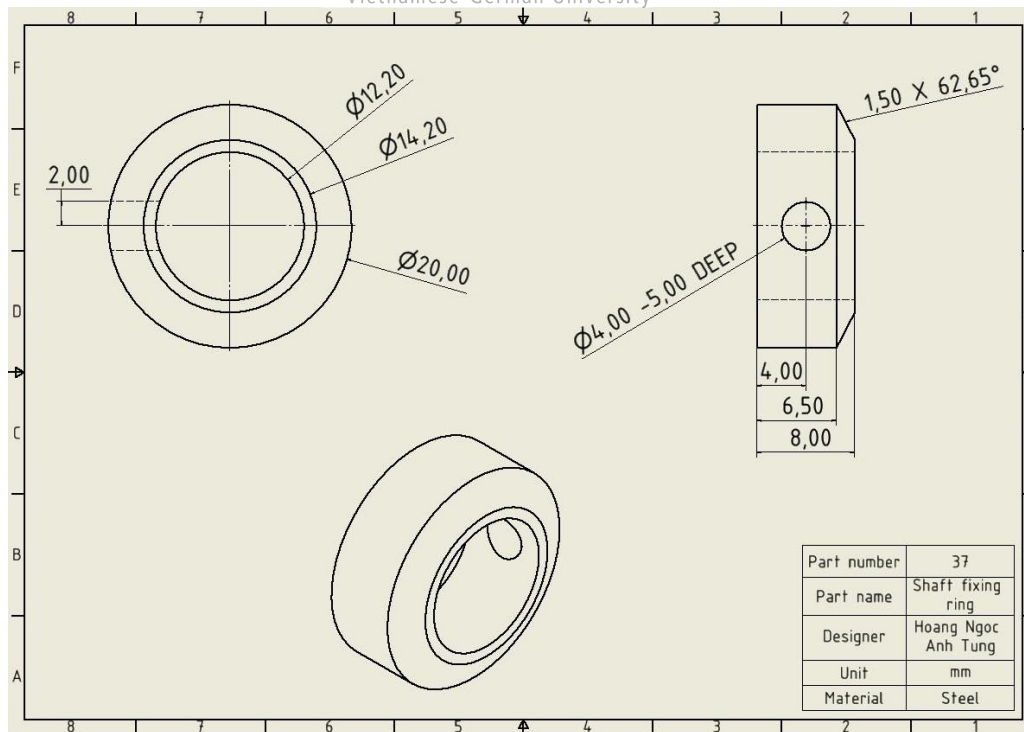
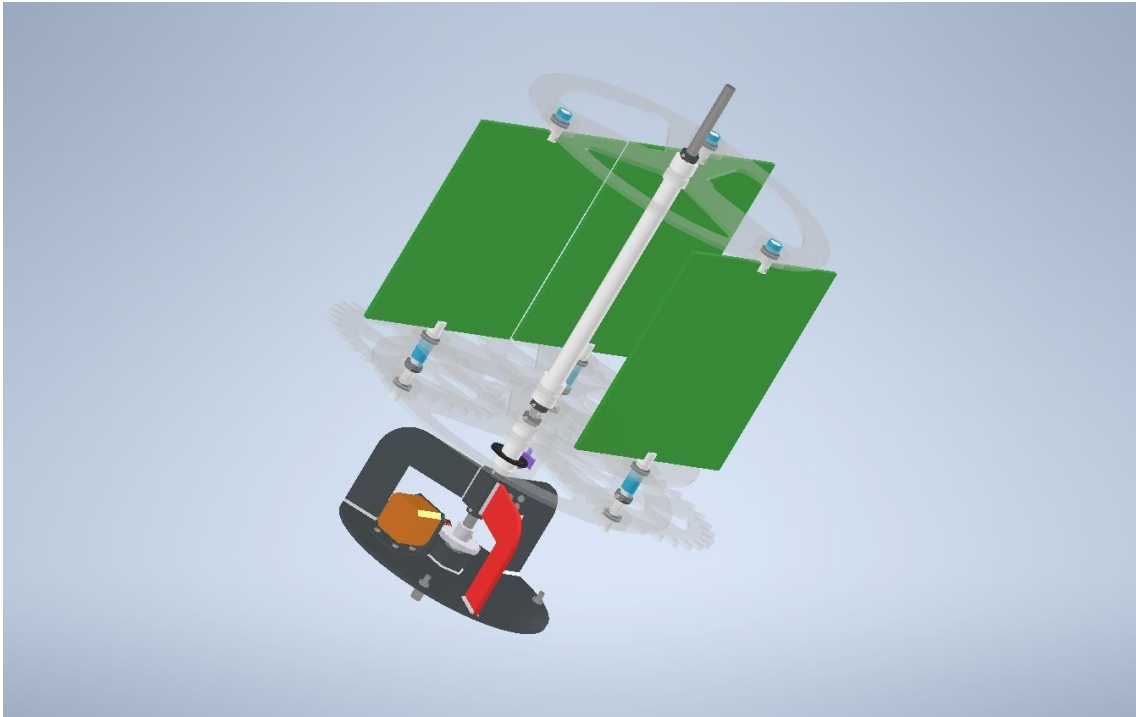
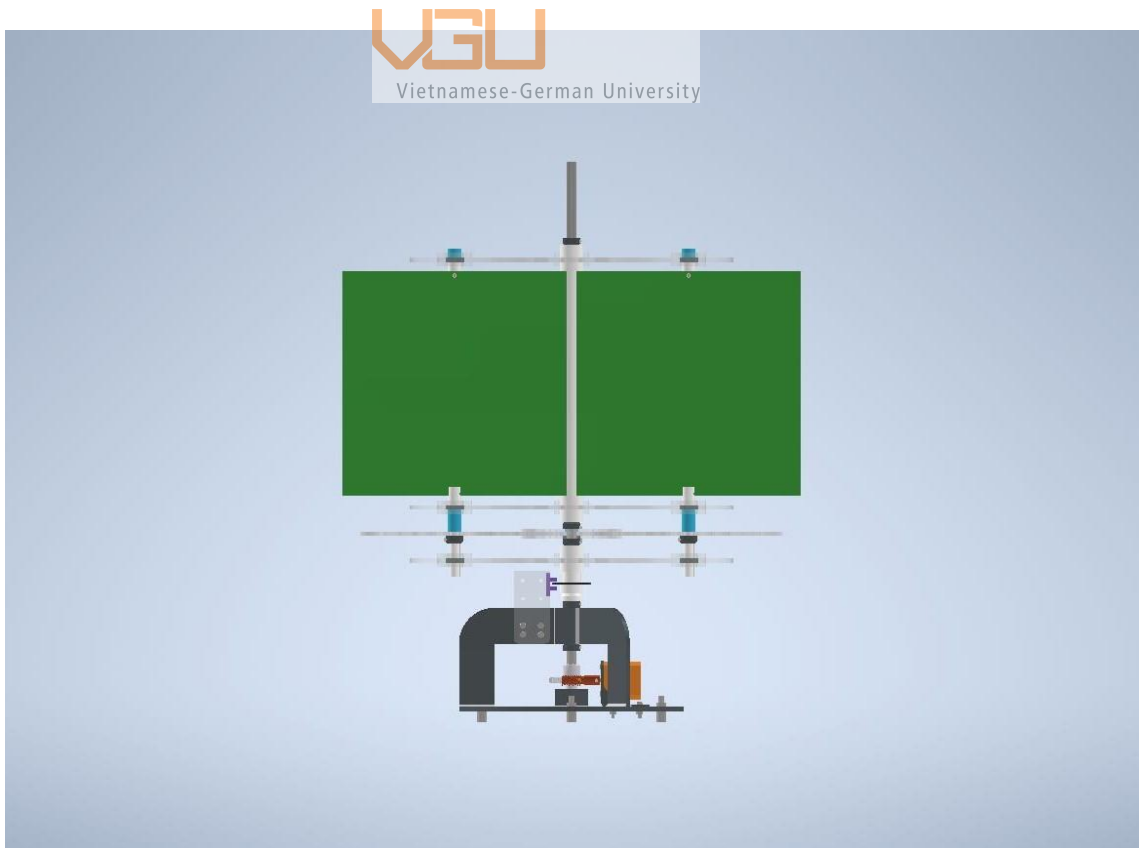


