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بسم الله الرحمن الرحيم

DESIGN AND BUILDING A SMALL WIND ENERGY CONVERSION SYSTEM

~~by~~By

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Walid Kh Dwaik

Mohammad Sufian Sultan

Basil Najeeb Al-Tamimi

Supervisor

Dr. Imad Al-Khatib

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A thesis submitted to

Mechanical Engineering Department

College of Engineering & Technologies

Palestine Polytechnic University

In partial fulfillment of the requirements for the degree of ~~Baccalaureate~~ Bachelor in Mechatronics Engineering

~~August~~ September -2003

شهادة تقييم مشروع التخرج

جامعة بوليتكنك فلسطين

فلسطين – الخليل

DESIGN AND BUILDING A SMALL WIND ENERGY CONVERSION SYSTEM

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من إعداد:

وليد خالد الدويك

محمد سفيان سلطان

باسل نجيب التميمي

بناء على توجيهات الأستاذ المشرف على المشروع وبموافقة جميع أعضاء اللجنة الممتحنة، تم تقديم هذا المشروع إلى دائرة الهندسة الميكانيكية في كلية الهندسة والتكنولوجيا للوفاء الجزئي بمتطلبات الدائرة لدرجة البكالوريوس.

توقيع مشرف المشروع

توقيع رئيس الدائرة

الإهداء

إلى أمهاتنا اللواتي ربيننا وسهرنوا على راحتنا حتى غدونا على ما نحن عليه.

إلى آبائنا الذين بذلوا كل جهد لكي يصنعوا منا رجالا يعتمد عليهم.

إلى أبطالنا البواسل – الذين هم في قلوبنا- المعتقلون في سجون الاحتلال.

إلى شهدائنا الأبرار الذين وهبوا أنفسهم في سبيل الله.

إلى جامعتنا جامعة بوليتكنك فلسطين.

إلى فلسطين بكامل ترابها من نهرها إلى بحرها.

إلى كل هؤلاء نهدي هذا العمل المتواضع.

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ACKNOWLEDGMENTS

We would like to express our appreciation~~s~~ to all people who helped us designing, producing and finalizing our graduation project. Special thanks are due to our supervisor Dr. Imad Al-Khatib, ~~to the head of mechanical engineering department~~ Dr.Ishaq Sider, to Eng.Yousef Sweity, to Eng. -Jalal El-~~Salaymeh,~~Salaymeh, to Dr. Mou'men Zughaier, to Mr. Tawfiq Amro, and to Mr. Abdul Nasser Sultan.

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ABSTRACT

DESIGN AND BUILDING A SMALL WIND ENERGY CONVERSION SYSTEM

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Walid Kh. Dwaik

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Palestine Polytechnic University

2003

Supervisor

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This graduation project aims at designing, building and setting an optimal small wind energy conversion system that would utilize the available wind energy and convert it into electrical power energy. This small power conversion system is intended to serve as an experimental system that might help afterwards utilizing wind energy in a large scale. The work represented here consists of an introductory describing the history of using wind energy conversion systems and a theoretical description explaining the working theory of small wind turbines and their feasibilitie~~y~~s. This is followed by a section describing the construction of wind turbines, starting from ~~the blade~~ designing the blades, building the nacelle, yaw drive, wind van, hub, and the tower, to the generator and the electrical storage system (~~UBS~~UPS). The final section in this thesis talks about the shaft speed control system and other ~~required~~ safety requirements ~~systems~~. It should be noted that a section describing system performance under testing should have been added but due to the ongoing circumstances we could not conduct a proper system performance testing. We leave it to our colleagues at the University.

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يهدف المشروع إلى تصميم و بناء نظام تحويل طاقة الرياح إلى طاقة كهر بائية كبـــديل لمصـــــادر الطاقـــة التقليدية. المشروع صغيرا نسبيا ولكنه يمثل تجربة أولية ودراسة مبسطة لبدء استخدام مثل هذا الأنظمة فـــي منطقتنا. الجانب النظري يطرح كل ما يتعلق ببناء عنفات الرياح الصغيرة وذلك بأسلوب مبسط يمكـــن مـــن خلاله استخدام التقنيات المحلية في إنتاجه.أما الجانب العملي فيمثل تطبيق للجزء النظري مع استغلال تام لكل ما يمكن توفيره من تكلفة في البناء. نعرض في تقريرنا نبذة عن تاريخ استخدام عنفات الرياح وعن الفوائـــد البيئية والاقتصادية وما يتعلق بحاجتنا في فلسطين لاستخدام مثل هذه التقنيات. ثم نتناول عملية البناء بـــدءا بكيفية بناء ريش العنفات، وما يتعلق بها من حسابات ثم بناء القاعدة، والبرج وباقي المتعلقات، ثـــم ننتقـــل لحديث عن المولد وعن نظام التخزين للطاقة الكهربائية. وفي النهاية نعرض كيفية بناء اجهزة التحكم فـــي سرعة دوران التربين وأنظمة الحماية. ومن الجدير ذكره انه بسبب الظروف الحالية لم نستطع عمل التجارب الخاصة بتقييم اداء هذا النظام ومنه نترك ذلك لزملائنا في الفصول القادمة.