Figure 37: Part 37-Shaft fixing ring

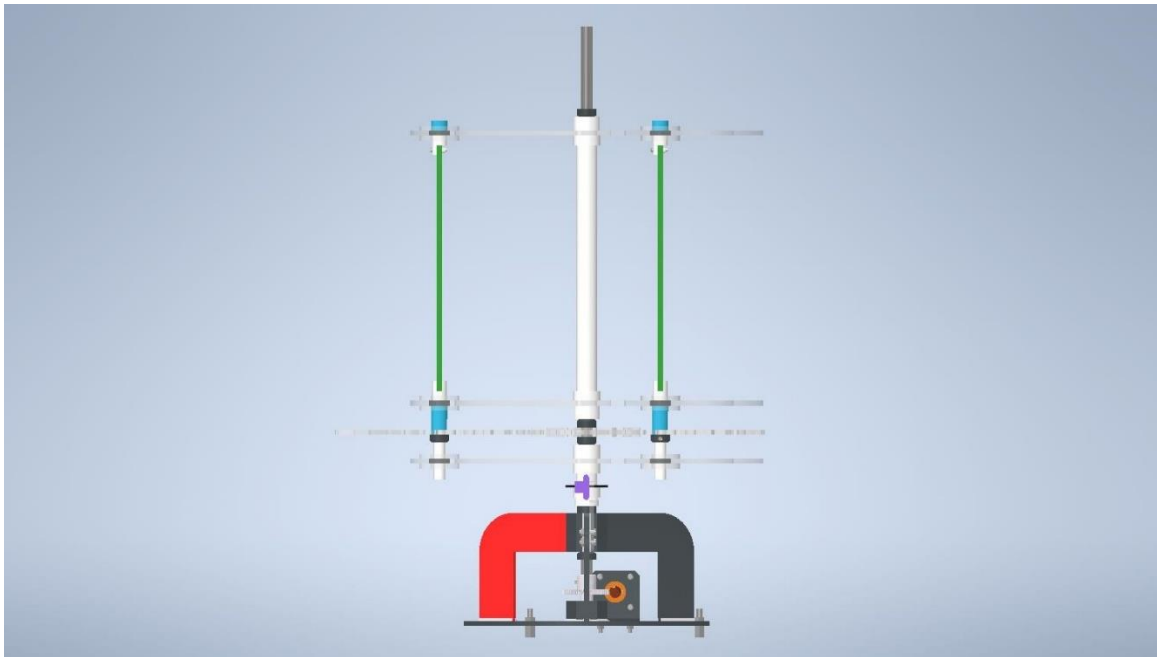
#### 2.2.4.2. Turbine assembly



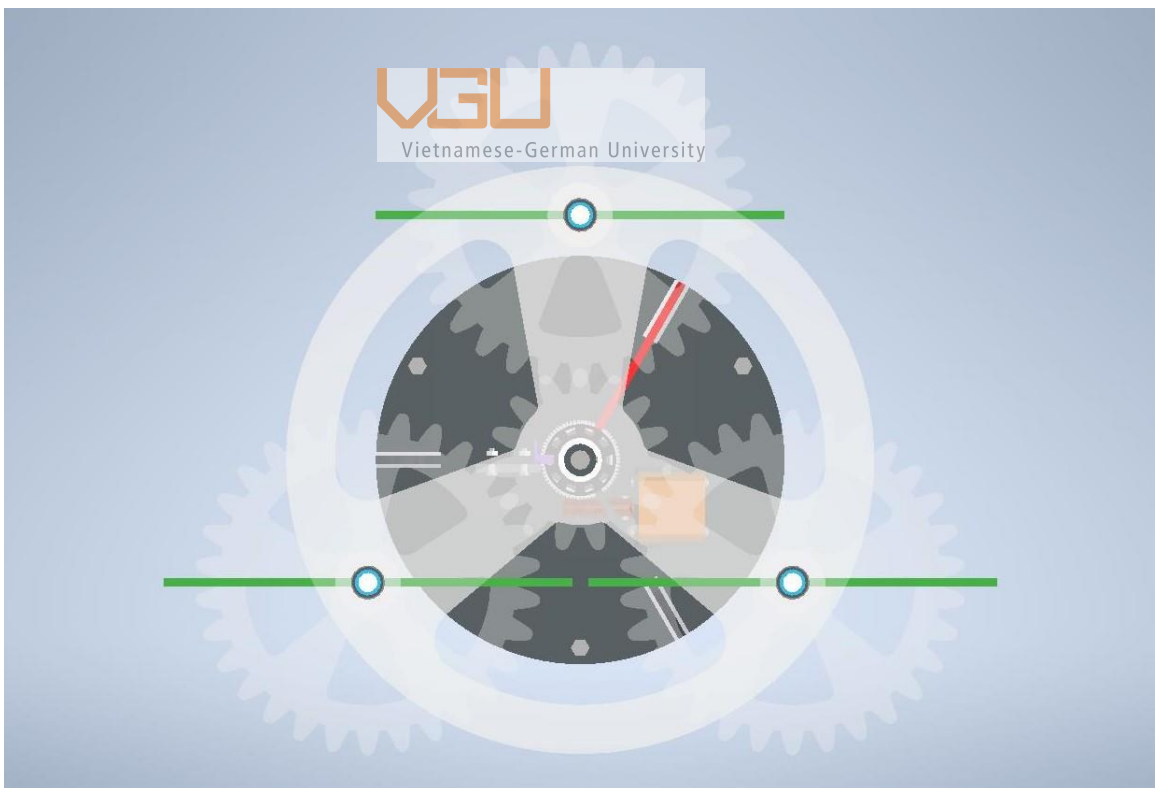
**Figure 38(a):** Wind turbine assembly (master view)



**Figure 38(b):** Wind turbine assembly (front view)



**Figure 38(c):** Wind turbine assembly (side view)



**Figure 38(d):** Wind turbine assembly (top view)

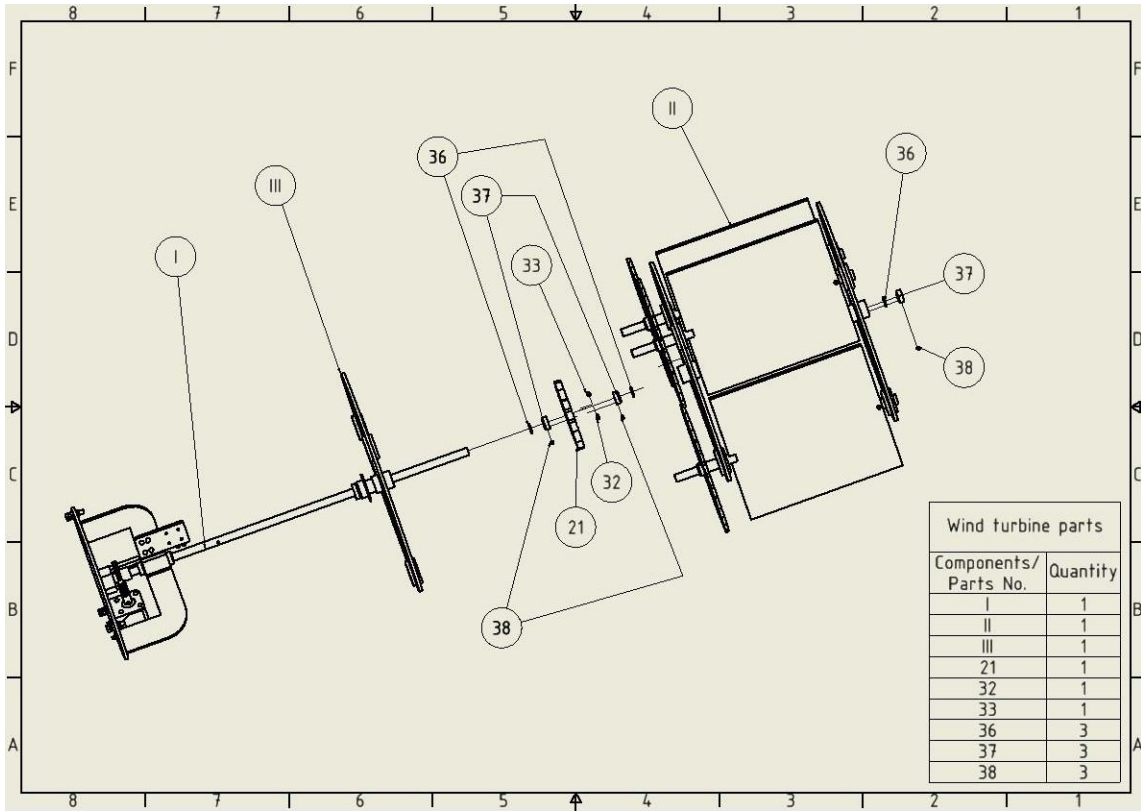


Figure 39: Wind turbine assembly presentation



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## CHAPTER 3 – ELECTRICAL DESIGN

### 3.1. PROPOSED SYSTEM

This section discusses about the hardware components that included in the project:

COMPONENTS	DESCRIPTION
Arduino UNO R3	Read sensor and controls the step motor driver
Stepper motor NEMA 17	Controls the wind turbine
Motor Driver A4988	Controls the stepper motor
Optical encoder V2 module	Feedbacks rotor's speed
Weather sensor	Indicate the direction of the wind
LM2596 module	Serves as step-down voltage regulator
7805 voltage regulator IC	Provides a regulated 5V output
I2C LCD	Displays blades angle and motor speed

**Table 3.1:** List of hardware components used in this project

The system only requires one 12VDC power supply source to fully operate, this source is either converted from 220VAC household power supply through an adapter or use 3 cells 18650 Lithium-ion battery pack. The Arduino microcontroller, the driver, LCD, and other modules take lower voltage current from the regulator, which eliminating the need for the second power supply.

The system's wiring circuit is shown in *Figure 3.1*.



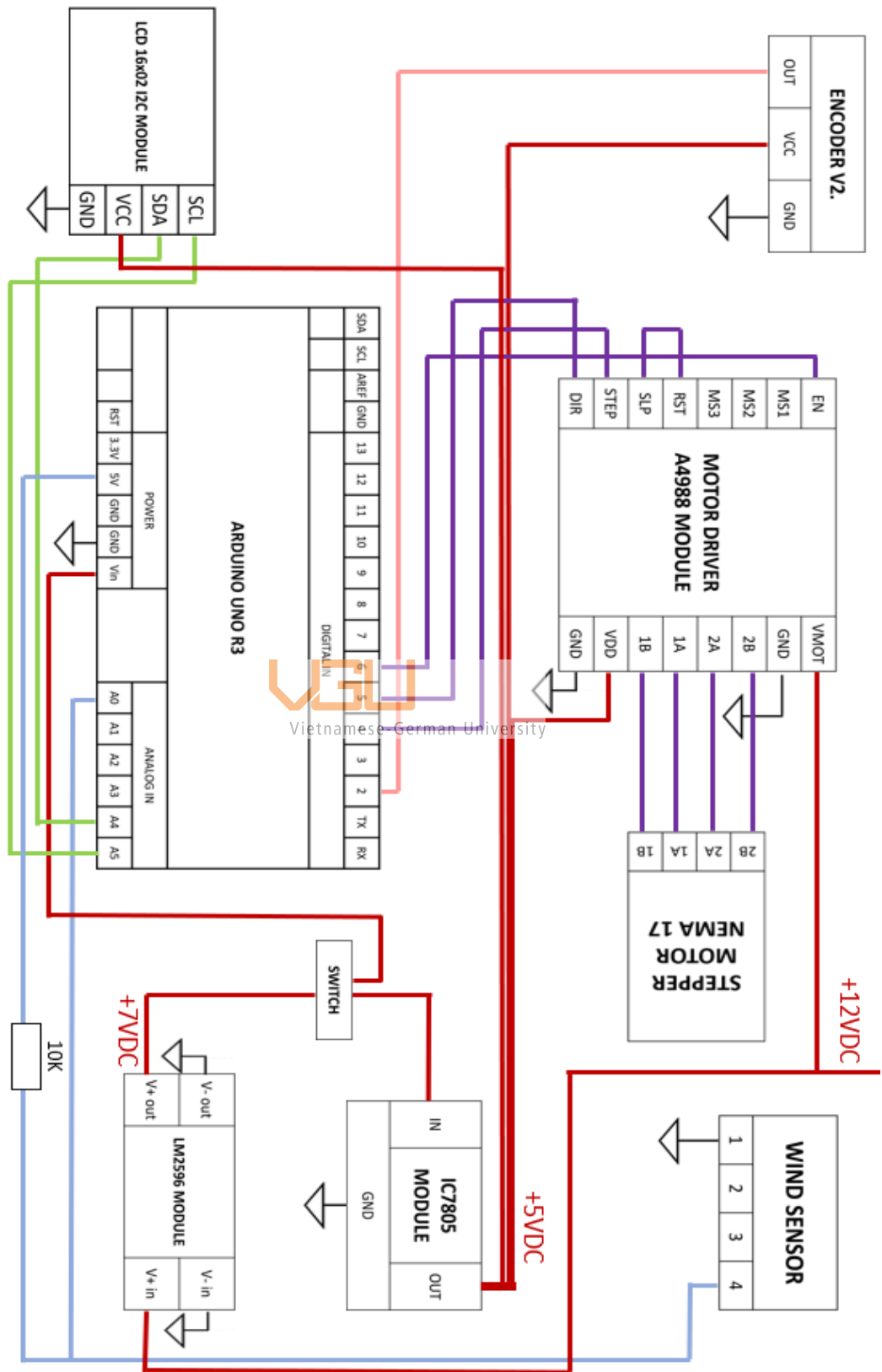


Figure 3.1: Wiring Diagram

## 3.2. HARDWARE IMPLEMENTATION

### 3.2.1. ARDUINO UNO R3 MICROCONTROLLER

Among many types of Arduino boards, this project uses the UNO R3 version because it is a low-power, cost-effective, high-performance microcontroller which is suitable for this experiment's purpose. Furthermore, it is easy to use, and all Arduino shields ever made are compatible with this version.

Arduino UNO R3 runs on Atmel Atmega328P. It has a lot of useful features, and many of them are sufficiently utilized in this project, such as the memory system, the port system, the Analog-to-Digital converter (ADC) and the serial communication system. "Atmega328P" denotes that it is an 8-bit microcontroller with 32KB of integrated flash memory and needs less power than its predecessors. This MCU operates due to a 16 MHz crystal on the UNO board [18].

When operating, the current consumption is 0.2mA. The Arduino UNO has a resettable polyfuse to prevent the board from drawing too much power, which may lead to shorts and overcurrent. Activated polyfuse results in breaking the connection automatically between the board and the power source, and it allows reconnection only when the overcurrent situation is solved.

Arduino has its own development board with a friendly programming language, allowing users to write and upload directly to the board through the Arduino IDE (Integrated Development Environment). Even though its main and original language is based on C++, it is still capable of compiling sketches in any other high-level programming language, such as Python [19]. The reason for this flexibility is that it initially saves the code as a piece of text, then converts it into binary machine code and produces a single hex file that may be interpreted by the board.

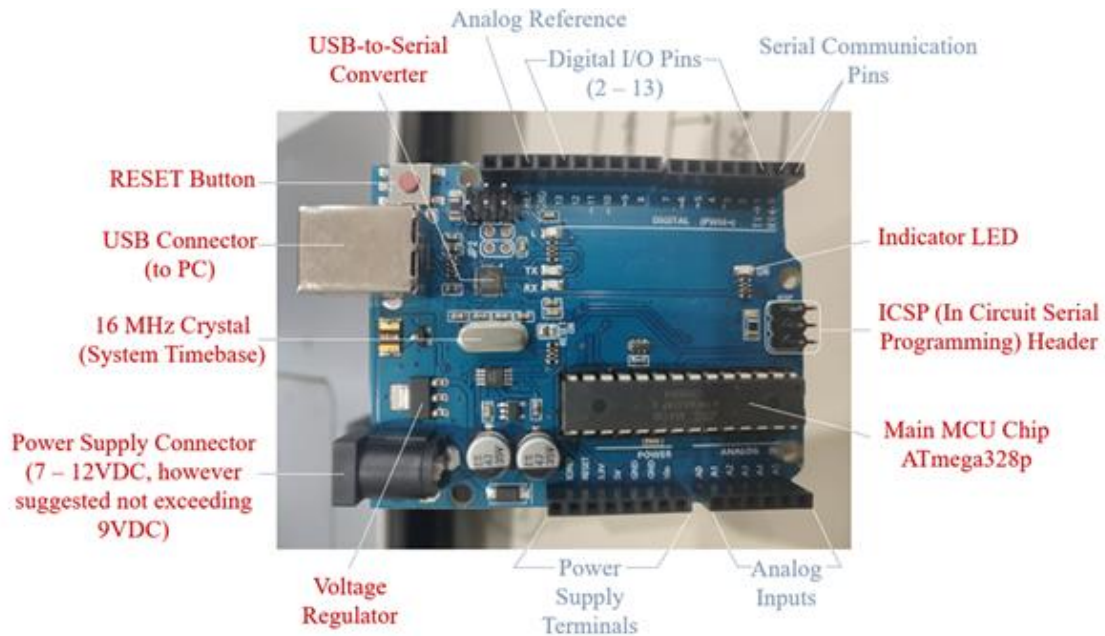


Figure 3.2: Arduino UNO R3 layout

### 3.2.2. STEPPER MOTOR NEMA 17

Controlling a wind turbine requires a certain degree of precision; thus, precise control is paid more attention to than speed. That is the reason why a stepper motor is used. The NEMA 17 is used to control the rotating motion of the wind turbine blades based on the wind direction.

Stepper motors rotate slowly in discrete steps, each step is defined by a small fixed angle. The NEMA 17 stepper motor is widely used in applications that need high precision, such as 3D printing and CNC technique [20]. However, NEMA 17 is not the model number of a specific stepper motor type because there are many different versions of it, varying in operating voltage, produced torque, and stepping angle. Since stepper motors are classified by the “American regulation NEMA (Associated Manufacturer of Electrical Supplies)” according to their size, it simply gets its name from the dimensions of its flange size, which is 1.7 inches. This motor can provide from 200 steps per revolution in full mode, and up to 3200 steps in 1/16 step mode. However, in this project, we need to motor to run fast and have high torque, and we

don't need the much precision, so we use full step mode, which is 200 steps per one revolution of 360 degrees. Thus, the stepping angle is:

$$\text{Stepping Angle} = \frac{360^{\circ}}{200 \text{ steps}} = 1.8^{\circ}/\text{step}$$



**Figure 3.3:** Step motor Nema 17

### **3.2.3. STEP MOTOR DRIVER A4988 AND SOCKET**

The A4988 motor driver module offers superior control for the NEMA 17, resulting in several available control modes, such as full, half, quarter, eighth, and sixteenth steps of the motor. This allows the highest precision state control mode to reach steps per revolution. For this project, full mode control is sufficient enough to achieve the expected performance of wind turbine blade control, which is 200 steps per revolution.

These motor drivers are very sensitive and require to correct amount of current supply in order to properly control the stepper motor. Too little current will result in skipped steps or no movement at all. Too much current will lead to unwanted

behaviors, such as unstable movements, overheating, and loud noise, and subsequently damage both the driver and the motor.

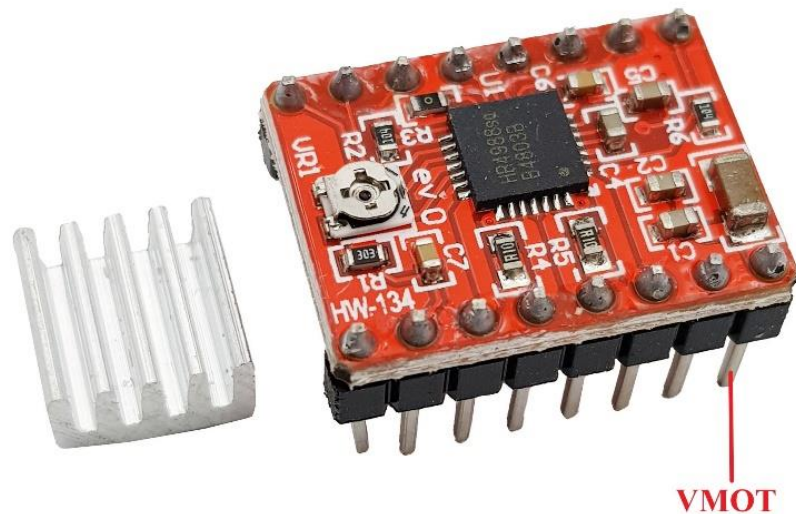


Figure 3.4: Step motor driver A4988 and heat sink

However, the driver itself is quite difficult to connect, we can use this socket to solve that problem, the socket is available with capacitors, motor power supply jacket, MS switch to set motor mode, step motor output pins base, and pins to control the motor.

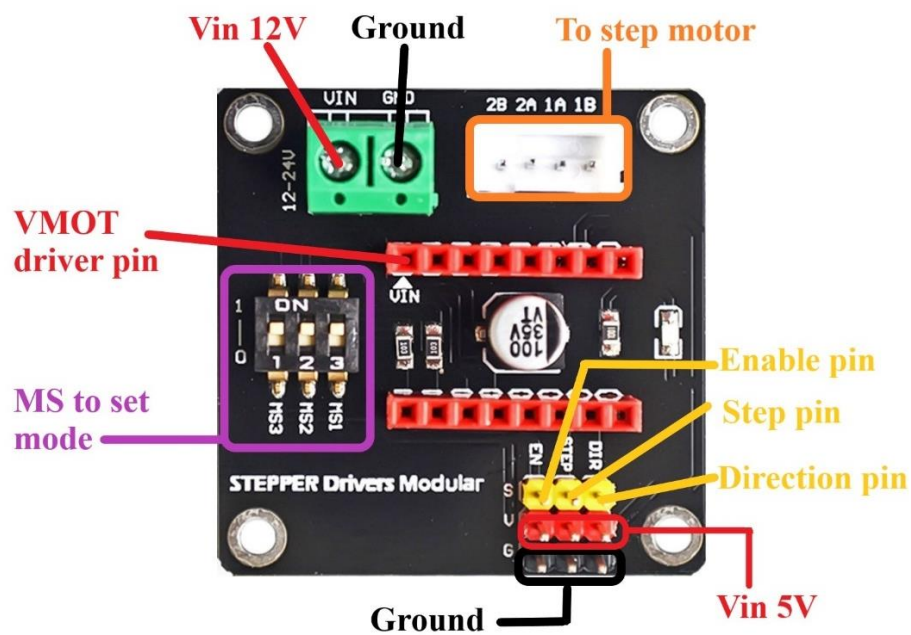


Figure 3.5: Socket for driver A4988

The MS pin configuration for this driver is relatively simple. We can base on the below table to set mode to step motor, since regular control mode is used, pins MS1, MS2 and MS3 are set LOW.

MS1	MS2	MS3	Microstep resolution
Zero	Zero	Zero	Ful step mode
One	Zero	Zero	1/2 step mode
Zero	One	Zero	1/4 step mode
One	One	Zero	1/8 step mode
One	One	One	1/16 step mode

**Table 3.2:** Logic table to set step motor mode [21]

### 3.2.4. OPTICAL ENCODER V2

An optical encoder V2 module is used for wind turbine speed measuring.

Typically, an optical rotary encoder is utilized because its reliability, robustness and inexpensive cost surpasses the advantages offered by any other technology, e.g., magnetic encoder. The integrated optical encoder V2 module is a combination of two components: an emitter, which is a light source; and a phototransistor to reflect the incoming light [22]. Additionally, an encoder wheel disc is equipped. It has ten slits evenly distributed around its edge, specifically designed to provide a pulse train of signals that the microcontroller may interpret and convert into expected output – the wind turbine’s speed.

For this model, the disc is attached to the turbine center shaft and the optical module is fixed on the turbine model’s base.

When the phototransistor detects appearance of light which means that light passes through the slit on the disc, it returns value of 1; and vice versa, when there is no light reflected, the output is 0. A series of 0 and 1 generates a pulse train in a form of a square wave that may be interpreted by the microcontroller. The microcontroller

counts the pulses, calculates the displacement between the wind turbine center shaft and the wind turbine's base and indicates wind turbine's speed by timing the frequency of these pulses.

The number of slits on the encoder wheel determines the resolution of the encoder. However, this prototype wheel disc is designed with 10 slits – a relatively low resolution – with the purpose of saving processing resources for the microcontroller. Furthermore, with support of Arduino's Attach Interrupt feature, a high accuracy is not necessarily required.



**Figure 3.6:** Optical encoder V2 and wheel disc

### **3.2.5. WEATHER SENSOR**

This weather sensor comes in a pack of three components: a rain gauge sensor is used for measuring both the temperature and the humidity; a cup-type anemometer is able to calibrate the wind speed; and a wind vane. However, the proposed system focuses on determining the wind direction to optimize the wind turbine's performance, therefore, only the wind vane is employed in this project.



**Figure 3.7:** Wind vane outlook

The wind vane is the very complicated. It functions as a wind indicator. In order to operate, the vane's axis is equipped with a magnet, generating a field, which can be tracked by the switch, allowing it to have the control ability over the switch status. A total of 8 switches is constructed, each connected serially with a resistor of different values (Table 3.3) [23]. The magnet will close the switches depending on the wind direction. Since the magnet is able to close two switches at one time, a combination of 16 different positions may be accurately indicated.