Contents

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List of Symbols

symbol	Description	Unit
N	Shaft speed	*[RPM]*
V	Wind speed	*[m/s]*
TSR or λ	Tip speed ratio	–
B	Number of blades	–
C	Chord width	*[m]*
β	Blade angle	*[degree]*
α	Angle of attack	*[degree]*
Φ	The angle between the apparent wind and the rotor plane	*[degree]*
Cl	Lift coefficient	–
Cd	Drag coefficient	–
M	Moment	*[N.m]*
σ	Stress	$[N/m^2]$
I	Moment of inertia	$[m^4]$
n	Factor of safety	–
T	Torque	*[N.m]*
τ	Shear stress	$[N/m^2]$
S_y ~~Sy~~	Yield strength	$[N/m^2]$
J	Moment of inertia	$[m^4]$
w_n	Natural frequency	*[rad/s]*
ρ	Air density	$[Kg/m^3]$
C_p ~~Cp~~	Coefficient of wind turbine	–
η	Efficiency	–
A	Area	$[m^2]$
D	Diameter	*[m]*
R	Rotor radius	*[m]*
r	Local radius	*[m]*
~~—~~	~~Blade angle~~	~~*[Degree]*~~

F	Force	*[N]*
e	Blade length /2	*[m]*
t	Thickness	*[m]*
Se	Endurance limit	*[MPa]*
S'_e	Endurance limit of specimen	*[MPa]*
K_a	Surface factor	–
K_b	Size factor	–
S_{ut}	Ultimate strength	*[MPa]*
a	Surface factor	–
b	Exponent value	–
W	Weight	*[N]*
P	Power	*[W]*
w	Angular velocity	*[rad/s]*
E_g	Electromotive force voltage	*[V]*
I_a	Armature current	*[A]*
r_a	Armature resistance	*[Ω]*

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Chapter One Introduction ~~Chapter Two~~

~~Wind Turbine Specifications and~~

Introduction

1.1 History of Utilizing Wind Energy

The term "wind energy" or "wind power" describes the process by which the wind is used to generate mechanical power or electricity using wind turbines. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or could be coupled to a generator that can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Wind is a form of solar energy caused by the uneven heating of the earth's irregular surfaces and hence the atmosphere by the sun. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by wind turbines can be used to generate electricity.

Since earliest recorded history, wind power has been used to move ships, grind grain and pump water. There is evidence that wind energy was used to propel boats along the Nile River as early as 5000 B.C. Within several centuries before Christ, simple windmills were used in China to pump water.

Wind was also utilized in Europe, where it was considered as an important source of energy. E.g. in Netherlands the 700 windmills in the Zaan district north of Amsterdam formed the nucleus of what would become the center of Dutch manufacturing in the 17th century and helped spur the industrial revolution. Wind energy was eclipsed by steam only at the end of the last century. As late as 1850, 90% of the power used in Dutch industry came from the wind.

Despite being overshadowed by fossil fuels, wind energy has never completely fallen out use. Revival of interest in wind energy in the 1970s prompted dramatic advancements in the technology. Now modern airfoils and materials enable today's wind turbines to extract 10 times more power from the wind than the windmill 100 years earlier.

In the United States, millions of windmills were erected as the American West was developed during the late 19th century. Most of them were used to pump water for farms and ranches. By 1900, small electric wind systems were developed to generate direct current, but most of these units fell into disuse as inexpensive grid power was extended to rural areas during the 1930s. By 1910, wind turbine generators were producing electricity in many European countries.

1.2 Wind Energy and The Environment

Numerous public opinion surveys have consistently shown that the public prefers wind and other renewable energy forms over conventional sources of generation. Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. In 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

1.3 Wind turbine classifications

Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator which supplies an electric current. Modern wind turbines fall into two basic groups; the horizontal-axis variety, like the traditional farm windmills used for pumping water; and the vertical-axis design, like the eggbeater-style. Modern wind technology takes advantage of advances in materials, engineering, electronics, and aerodynamics. Wind turbines are often grouped together into a single wind power plant, also known as a wind farm, and generate bulk electrical power.

In 2001, world wind capacity soared past the 24000 MW mark, having doubled in the past two years. Of that amount, about 6500 MW was installed during 2001 alone. Since 1990, wind has been the fastest-growing power source worldwide on a percentage basis, with an annual average growth rate of just over 25%. During the past two years, it has i.e. tripled in Germany and quadrupled in Spain.

The "top 5" nations listed in Table 1.1 accounted for over 95% of the total wind energy produced in 2001.

Table 1.1 Wind energy produced in 2001[1]

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Country	Capacity (MW)
Germany	8750
USA	4261
Spain	3337
Denmark	2417
India	1407

Elsewhere, wind is catching on slowly but steadily, with new plants having been built recently in Portugal, Morocco, Jordan, and other countries.

[1] "The Most Frequently Asked Questions about Wind Energy" Department of Energy and the National Renewable Energy Laboratory 2002.

Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine, such as the one built in Hawaii, has propellers that span the more than the length of a football field and stands 20 building stories high, and produces enough electricity to power 1400 homes. A small home-sized wind machine has rotors between 1 and 9 meters in diameter and stands upwards of 10 meters and can supply the power needs of an all-electric home or small business.

The wind turbine sizes can be classified as appear in Table1.2.

Table1.2 Wind turbine sizes[1]

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Wind Turbine size	Rated output (*kW*)	Rotor Diameter (*m*)	Swept Area (m^2)
Small	*0 to 20*	*1 to 10*	*0.5 to 80*
Medium	*20 to 200*	*10 to25*	*80 to 500*
Large	*200 to 1500*	*More than 25*	*More than 500*