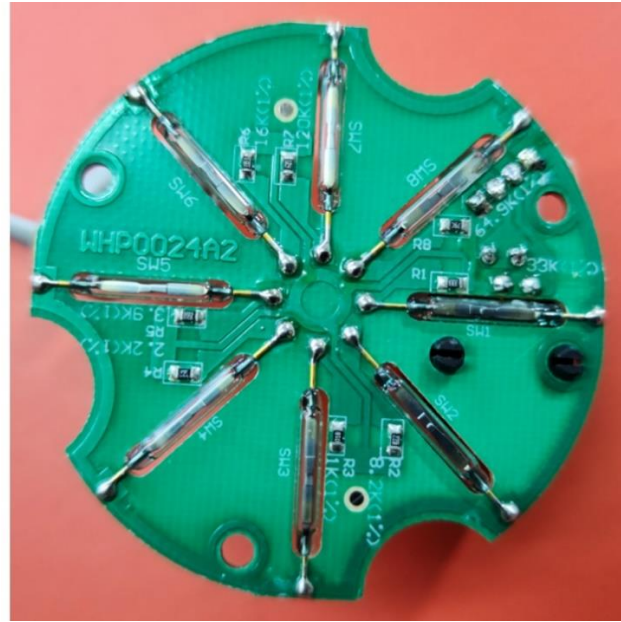
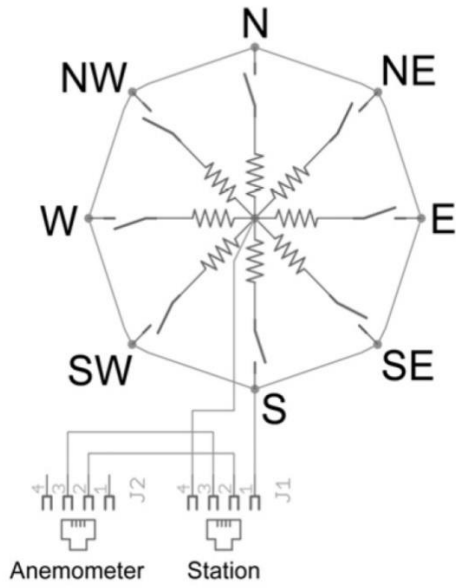


Figure 3.8: Resistor diagram and in the wind vane

Another resistor with value of 10K Ohms is connected in series with the wind vane and microcontroller circuit. Every resistor is connected to an active switch serves as a voltage divider, resulting in a distinct voltage value for each wind direction. The Arduino board can read the voltage that was acquired.

Position	Direction	Resistance (Ohms)	Voltage (V=5v, R=10k)
0	0	33k	3.84v
1	22.5	21.88k	3.43v
2	45	64.9k	4.33v
3	67.5	42.12k	4.04v
4	90	120k	4.62v
5	112.5	14.12k	2.93v
6	135	16k	3.08v
7	157.5	3.14k	1.19v
8	180	3.9k	1.4v
9	202.5	1.41k	0.62v
10	225	2.2k	0.9v
11	247.5	0.688k	0.32v
12	270	1k	0.45v
13	292.5	0.891k	0.41v
14	315	8.2k	2.25v
15	337.5	6.57k	1.98v

Table 3.3: Resistor and voltage value at each position and direction

To read the voltage, we use `analogRead` function from Arduino, this function will transform the voltage of wind vane resistor from 0 and to 5V into integer values between 0 and 1023. The table below shows only the averaged values returned by the Arduino with the value of the angle recorded, from this value, a range of  $\pm 5$  averaged values for the angle is generated.

Position	Direction	Average number read by Arduino
0	0	790
1	22.5	409
2	45	463
3	67.5	81
4	90	92
5	112.5	64
6	135	183
7	157.5	124
8	180	286
9	202.5	244
10	225	632
11	247.5	600
12	270	946
13	292.5	829
14	315	889
15	337.5	705

**Table 3.4:** Value reading by Arduino at each position

### 3.2.6. LM2596 VOLTAGE REGULATOR MODULE

The Arduino board supply current is not sufficient for powering most motors directly, hence, the stepper motor and the microcontroller will share one mutual power supply of 12V. In order to avoid damaging the Arduino board with such high voltage, a step-down voltage regulator is inserted into the circuit for the microcontroller. It

takes input voltage of supply power source and reduce it to a lower fixed output voltage of 7V DC before feeding the Arduino board [24]. Its output voltage can be adjusted by turning the potentiometer on the module.

Another purpose of using this module is to protect the microcontroller from voltage spikes by ensuring a supply DC voltage with negligible ripples to the electronic circuit components, especially those sensitive ones, such as the Arduino board and the stepper motor driver NEMA 17 module.

The LM2596 series operates at a 150 kHz switching frequency, meaning it is capable of filtering components of smaller sizes than would be expected with lower frequency switching regulators.



Figure 3.9: LM2596 voltage regulator module

### 3.2.7. 7805 VOLTAGE REGULATOR IC

The 7805 Voltage Regulator IC with its functionality of voltage regulator is commonly used in most of the electronics project. It provides a constant +5V output voltage for a wide range of input voltage supply. The name 7805 signifies two meaning. “78” means that it is a positive voltage regulator and “05” means that it provides 5V as output.

Although the Arduino has a port to provide 5V, this port only provides a current of 50mA, which is not enough for devices such as LCD, step motor driver and encoder

to operate, and will cause power shortage to the Arduino, which may damage the board, this IC is used to provide power for these devices to operate smoothly and efficiently.

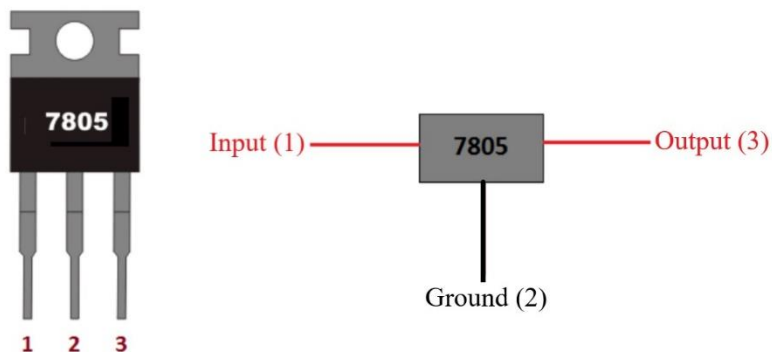


Figure 3.10: 7805 voltage regulator IC pinout diagram

Pin number	Name	Function
1	Input	Input voltage (5-18V DC)
2	Ground	Ground
3	Output	Output regulated 5V DC

Table 3.5: 7805 voltage regulator IC pinout name and function



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### 3.2.8. I2C LCD

A liquid crystal display (LCD) is employed for its basic functionality of displaying. It has a total of 16 pins that is designed to exactly fit into the standard Arduino UNO pin layout. However, this amount of pin connections consumes a lot of space and limits accessibility to other pins on the board. To avoid this unnecessary waste of space and time, and also potential wiring mistakes, an I2C LCD adaptor module is used [25].

The I2C bus considers all 16 pins of the LCD as an input and transform it into an output under the form of 4 physical pins. Therefore, instead of 16 connections, it reduces into 4 connections to make, and as a result, the setup experiment platform is neat and troubleshooting work becomes simpler.



Figure 3.11: LCD screen with 16 pins



Figure 3.12: I2C connected to LCD with 4 pins output

### 3.3. CONTROL PROGRAM

#### 3.3.1. CODE STRUCTURE

The specific goal of this program is to create an open-loop control system, where input is received by the wind sensor. This piece of information is then processed by the Arduino microcontroller and the motor is then controlled to run toward the desired position based on the wind direction.

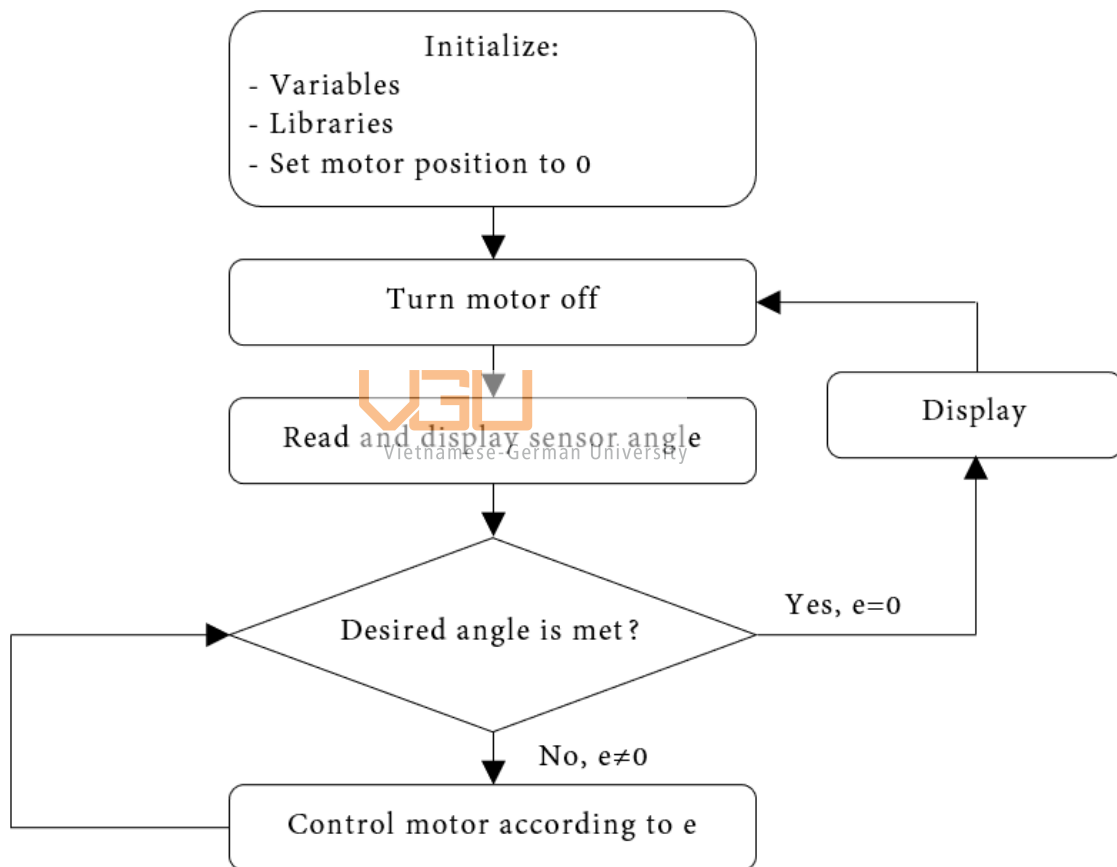


Figure 3.13: Program's flow chart

#### 3.3.2. CODE EXPLANATION

The Arduino IDE has a built-in library called Stepper Library that supports driving stepper motors, allowing control over both unipolar and bipolar types. However, the

functions available in this built-in library is considerably simple, limited only in constant speed and direction control and therefore, not fully exploit stepper motors' features.

The solution is initially developed by Mike McCauley with a continuously updated library known as the AccelStepper library. One of the significant advantages of this library over the original one is the ability to interfering with the motor's acceleration and deceleration rate adjustments. By implementing this AccelStepper library, along with the target position, the stepper motor's initial speed, acceleration and deceleration rate, and highest speed can all be adjusted. [26].

To carry out accurate angular position control, a particular initial direction needs to be set as the reference point. Here the reference point is chosen such that when the turbine's position value is 0, the actual rotor shaft is pointing towards the North direction. In the initial setup section of the code, the turbine's position is set to 0. The program is determined to implement the regular full step mode of the NEMA 17 stepper motor, which means every 200 steps make a revolution. This value is also taken into account and must be declared as a constant of 1 revolution.

```
22  int lastPosition = 0;
23  int distanceNeedToGo;
24  const int stepsPerRevolution = 200;
```

Once being activated, the microcontroller starts to collect wind direction data from the wind vane sensor. This information is then proceeded by a particular function created for motor controlling. This way enables the task to be invoked repeatedly with a more manageable manner.

```
130  // turn motor according to wind sensor
131  targetPosition = WSDposition;
132  turnMotor(targetPosition);
```

As discussed earlier in Chapter 2, the worm gear system is arranged for motion transmission from the step motor to the turbine control shaft with the gear having 64 teeth. Each gear tooth is corresponding to one direction, giving us a range of position 0 to 63, and requiring the stepper motor to complete one rotation to change

one direction. Additionally, as this is a worm gear system, when the motor revolves 64 times it will return to starting position, that results in two options for movement from the current position (`lastPosition`) to the desired position (`motorPosition`). The microcontroller carries out a series of calculations to compare and determine to which way the motor will follow so that the travel distance will be the shortest and most convenient.

```
150 void turnMotor(int motorPosition) {
151     //turn motor to motor position
152     int distanceNeedToGo1 = motorPosition - lastPosition;
153     int distanceNeedToGo2 = (motorPosition - lastPosition) - 64;
154     if (abs(distanceNeedToGo1) <= abs(distanceNeedToGo2)) {
155         distanceNeedToGo = distanceNeedToGo1 * stepsPerRevolution;
156     } else if (abs(distanceNeedToGo1) > abs(distanceNeedToGo2)) {
157         distanceNeedToGo = distanceNeedToGo2 * stepsPerRevolution;
158     }
159     motorOne.move(distanceNeedToGo);

```

The determination process may be briefly described as: firstly, compare the `distanceNeedToGo` with 0, once this value is non-zero, the microcontroller begins to activate the motor and give controlling commands for it to rotate and reach the required position, e.g., the `runToPosition` function. However, when the target position is 0, the `runToPosition` command will control the motor to sequentially rotate from its current position back to 0 without considering the shortest travel distance. To avoid this situation, the `run` function is called out if the target position is 0, which is the reference position.

```
160     if (motorOne.distanceToGo() != 0) {
161         motorOne.enableOutputs();
162         if (motorPosition == 0) {
163             while (motorOne.distanceToGo() != 0) {
164                 motorOne.run();
165             }
166         } else {
167             motorOne.runToPosition();
168         }

```



Once motor's position is achieved as desired, its new current position is saved by declaring it to be `lastPosition`. This enables further control process to be repeatedly done using the same method. If no new direction is detected, the motor will be turned off for energy saving purpose.

```
169 | | lastPosition = motorOne.currentPosition() / stepsPerRevolution;  
170 | | motorOne.disableOutputs();
```

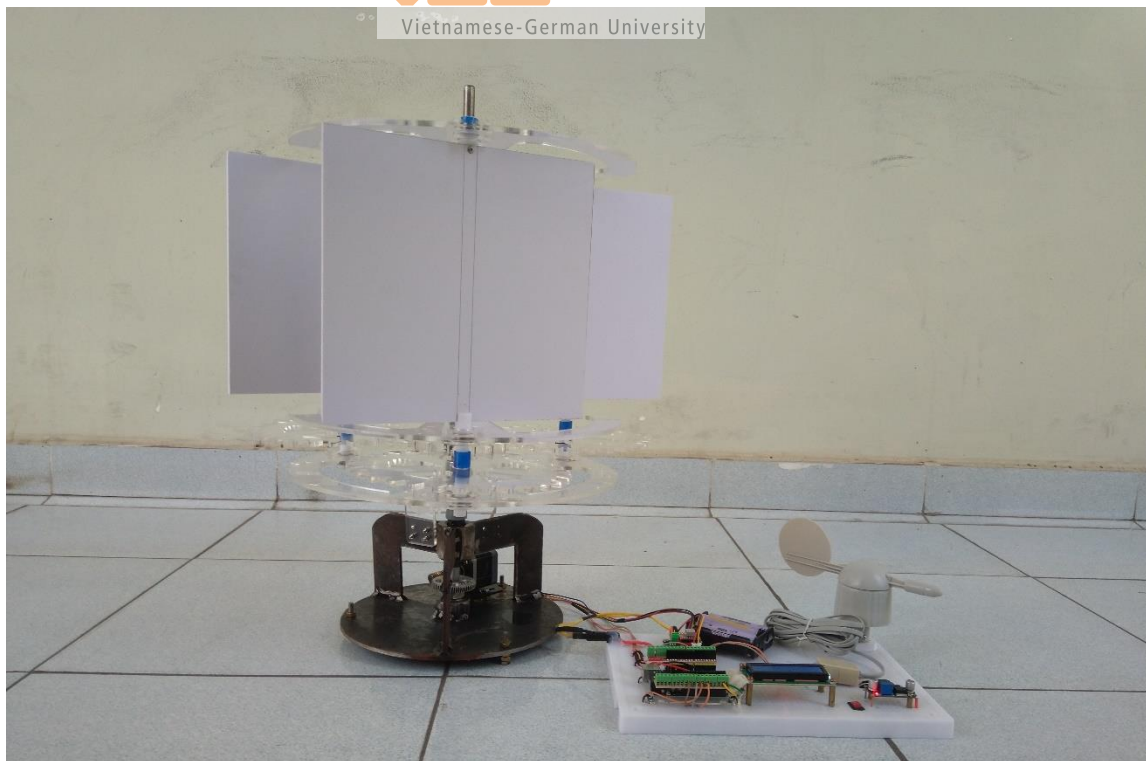
# CHAPTER 4 - INSTALLATION AND EXPERIMENT 1

## 4.1. SYSTEM SETUP

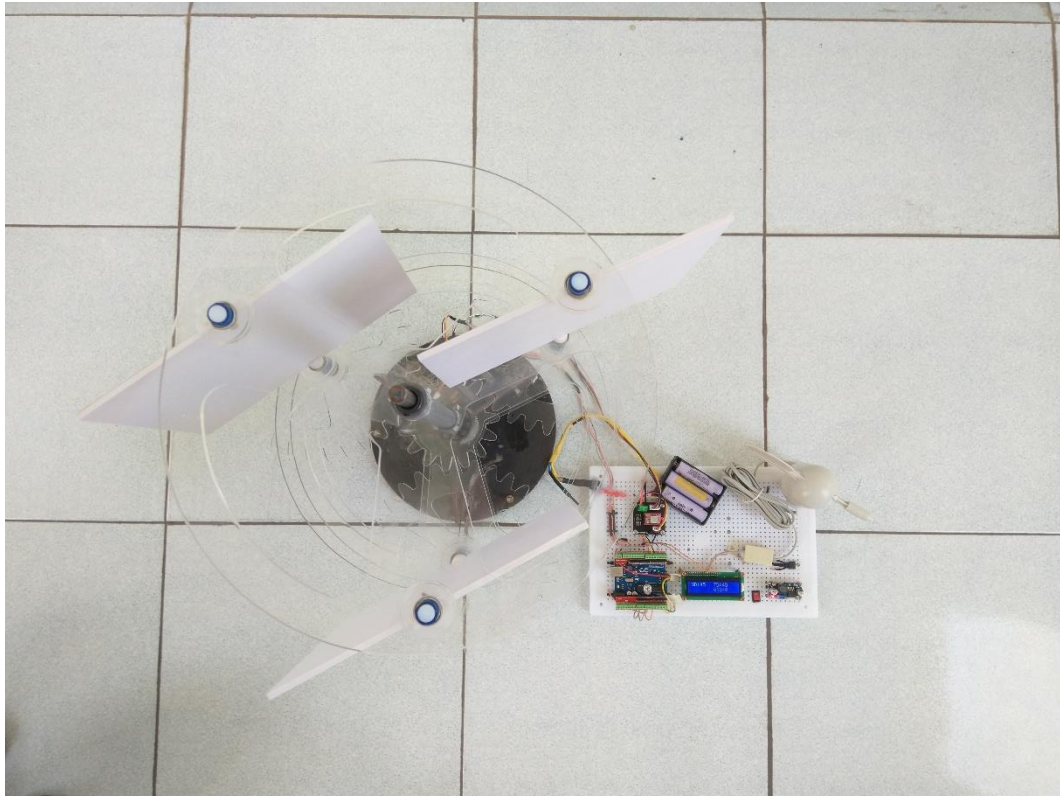
The experiment took place at the intersection of two corridors, whose walls were built parallelly or perpendicularly to each others. This condition created a variety of wind directions and they were changing continuously. The purpose of this set up was to test the accuracy and sensitivity of the controller, in other words, to check if the controller was able to react in a timely manner according to the wind direction. Another equally important purpose was to examine the wind turbine operation.

The synchronization of direction adjustment was also taken into consideration while setting up, as the North arm of the turbine and the North direction of the wind vane were pointed in the same direction.

*Figures 4.1(a)- 4.1(d)* show different points of view of the installation.



**Figure 4.1(a):** Prototype of wind turbine (front view)



**Figure 4.1(b):** Prototype of wind turbine (top view)



**Figure 4.1(c):** Prototype of wind turbine (angle view)



**Figure 4.1(d):** Prototype of wind turbine (angle view)



**Figure 4.2:** Stepper motor and worm gear system

## 4.2. EXPERIMENT

### 4.2.1. MECHANICAL SYSTEM EXPERIMENT

Table 4.1 shows the target of the design and the result of the experiment.

Target	Description	Result
1	The system has a sturdy base, low center of gravity to be able to stand firmly in the wind.	Achieved
2	The system works stably, there is no strong vibration phenomenon, the parts are firmly attached, stay in correct position.	Achieved
3	In spur gear system, three planet gears can rotate around a sun gear smoothly without hindrance.	Achieved
4	Worm gear system permits only one way of transmission as proposed, which prevents the damage may occur by the wind pressure.	Achieved
5	Spur gear system can transmit the rotating movement to the blades with the correct design speed.	Unsatisfactory result (*)

Table 4.1: Experiment's Targets and Results

(\*) As proposed, the turbine blade rotates around itself with a speed of  $\frac{\omega}{2}$  when the speed of turbine is  $\omega$ . By design, this spinning movement of the blade is established by the planetary gear system.

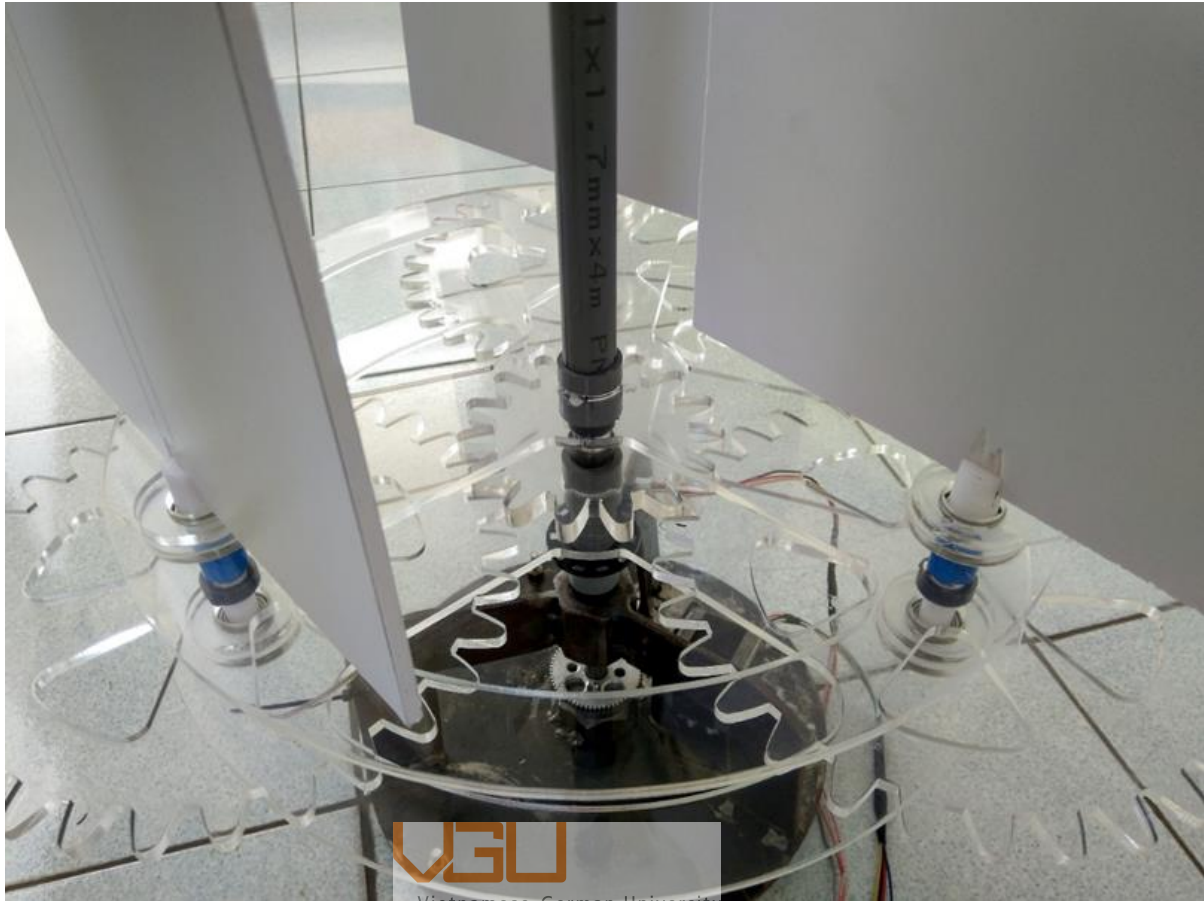


Figure 4.3: Spur gear system

The result obtained from the experiment showed that the interest speed is  $\frac{3\omega}{2}$ , which was 3 times the necessary value. The wind blade position analysis mentioned in Chapter 2 was therefore incorrect at positions A and C. Further studies were made in order to perceive the causes of failure, which lay in the confusion made in the determination of the planet gear's behavior. This effect can be explained by the so-called Coin Rotation Paradox.