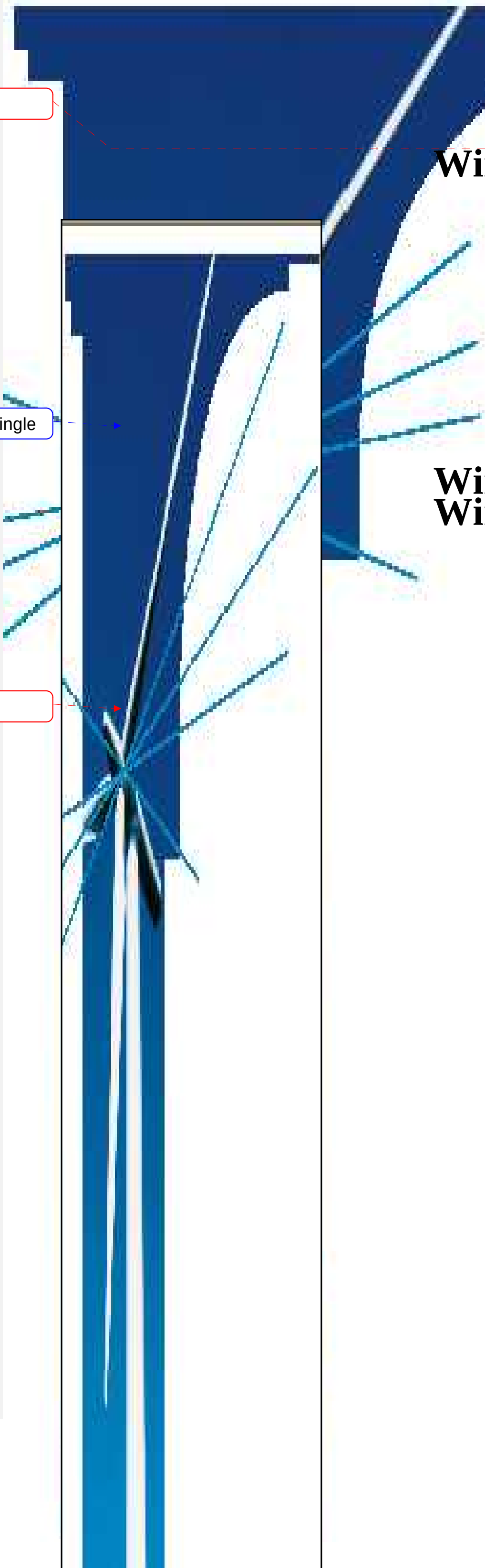
1.4 Wind Turbine in Palestine

In Palestine renewable energy sources, including wind, are considered very important especially because they are not subjected to monopoly and because they can be utilized using the available local technology. It is known that solar energy has been used for long time in Palestine mainly for producing hot water for domestic use. In some applications, photovoltaic is being used to convert directly solar energy into electrical energy. Wind energy has been recently used for experimental purposes only. At the Renewable Energy and Environment Research Unit (REERU) of the Palestine Polytechnic University, there have been several attempts to design and produce systems utilizing solar energy, such as the solar high concentrating collector, and the wind energy. It is worth mentioning that wind energy has a promising

[1] "The Most Frequently Asked Questions ~~About~~about Wind Energy" Department of Energy and the National Renewable Energy Laboratory 2002.

potential in the energy conversion processes. However it is essential to prepare a wind map for Palestine indicating the potential sites for wind energy systems. Here in Hebron there exist a potential for using the natural circulation of wind considering the dominant wind speed and direction resulting from the see breeze and the catabatic/anabatic circulation from and to Hebron hills.

The idea of utilizing wind energy for producing electrical energy serving the needs of the university campuses in the range exceeding 300W is fascinating. Building and testing an experimental wind power system will help in developing a range of power conversion systems on the national level capable of delivering electrical power to remote areas where electrical grids do~~es~~ not exist.



Chapter Two

Chapter Two

Wind Turbine Specifications and components

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Wind turbine Specifications and Components

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2.1 Wind Turbine Specifications

The work presented here, is an attempt to design and manufacture a small wind power system capable of producing electrical energy in the range of 300W that can be utilized in providing lighting source, operating a water pump or a communication unit located in remote areas. In order that the energy produced can meet the demand in a stabilized manner, a storage system will be used. The project items, including the tower, the casing, the permanent magnetic generator, the turbine blades, the wind direction tail, etc. In table 2.1 below, specification of the wind turbine are presented. These design specifications were chosen based on the technical and economical considerations. Figure 2.1 shows flow chart drawings of system work.

Table 2.1 Wind turbine specifications

Rated wind speed	*5m/s*
Rated output power	*300W*
Type	*3 blades, upwind, horizontal axis*
Rotor diameter	*3.9m*
Over speed protection	*Pitch control system & Brake control system*
Drive	*Direct (no gears are used)*
Generator type	*Permanent magnet DC*
Output form	*220VAc, 50Hz*
Tower type	*Lattice*
Tower height	*6m*
Rated rotational speed	*130 RPM*
Blade material	*Fiber glass*
Blade Airfoil (Shape)	*NACA 4412*
Maximum Wind Speed (in Hebron)	*13m/s*

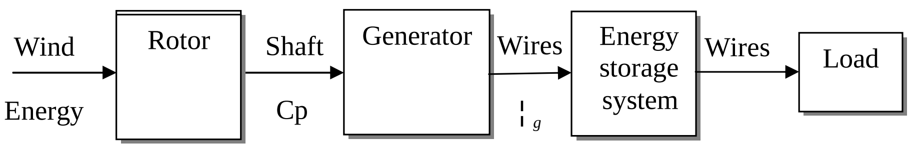

Fig 2.1 Flowchart diagram describing wind turbine work

2.2 Wind turbine components

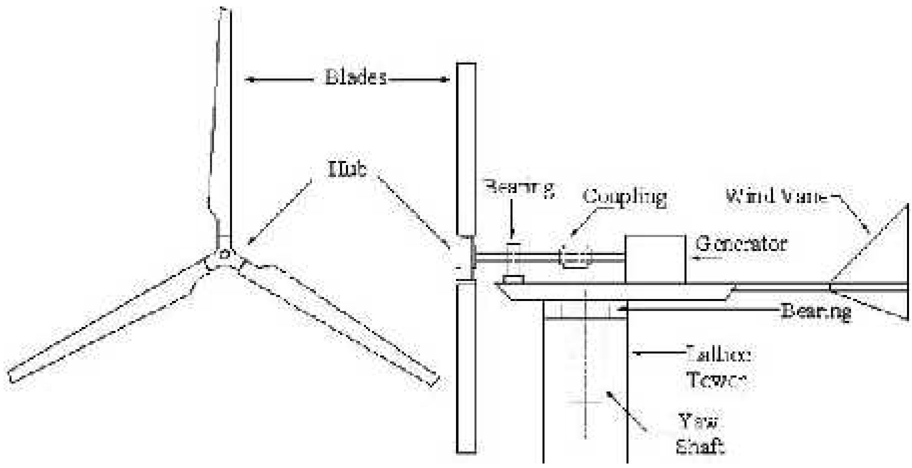

Fig ~~2.2 Wind~~2.2 Wind Turbine Components

The parts presented in the schematic figure are listed as:

1. Blades: Three blades are connected to the central hub. ~~will~~ They are converting ~~form the wind~~wind ~~turbine~~ energy ~~that will be converting wind energy~~ into mechanical energy.
2. Controller: The main function is to control the shaft speed according to the wind speed.
3. Generator: Converts the mechanical energy into electrical energy.
4. Hub: The blades on the wind turbine are bolted to the hub.
5. Tower: Tower is made from lattice steel. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

6. Wind vane: To keep the blades facing to the wind direction.
7. ~~UBS~~UPS: system for storage electrical (output) energy.
8. Bearings: to support the shafts and decrease the friction.
9. Rotor shaft: transmit the rotational motion from the rotor to the generator.
10. Yaw shaft: allow the nacelle to rotate around the tower.
11. Coupling: to connect between the rotor shaft and generator shaft.

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Wind Turbine Principle of Work

3.1 Airflow Effects on Turbine Blades

The wind energy will cause the rotor to rotate and convert wind energy to mechanical energy by rotating the shaft connected to a generator that will convert this mechanical energy into electrical. This electrical energy is stored in batteries and then to the load.

A total aerodynamic force is generated when a stream of air flows over and under an airfoil that is moving through the air. The point at which the air separates to flow about the airfoil is called the point of impact as shown in Fig. 3.1 below.

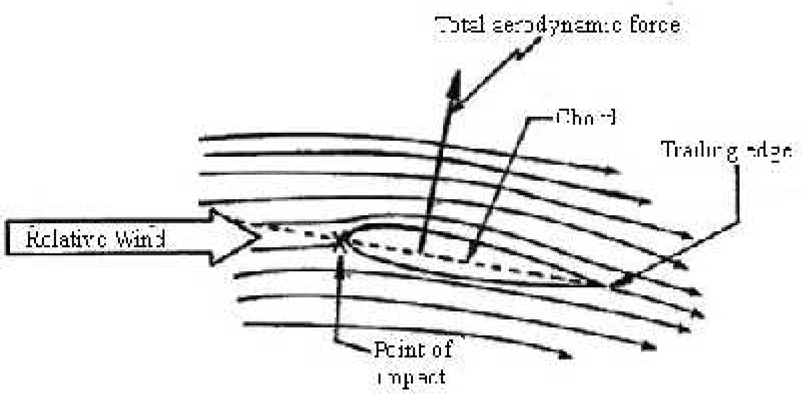

Fig 3.1 Airflow around an airfoil

A high pressure area or stagnation point is formed at the point of impact. Normally the high pressure area is located at the lower portion of the leading edge, depending on angle of attack. This high pressure area contributes to the overall force produced by the blade.

Fig3.1 also shows airflow lines that illustrate how the air moves about the airfoil section. Notice that the air is deflected downward as it passes under the airfoil and leaves the trailing edge. Remember Newton's third law which states "every action has an equal and opposite reaction." Since the air is being deflected downward, an equal and opposite force must be acting upward on the airfoil. This force adds to the total aerodynamic force developed by the airfoil. At very low or zero angles of attack, the deflection force or impact pressure may exert a zero positive force.

3.2 Aerodynamic forces

Air passing over the top of the airfoil produces aerodynamic force in another way. The shape of the airfoil causes a low pressure area above the airfoil according to Bernoulli's Principle, and the decrease in pressure on top of the airfoil exerts an upward aerodynamic force. Pressure differential between the upper and lower surface of the airfoil is quite small - nearly 1 percent. Even a small pressure differential produces ~~substantial~~substantial force when applied to the large area of a rotor blade.

The total aerodynamic force, sometimes called the resultant force, may be divided into two components called lift and drag as shown in ~~fig3~~Fig3.2. Lift acts on the airfoil in a direction perpendicular to the relative wind. Drag is the resistance or force that opposes the motion of the airfoil through the air. It acts on the airfoil in a direction parallel to the relative wind:

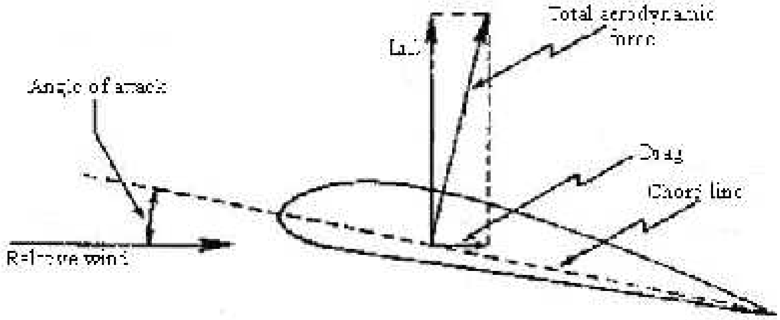

Fig 3.2 Forces acting on an airfoil

Many factors contribute to the total lift produced by an airfoil. Increased speed causes increased lift because a larger pressure differential is produced between the upper and lower surfaces. Lift does not increase in direct proportion to speed, but varies as the square of the speed. Thus, a blade traveling at 10m/s has four times the lift of the same blade traveling at only 5m/s. Lift also varies with the area of the blade. A blade area of 30 square meters will produce twice as much lift as a blade area of only 15 square meters. Angle of attack also has an effect on the lift produced... Air density is another factor that directly influences lift.

Two design factors, Airfoil Shape and Airfoil Area are primary elements that determine how much lift and drag a blade will produce. Any change in these design factors will affect the forces produced. Normally an increase in lift will also produce an increase in drag. Therefore, the airfoil is designed to produce the most lift and the least drag within normal speed ranges.

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Chapter Four
Mechanical Design

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Mechanical Design

4.1 Design and Manufacturing of Turbine Blades

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4.1.1 Blade ~~Manufacturing~~manufacturing process:

In constructing the blade we shall select the suitable airfoil, and suitable material, in our project we have chosen [NACA 4412] as an airfoil reference and polystyrene coated with fiberglass as the blade material.

The process implies by printing airfoil sections as template. Each section differ from previous section with 5cm in radius, then cutting polystyrene foam as geometrically similar to each template section, which can later be glued together, painted (to prevent resin dissolving the polystyrene) and then coated with fiberglass.

(In Appendix B, template section is drawn to a specific geometrical scale).

The shape of the blades chosen for the wind system is [NACA 4412 airfoil reference][1], the length of the blade is taken to be 1.8 m which is made of fiberglass. The number of blades is 3; this because a 3 bladed rotor is easy to balance and yaws smoothly.

4.1.2 Tip speed ratio (TSR or λ):

The 'tip-speed-ratio' is the speed at which the blade tip should run compared to the wind speed. The shaft speed in revolutions per minute (RPM) depends on the tip speed and the rotor diameter.

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$$N = \frac{V \times \lambda \times 60}{D \times \pi} = 300\,RPM \qquad 4.1^{[2]}$$

Where N: shaft speed (RPM)

V: wind speed (m/s)

λ: tip speed ratio

D: rotor diameter (m)

[1] The United States National Advisory Committee for Aero-nautics

[2] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997, ISBN 1-898049-13-0

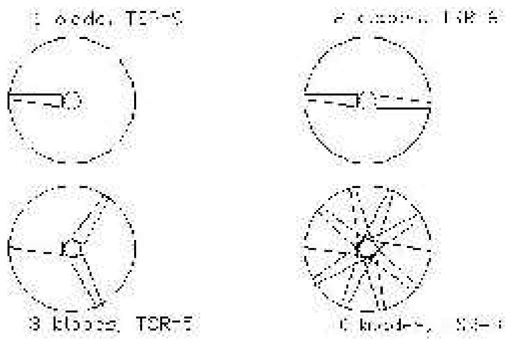

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Fig 4.1 Relation between tip speed ratio and blades number

As shown in F~~f~~ig~~ure~~ 4.1 the tip speed ratio is inversely proportional to the number of blades according to this formula:

$$B = \frac{80}{\lambda^2} \qquad (4.2)$$ [1]

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Where B: number of blades

λ: tip speed ratio

4.1.3 Chord width ~~(C( )~~C ~~:~~):

The width of the blade.

$$C = \frac{16\pi\, R(R/r)}{9\lambda^2 B} \qquad (4.3)$$

Where: ~~C :~~C: chord width (m).

~~R :~~R: rotor radius (m).

r: local radius ~~at~~ (m).~~which we compute chord width (C) and blade angle (β) (m)~~

Equation 4.3 used for the outer part of the blade because it is the most important part in gathering wind energy~~)~~.

[1] All blade Equations refer to Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

4.1.4 Chord line:

It is defined as the longest line within the blade section, and it joins the leading edge to the trailing edge.

4.1.4 Blade angle (β):

It is the angle between the chord line and the rotor plane (see Ffig 4.4).

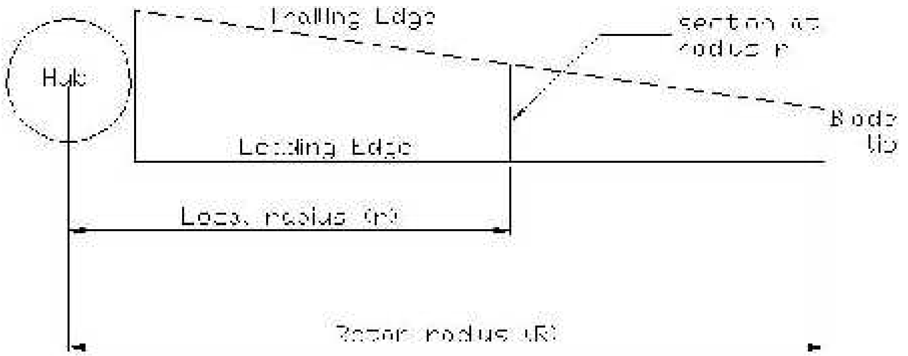

Fig 4.2 Blade glossary

To create a blade design we need to specify the chord width and blade angle at each station along the span of the blade, as shown in Ffigure 4.3:

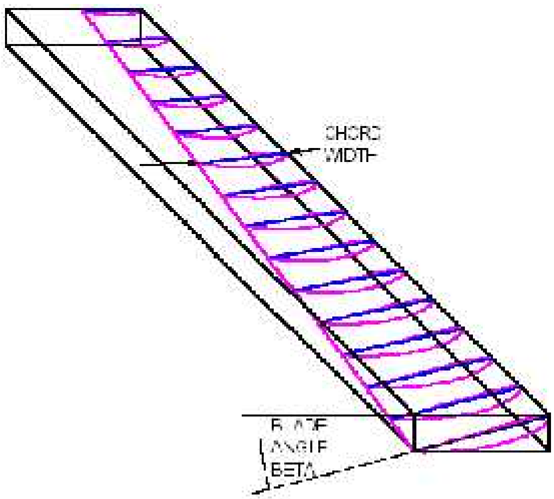

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Fig 4.3 Blade sections

=¤ –~ (4.4)

Where: : Blade angle .

¤ : The angle between the apparent wind & the rotor plane.

~ : The angle between the apparent wind & the chord line.

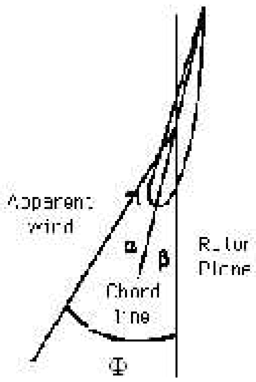

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Fig ~~4.4 Blade~~4.4 Blade angle

$$¤ = \tan^{-1}\left(\frac{2R}{3r\,a}\right) \quad \text{For outer diameter} \qquad (4.5)$$ [1]

Then:

$$= \tan^{-1}\left(\frac{2R}{3r\,a}\right) - \sim \qquad (4.6)$$ [2]

To find the angle of attack (~) - which is always constant - we have to look for the maximum lift coefficient (Cl), minimum drag coefficient (Cd), and the maximum lift/drag ratio according to the

~~figures~~Figures 4.5 ~~& 4.6.~~:

From the Fig 4.5 we can find ~ to be 5 degrees, Cl equals 0.8, and Cd is 0.06 which means that we can capture the most power from the wind. We can rewrite Eq 4.6 as in Eq 4.7.