Given two identical coins in contact with each others, with set up like in *Figure 4.2*. With blue coin kept in stationary, in order for the green coin to perform a full revolution around the blue one, the question is how many times does green coil revolve in total.

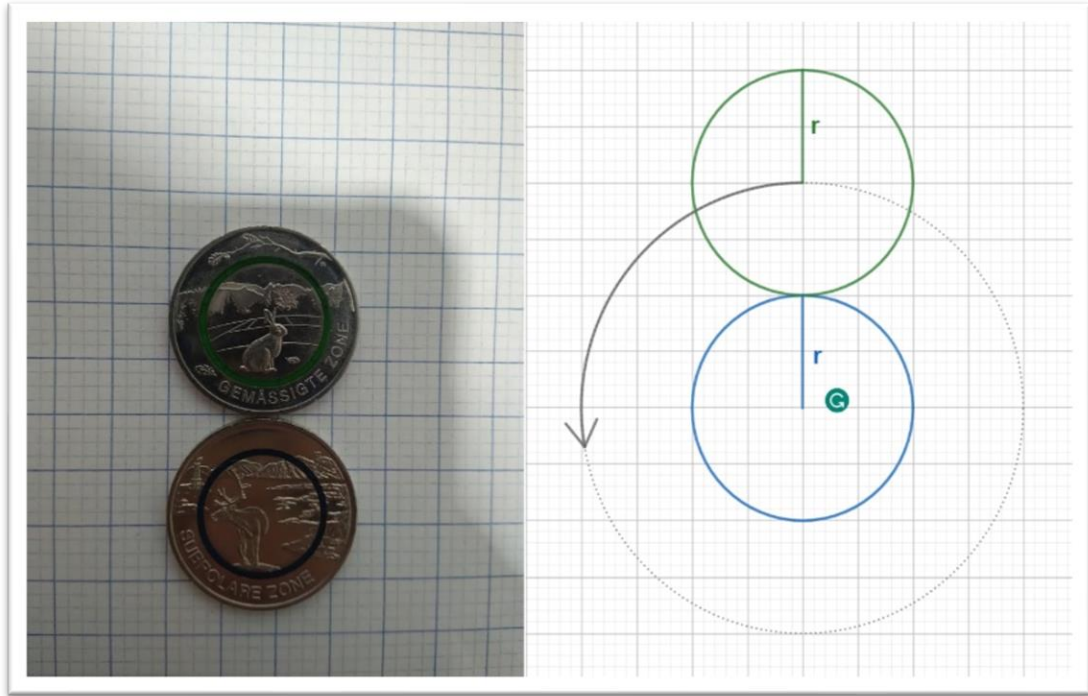


Figure 4.4: Coin Rotation Paradox Explanation



At first glance, the answer appears to be one revolution, however this is not the precise one. This is an extremely deceiving question, this same kind of problem even appeared in the Scholastic Aptitude Test (SAT) on May 1, 1982 and only 3 out of 300,000 test takers properly answered it [27]. The correct answer for this question is two revolutions. There are several ways to describe this issue, but the two most common ones are: First one is that the rotation path has to be considered at the center point of the green coin which is the circle with  $2r$  radius. Therefore, the green coin has to rotate two revolutions to complete the path. The second method is that one revolution due to the distance of rolling – since the two circles have the same radius, and one more revolution when green circle only revolves around the center point of blue coin (not rolling). In this thesis, one revolution caused by the planetary gears' movement around the center was not accounted, therefore the blades revolve faster than designed. The adjusted method will be discussed in Chapter 5.

## 4.2.2. ELECTRICAL SYSTEM EXPERIMENT

Table 4.2 examines the objectives of the controlling system.

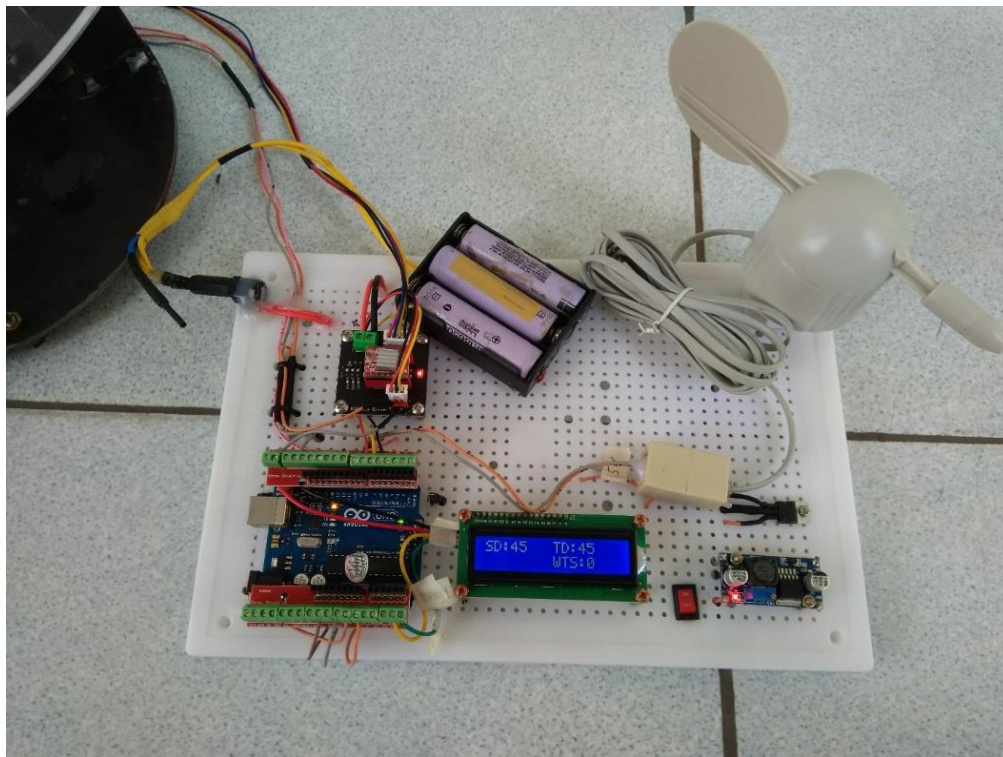
Target	Description	Result
1	Read the correct angle of wind from the wind vane.	Achieved
2	Control the stepper motor to operate most effectively by determining the shortest distance.	Achieved
3	Measure the correct rotation speed of the turbine	Achieved
4	LCD displays necessary values – wind direction, turbine direction and rotation speed	Achieved
5	Operate normally using battery	Achieved

**Table 4.2:** Electrical controlling system objectives and results

It can be concluded that the control system has successfully met all the requirements. Therefore, further improvements will be focused on the mechanical design, aiming to overcome the addressed failure.



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**Figure 4.5:** The wind turbine controller system design



# CHAPTER 5 - IMPROVEMENT AND EXPERIMENT 2

## 5.1. IMPROVEMENT

### 5.1.1. IDEA OF IMPROVEMENT

As discuss in chap 4, when rotating around the center shaft, the blade already rotates 1 revolution by itself, so to make the blade spin only half-speed of the turbine, it need to be subtracted by  $\frac{1}{2}$  turning speed. Thus, in this design, the pulley system would be used, with the **pulley O** is fix at the center, and **pulley B** is twice bigger than **O** and go around **O** at constant distance with rotational speed  $\omega$ , 2 pulleys are connected by the belt. When rotate around fixing O one revolution counterclockwise, due to the characteristic of pulley system, the pulley O will make the P spin  $\frac{1}{2}$  revolution clockwise. At the same time, pulley P also turn 1 revolution counterclockwise by itself, as the result, the pulley P will semi-turn around itself while rotating around O.



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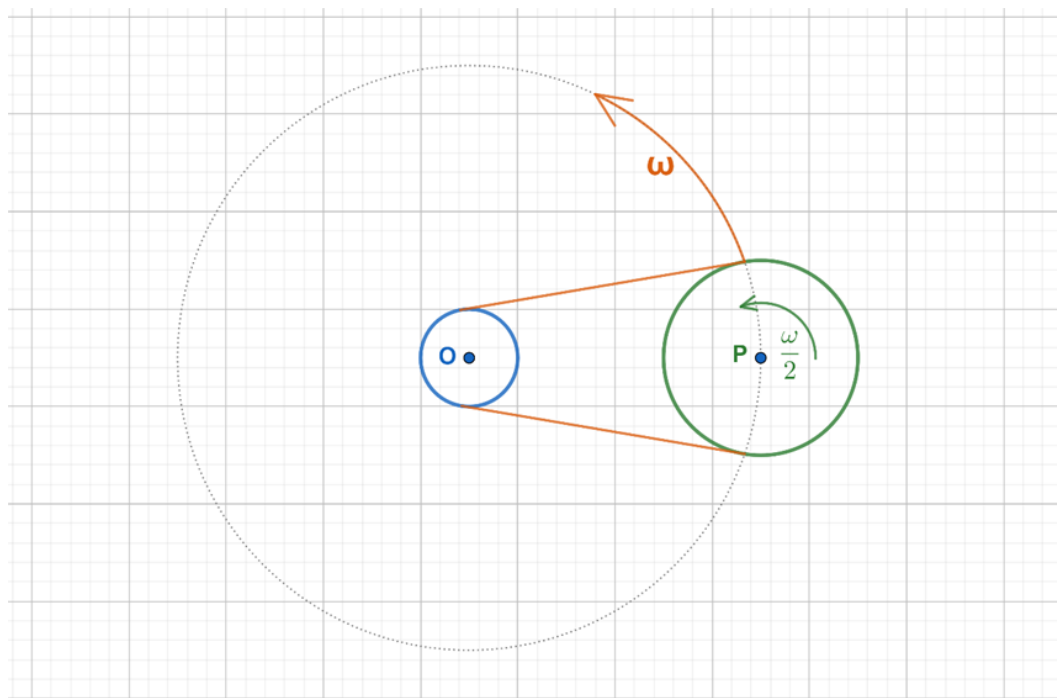


Figure 5.1: Pulley system

### 5.1.2. MECHANICAL DESIGN

A system of GT2 timing pulleys will be used, instead of drive belt in order to realize this theory. With many advantages, such as reliable transmission, no sliding while running, a steady gear ratio, high transmission efficiency and energy-saving are suitable for applying in this project. Additionally, GT2 timing pulleys are more compact than a spur system and either available on the market.