[1] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

[2] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

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$$= \tan^{-1}\left(\frac{2R}{3r\,a}\right) - 5 \qquad (4.7)$$ [1]

After finding the chord width (C) and blade angle ( ) for each station; we can construct the blades.

[Results of blade equations attached at end of this chapter in table 4.2.]

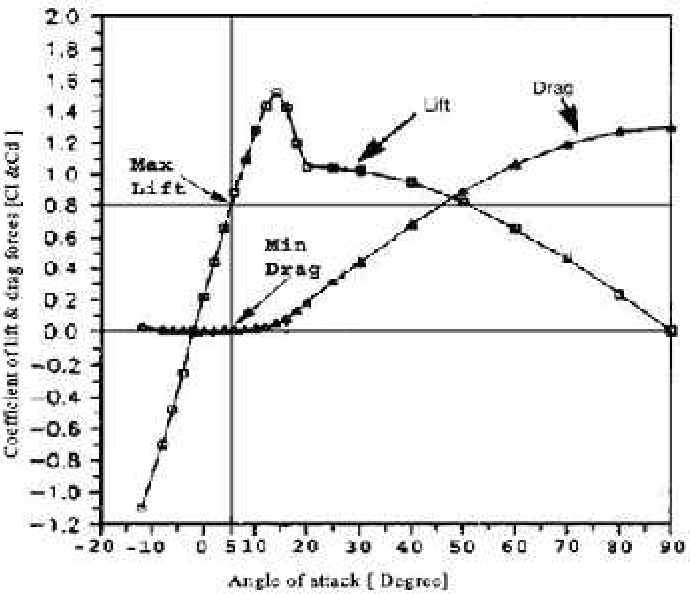

Fig 4.5 Cl & Cd versus angle of attack[2]

~~From the two figures 4.5 & 4.6 we can find ~ to be 5 degrees, Cl equals 0.8, and Cd is 0.06 which means that we can capture the most power from the wind. We can rewrite Eq 4.6 as in Eq 4.7.~~

---

[1] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

[2] Henrik Stiesdal, "The Wind Turbine Components and Operation" Translation: John Furze, Hugh Piggott, autumn 1999.

Fig 4.6 Angle of attack

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$$= \tan^{-1}\left(\frac{2R}{3r\,a}\right) \quad 5 \qquad (4.7)$$ [1]

~~Now after we can find the chord width and blade angle for each station; we can design our blades.~~

~~[Results of blade equations attached at end of this chapter in table 4.2.]~~

4.2 Testing Blades Strength

It is intended by strength testing to determine whether the stresses in the fiberglass blades are safe or not. We need to have a margin of safety in ~~ar~~range which can withstand unexpected events, and associated fatigue. The main stress on small wind turbine blades arises from thrust forces. Thrust force imposes a bending stress on the blade (see Fig 4.7).

[1] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

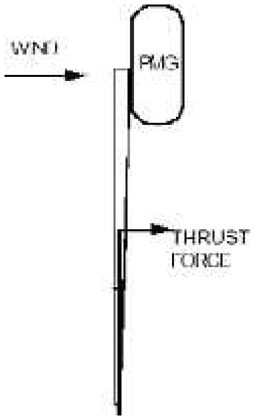

Fig ~~4.7 Thrust~~4.7 Thrust force

$$F = Fl\cos ¤ + Fd\sin ¤ \qquad (4.8)$$

Where: *F*: Thrust Force.

Fl: Lift Force.

Fd: Drag Force.

¤ : The angle between the apparent wind & the rotor plane.

$$Fl = Cl\,(° /2)\,AV^2 \qquad (4.9)$$

$$Fd = Cd\,(° /2)\,AV^2 \qquad (4.10)$$

Where: *Cl*: Lift force coefficient.

Cd: Drag force coefficient.

° : Air density [$1.225\,kg/m^3$].

A : Blade surface area .

$$¤ = \tan^{-1}\left(\frac{2R}{3rª}\right) \qquad (4.11)$$

$$F = (° /2)\,AV^2\,(Cl\cos ¤ + Cd\sin ¤) = 139N \qquad (4.12)$$ [1]

[1] All blade equations from Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

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It is difficult to find the ~~centroid~~cancroid or the area for an airfoil shape; so we will consider the blade as a hollow rectangular shape as in F~~f~~ig~~ure~~ 4.8:

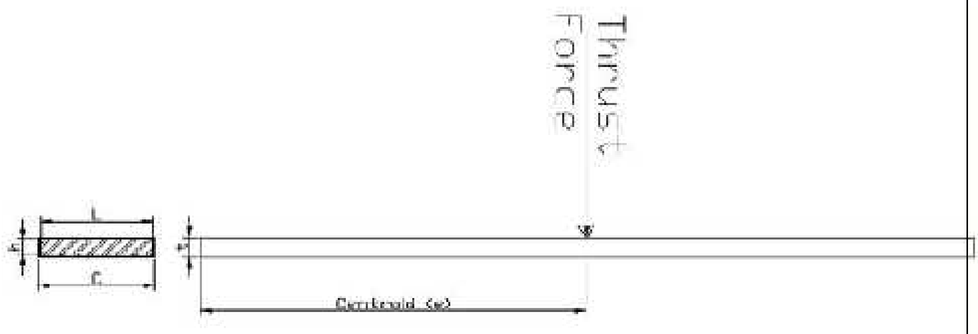

Fig 4.8 Blade cross section

$$M = F * e = 33.8\,N.m \qquad (4.13)$$

$$\pm = \frac{M \times \frac{t}{2}}{I} = 20.5\,MPa \qquad (4.14)$$

Where:

M: The moment (*N.m*).

±: The stress (*N/m*^{2}).

F: Total force on the blades (*N*).

I: Moment of inertia (m^4).

$$e : \text{blade length}/2 \ (m) \qquad (4.15)$$

$$I = \frac{C \times t^3}{12} - \frac{Lh^3}{12} = 1.4765 \times 10^{-6}\, m^4 \qquad (4.16)$$

t : *thicknes* (m).

h : *inner thicknes* (m).

C : *chord width* (m).

L : *inner chord width* (m).

For safety design:

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$\pm \leq S_y$

$$n_{blade} = \frac{S_y}{\pm} = 5 \qquad (4.17)$$

Where:

n_{blade} : Factor of safety of the blade.

S_y : Yield strength of Fiberglass material (S_y =*103.5 MPa*[1]).

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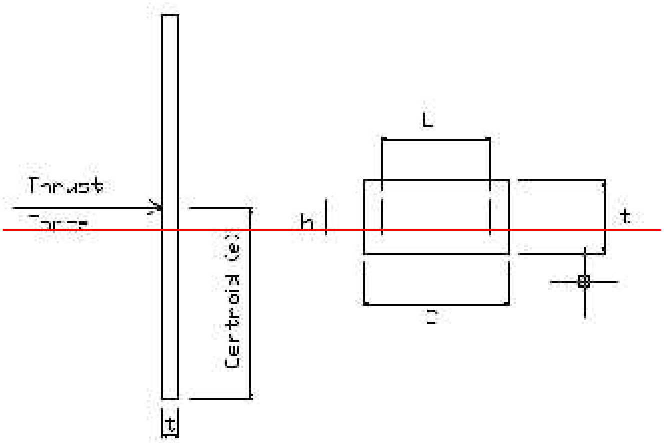

~~Fig 4.8 Blade cross section~~

~~For safety design:~~

$\pm \leq S_y$

$$n_{blade} = \frac{S_y}{\pm} \qquad (4.17)$$

Where

~~n_{blade} :Factor of safety must be ≥1~~

S_y :Yield strength

[1] William D. Callister Jr, Materials Science & Engineering, 4th Ed, John Wiley & Sons Inc, 1996.

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4.3 Generator Shaft Design:

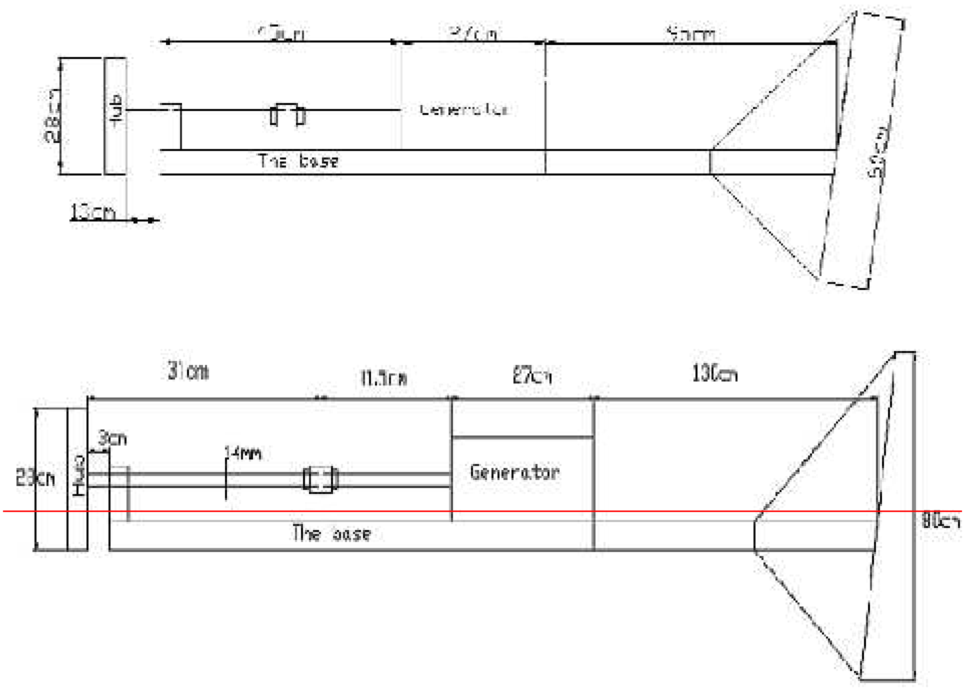

Fig 4.9 The nacelle dimension

Fig 4.9 shows the nacelle proper dimension & Fig 4.10 shows the shape of the generator shaft.

The shaft rotation is due to the rotation of blades, where the torque produced from the rotation of the blades given according to the following equation:

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$$T = \frac{V^2 \times R^3}{a^2} = 39.4\, N.m \qquad (4.18)$$ [1]

Where: a : tip speed ratio.

V: wind speed (m/s).

R: Rotor radius (m).

[1] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.

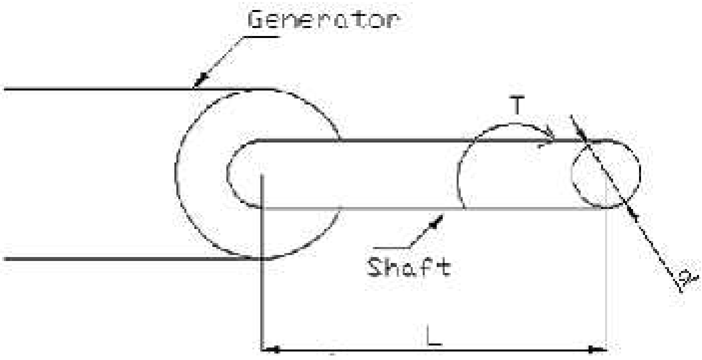

Fig 4.10 Generator shaft

Fig 4.9 shows the nacelle proper dimension & Fig 4.10 shows the shape of the generator shaft.