**Figure 5.2:** Part 39-GT2 30Teeth Bore 12mm Timing Pulley Wheel



**Figure 5.3:** Part 40-GT2 60Teeth Bore 12mm Timing Pulley Wheel



**Figure 5.4:** Part 41-GT2 timing belt width 6mm

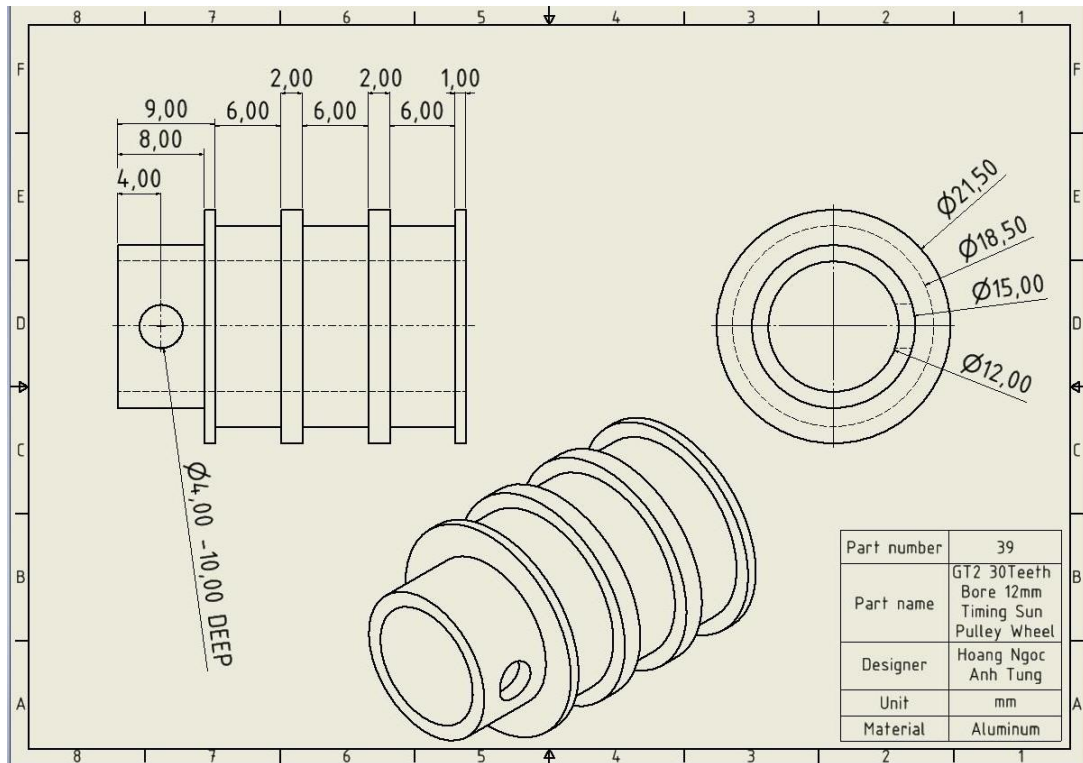


Figure 5.5: Part 39-GT2 30Teeth Bore 12mm Timing Sun Pulley Wheel design

With the GT2 60Teeth Bore 12mm Timing Pulley Wheel, the original design and dimension are maintained. Vietnamese-German University

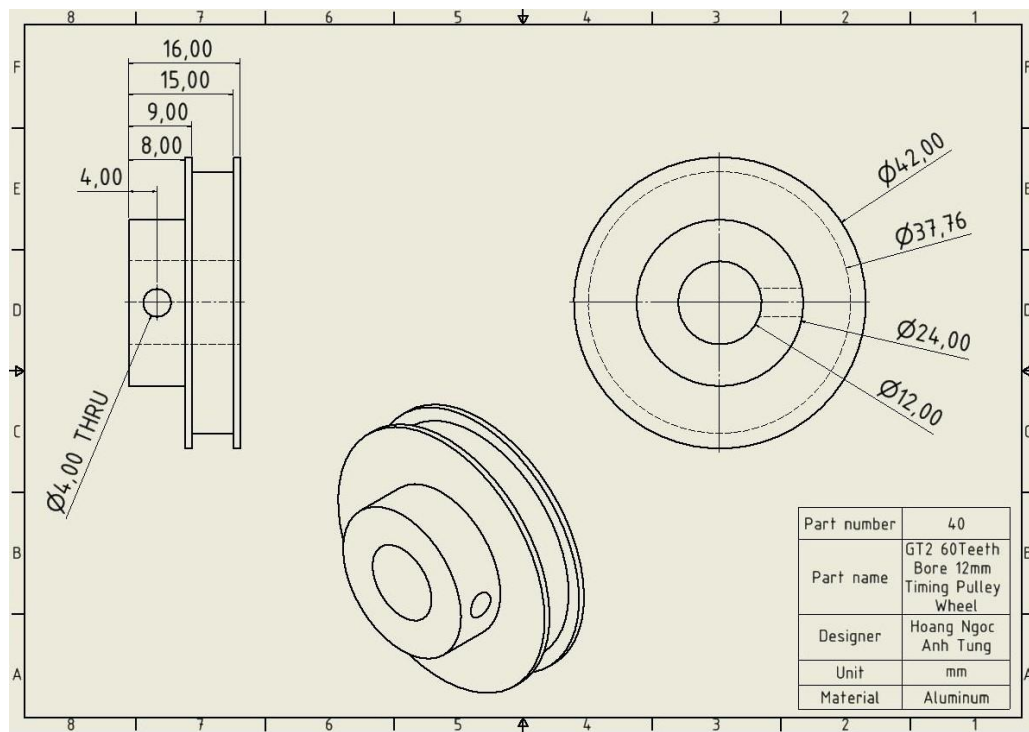


Figure 5.6: Part 40-GT2 60Teeth Bore 12mm Timing Pulley Wheel design

To calculate the length of the belt, formula below is then used:

$$L_B = 2d_p + \frac{\pi(d_1 + d_2)}{2} + \frac{(d_1 - d_2)^2}{4d_p}$$

Where,

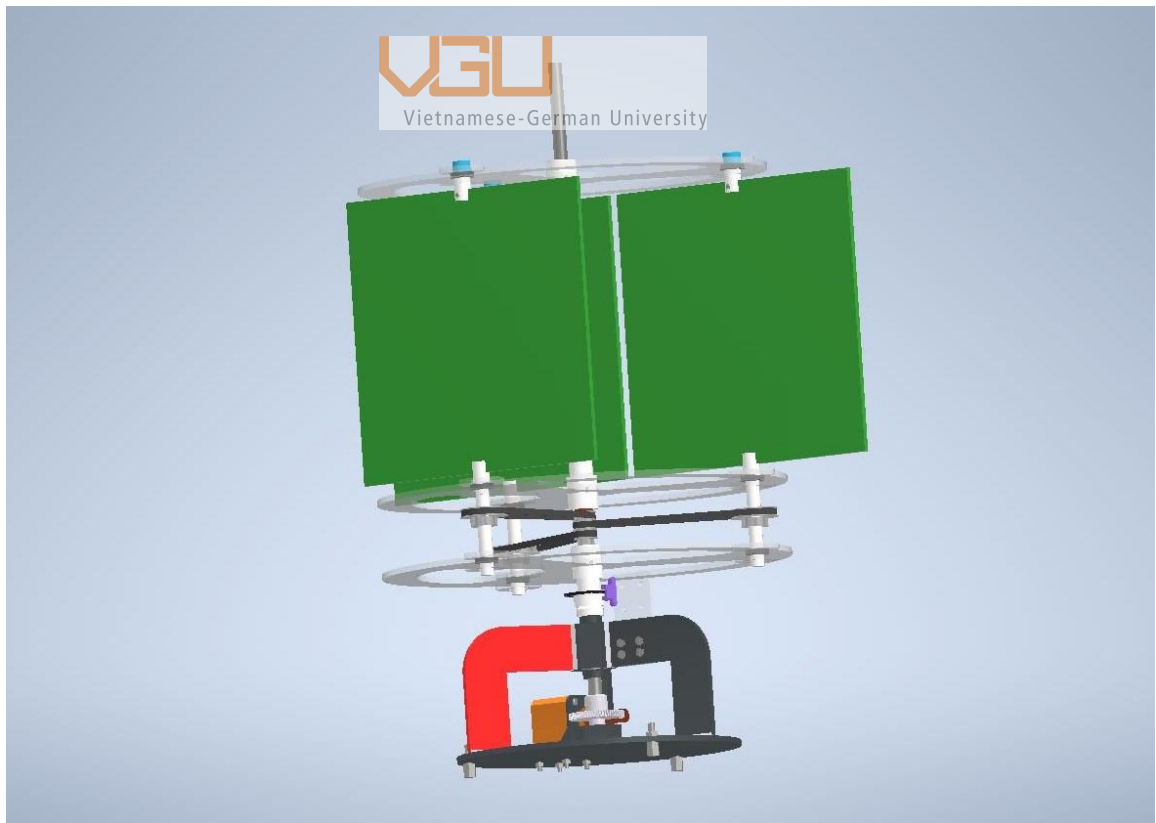
$L_B$  is the length of the belt

$d_p$  is the distance between 2 centers of pulley, which is 150mm

$d_1, d_2$  is the diameter of pulley 1 and 2, which are 18.5mm and 37.76mm respectively.

So, the belt's length is  $L_B = 389\text{mm}$ .

To assemble the improved design, turbine base (I) and lower part (III) are maintained as original, then the pulley system is replaced the spur gear system at the bottom of upper part (II) and between part II and III.



**Figure 5.7(a):** Improved wind turbine assembly

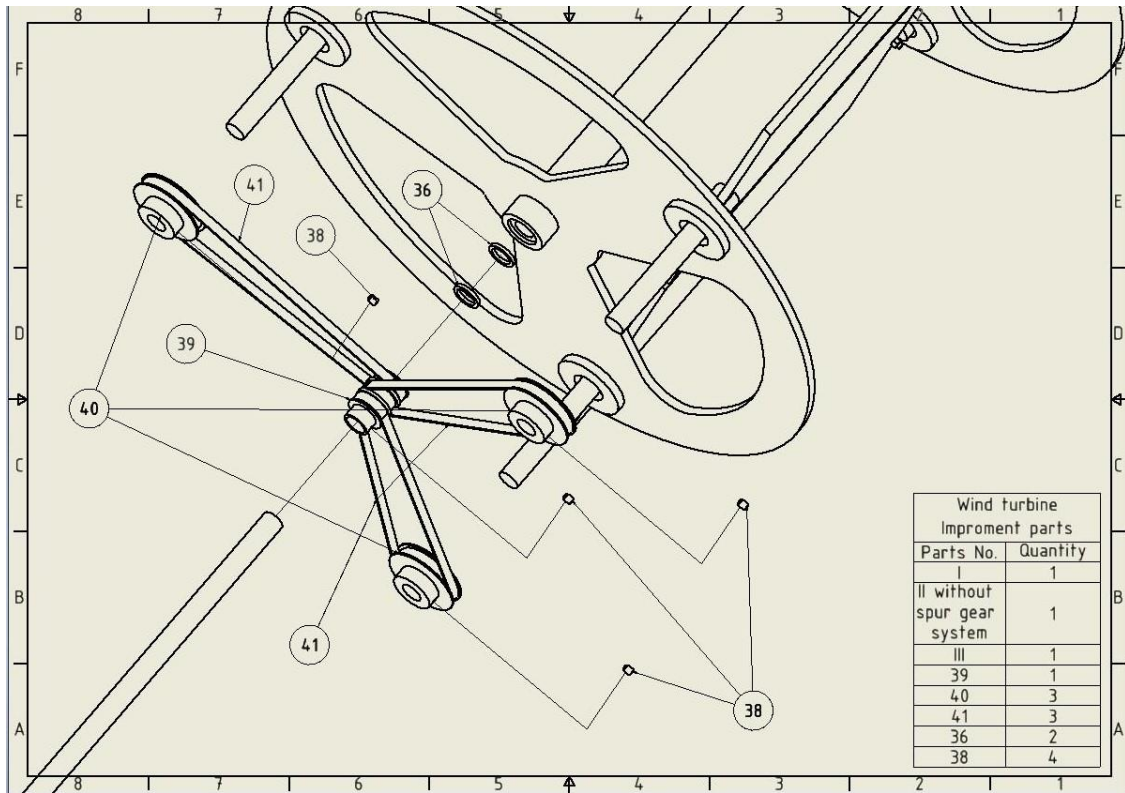


Figure 5.7(b): Improved wind turbine assembly presentation



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## 5.2. INSTALLATION AND EXPERIMENT 2

### 5.2.1. SYSTEM SET UP

The experiment is depicted in the figure below. To begin, it is necessary that the wind vane's and the turbine's North direction were same pointing forward the fan. Then, the blade's angle at four primary positions will be checked if correct. If this is the case, wind turbine's ability to rotate will be examined by an Asia fan having a 45W power and a 40cm-diameter propeller.



**Figure 5.8(a):** Improved prototype of wind turbine (angle view)  
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**Figure 5.8(b):** Improved prototype of wind turbine (angle view)



**Figure 5.8(c):** Improved prototype of wind turbine (top view)



**Figure 5.9:** GT2 Timing Pulley system



### 5.2.2. EXPERIMENT 2 RESULT

This improvement accomplishes the final requirement of the mechanical design. The pulley system can transmit the rotating movement to the blades with the correct design speed of  $\frac{\omega}{2}$  when the rotation speed of the wind turbine is  $\omega$ . Therefore, all 4 wind blade positions analysis mentioned in Chapter 2 was accurate and the Three-Bladed, Semi-Rotating Vertical Axis Wind Turbine can rotate in the wind. To test the wind turbine rotation ability, the 45W fan with various distance from the turbine and power is applied. The table below show the turbine rotation speed (rpm) measures by the Encoder V2:

Wind turbine rotation speed (rpm) according to distance from fan and fan power		Distance of turbine from fan (mm)		
		200	500	1000
Power of the fan	Maximum	102	72	54
	Average	78	48	24
	Minimum	54	24	0

Table 5.1: Wind turbine RPM



Figure 5.10: RPM shows by the LCD

# CHAPTER 6 - CONCLUSION AND FUTURE WORK

## 6.1. CONCLUSION

The essential target of this thesis, which is conceptualizing, designing and assembling a functional Three-Bladed, Semi-Rotating Vertical Axis Wind Turbine has been achieved. Through 2 experiments, all the required target of design has been obtained. These are the following steps to accomplish this goal:

- Developed an aerodynamic model of the wind turbine.
- Design a wind turbine model using Inventor software
- Examine the design and analyze the rationale of failure
- Renovate the prototype and re-test.

The conclusion is that this is a viable idea, and can be put into market although, many further researches are needed to be conducted. Additionally, I personally have learned the hard way that rigorous investigation and calculation are absolutely important before entering the real world, and having a plan as well as a clear aim is especially vital when working in group.

## 6.2. FUTURE WORK

The main goal of this thesis is to develop a conceptual prototype of a vertical axis wind turbine in order to determine the feasibility of the idea. Therefore, criteria upon mass production for household application were not thoroughly considered. Further improvements and optimizations, however, are readily available. This chapter aims to discuss those ideas.


The product should be redesigned for outdoor use, e.g., electronic and mechanical parts need to specifically coated to be protected against environmental factors such as rain or dust, also for smooth operation moving parts should be lubricated

regularly. Because the main purpose of wind turbine is electricity production, a small generator is desired to be added to the system to measure the output current.


Aerodynamics characteristics should also be put into consideration; thus, a more efficient airfoil blade form must be carefully designed. Calculations and simulations using a wind tunnel are necessary for measuring the correct wind force in reality. Also, the influence of the blades on each others needs to be considered. However, as computers have developed and processing power has increased due to Moore's law, testing on a prototype is not the only option. Nowadays, the engineer can use Computational Fluid Dynamics (CFD) which is the technique of employing computing to solve the equations of motion in order to forecast physical fluid flow theoretically, to test a new product, such as a wind turbine [28]. Therefore, to create a better airfoil for the blade, it is possible to test them first by using CFD, then making a prototype later.

The control system in this thesis allows the turbine to alter based on the wind direction without addressing the safety factor, which is one of the most significant aspects in engineering design, and thus, further development should be thoroughly tested under various situations where emergency system is needed. The power produced by the turbine stays is stable as the wind speed rising until the cut-out speed which in turn differs per turbine. At this point the turbine has to stop to avoid undue stress on the rotor in turn cause permanent fractures [29]. Moreover, a wind speed sensor needs to be brought in so the rotational speed can be calculated and controlled more accurately base on the wind speed because the turbine as well as the generator will generate the greatest amount of power when spinning at a constant speed [11].

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## APPENDIX

```
1 //arduino pin define
2 #define motorPinStep 4
3 #define motorPinDir 5
4 #define motorPinEnable 6
5 #define encoPin 2
6
7 //include stepmotor library
8 #include <AccelStepper.h>
9 AccelStepper motorOne(1, motorPinStep, motorPinDir);
10 AccelStepper setEnablePin(motorPinEnable);
11
12 //include LCD library
13 #include <Wire.h>
14 #include <LiquidCrystal_I2C.h>
15 LiquidCrystal_I2C lcd(0x27, 16, 2); //SCL A5 SDA A4
16
17 //global variables
18 int voltage;
19 int WSDposition;
20 int WSDangle;
21 int targetPosition;
22 int lastPosition = 0;
23 int distanceNeedToGo;
24 const int stepsPerRevolution = 200;
25 int counter = 0;
26 int rpm = 0;
27 const int waitingTime = 1000;
28 unsigned long current;
29 unsigned long lastTime;
30
```

```

31
32 void setup() {
33     //define pin
34     pinMode(motorPinStep, OUTPUT);
35     pinMode(motorPinDir, OUTPUT);
36     pinMode(motorPinEnable, OUTPUT);
37     pinMode(A0, INPUT);
38     pinMode(encoPin, INPUT);
39
40     //stepmotor setting
41     motorOne.setMaxSpeed(800);
42     motorOne.setAcceleration(100);
43     motorOne.setCurrentPosition(0);
44     motorOne.disableOutputs();
45
46     // LCD setting
47     lcd.init();
48     lcd.backlight();
49
50     //rotate speed Vietnamese-German University
51     attachInterrupt(0, count, RISING);
52 }
53
54
55 void loop() {
56     //Reading sensor
57     voltage = analogRead(A0);
58     //WSDpositionsensor 0
59     if (voltage >= 785 && voltage <= 795) {
60         | WSDposition = 0;

```

```

61     }
62     //WSDpositionsensor 1
63     if (voltage >= 404 && voltage <= 414) {
64         | WSDposition = 60;
65     }
66     //WSDpositionsensor 2
67     if (voltage >= 458 && voltage <= 468) {
68         | WSDposition = 56;
69     }
70     //WSDpositionsensor 3
71     if (voltage >= 76 && voltage <= 86) {
72         | WSDposition = 52;
73     }
74     //WSDpositionsensor 4
75     if (voltage >= 87 && voltage <= 97) {
76         | WSDposition = 48;
77     }
78     //WSDpositionsensor 5
79     if (voltage >= 59 && voltage <= 69) {
80         | WSDposition = 44;
81     }
82     //WSDpositionsensor 6
83     if (voltage >= 178 && voltage <= 188) {
84         | WSDposition = 40;
85     }
86     //WSDpositionsensor 7
87     if (voltage >= 119 && voltage <= 129) {
88         | WSDposition = 36;
89     }
90     //WSDpositionsensor 8

```

```

91     if (voltage >= 281 && voltage <= 291) {
92         |   WSDposition = 32;
93     }
94     //WSDpositionsensor 9
95     if (voltage >= 239 && voltage <= 249) {
96         |   WSDposition = 28;
97     }
98     //WSDpositionsensor 10
99     if (voltage >= 627 && voltage <= 637) {
100    |   WSDposition = 24;
101    }
102    //WSDpositionsensor 11
103    if (voltage >= 595 && voltage <= 605) {
104    |   WSDposition = 20;
105    }
106    //WSDpositionsensor 12
107    if (voltage >= 941 && voltage <= 951) {
108    |   WSDposition = 16;
109    }
110    //WSDpositionsensor 13
111    if (voltage >= 824 && voltage <= 834) {
112    |   WSDposition = 12;
113    }
114    //WSDpositionsensor 14
115    if (voltage >= 884 && voltage <= 894) {
116    |   WSDposition = 8;
117    }
118    //WSDpositionsensor 15
119    if (voltage >= 700 && voltage <= 710) {
120    |   WSDposition = 4;

```

```

121     }
122
123     //print wind sensor position
124     WSDangle = (WSDposition * 360) / 64;
125     lcd.setCursor(0, 0);
126     lcd.print("SD:");
127     lcd.setCursor(3, 0);
128     lcd.print(WSDangle);
129
130     // turn motor according to wind sensor
131     targetPosition = WSDposition;
132     turnMotor(targetPosition);
133
134     //speed measure
135     current = millis();
136     if ((current - lastTime) >= waitingTime) {
137         rpm = counter * 6;
138         lastTime = current;
139         counter = 0;
140     }
141     lcd.setCursor(8, 1);
142     lcd.print("WTS:");
143     lcd.setCursor(12, 1);
144     lcd.print(rpm);
145
146     delay(50);
147     lcd.clear();
148 }
149
150 void turnMotor(int motorPosition) {

```

```

151 //turn motor to motor position
152 int distanceNeedToGo1 = motorPosition - lastPosition;
153 int distanceNeedToGo2 = (motorPosition - lastPosition) - 64;
154 if (abs(distanceNeedToGo1) <= abs(distanceNeedToGo2)) {
155     distanceNeedToGo = distanceNeedToGo1 * stepsPerRevolution;
156 } else if (abs(distanceNeedToGo1) > abs(distanceNeedToGo2)) {
157     distanceNeedToGo = distanceNeedToGo2 * stepsPerRevolution;
158 }
159 motorOne.move(distanceNeedToGo);
160 if (motorOne.distanceToGo() != 0) {
161     motorOne.enableOutputs();
162     if (motorPosition == 0) {
163         while (motorOne.distanceToGo() != 0) {
164             motorOne.run();
165         }
166     } else {
167         motorOne.runToPosition();
168     }
169     lastPosition = motorOne.currentPosition() / stepsPerRevolution;
170     motorOne.disableOutputs();
171 }
172
173 //print real wind turbine angle
174 int WTangle = (motorPosition * 360) / 64;
175 lcd.setCursor(8, 0);
176 lcd.print("TD:");
177 lcd.setCursor(11, 0);
178 lcd.print(WTangle);
179 }
180
181
182 void count() {
183     counter++; // count pulse
184 }
185

```



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