The shaft rotates is due to the rotation of blades, where the torque produced from the rotation of the blades can be written according to the following equation:

$$T = \frac{V^2 \times R^3}{a^2} \qquad (4.18)^{1}$$

Where: a : tip speed ratio.

V : wind speed [m/s].

R: Rotor radius [m].

We have rotating shaft supported in ball bearing at the two ends. In designing the shaft we have to study the strength of shaft and to estimate the life of shaft due to rotation. The shaft material is cold drawn steels (AISI NO: 1050).

From mechanical properties of steels we find that tensile strength of the shaft material is ($S_{ut} = 690 MPa$), and yield strength ($S_y = 580 MPa$)[2].

Firstly we will estimate the endurance limit due to the rotation.

$$S_e = K_a K_b S_e^{'} = 264.89 MPa \qquad (4.19)$$

[1] Hugh Piggott, Windpower Workshop, Centre for Alternative Technology Publications, May 1997.
[2] See Table A-20, Joseph Shigley & Charles Mischke, Mechanical Engineering Design, 5th edEd.

Where :

S_e : endurance limit

$S_e^{'}$: endurance limit of test specimen

K_a : surface factor

K_b : size factor

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$$S_e^{'} = 0.504 S_{ut} = 374.8\,MPa \qquad (4.20)^{1}$$

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$$K_a = aS_{ut}^{b} \qquad (4.21)$$

Where:
a: surface factor.[2]
b: exponent~~xponent~~ factor.

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$$K_b = \left(\frac{D}{7.62}\right)^{-0.1133} \qquad (4.22)^{3}$$

Where D: shaft diameter.

Then we will estimate the factor of safety due to the torque (T).

$$2_{\max} = \frac{16T}{®D^3} = 73.16\,MPa \qquad (4.23)$$

T : the tourqe (N.m)

D : shaft diameter (m)

$2_{\max}$: max shear stress (Mpa)

$$n_{shaft} = \frac{S_y}{2_{\max}} = 4 \qquad (4.24)$$

Where:

n_{shaft} : Factor of safety of the shaft.

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S_y : Yield strength of cold drawn steel material.

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After calculating the parameter we find that $2_{\max} \le S_e$, so the shaft has infinite life.

---

[1] See Eq(7-9) page 281, Joseph Shigley & Charles Mischke, Mechanical Engineering Design, 5th ed.
[2] See Table 7-4, page 283, Joseph Shigley & Charles Mischke, Mechanical Engineering Design,5th ed.

[3] See Eq(7-15) page 283, Joseph Shigley & Charles Mischke, Mechanical Engineering Design, 5th ed.

Figure 4.11 shows the relation between wind speed versus starting torque and Shaft speed of the wind turbine which designed in our project.

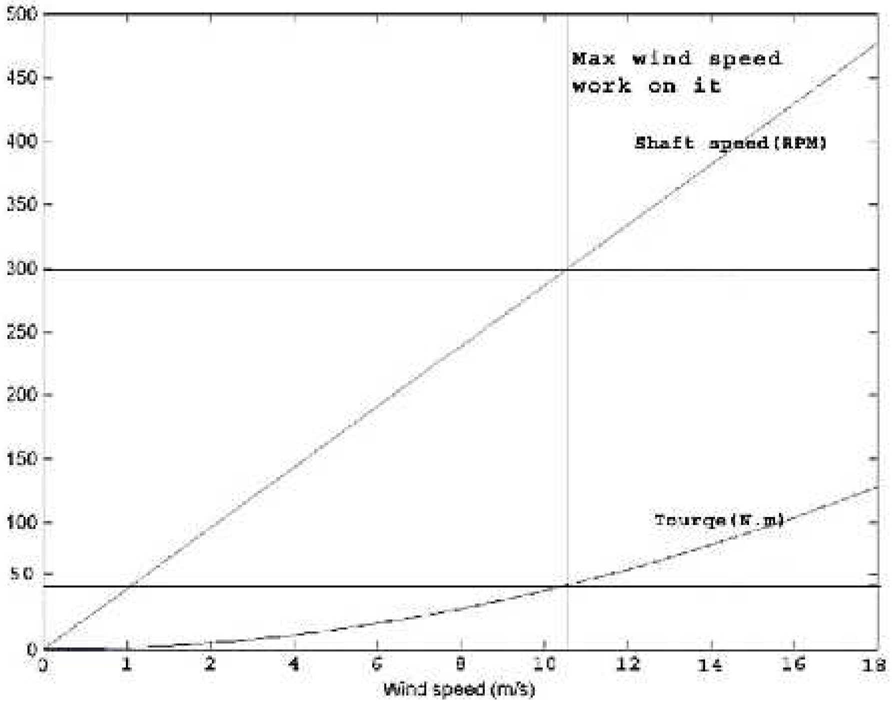

Fig 4.11 Shaft speed and starting torque versus wind speed

~~Figure 4.11 shows the relation between wind speed versus starting torque and Shaft speed of the wind turbine we have designed in our project, where tip speed ratio = 5, and rotor diameter 3.9m.~~

4.4 Tower Design:

4.4.1 Static analysis:

Designing the tower depends on both the height of the tower, which depends on the diameter of the turbine, the weight of the nacelle and the casing with all components and the maximum prevalent wind speed at the location where the wind turbine system is supposed to be installed. Elements needed to be identified or taken into account when designing are: the thickness of the tower's members, type of steel used and the aerodynamic force acting on the blades.

It could be seen in Fig 4.12, that the most critical forces are those acting on members 1,2,3, therefore, design should be made considering safety design these points; because the forces on the members above members 1,2,3, is less.

Because the tower has four legs, two legs from each side, we will consider the symmetrical shape and which makes us design considering the weight of half of the tower. We have used the method of sections to find F1, F2, and F3; ~~and~~ according to static equations then:

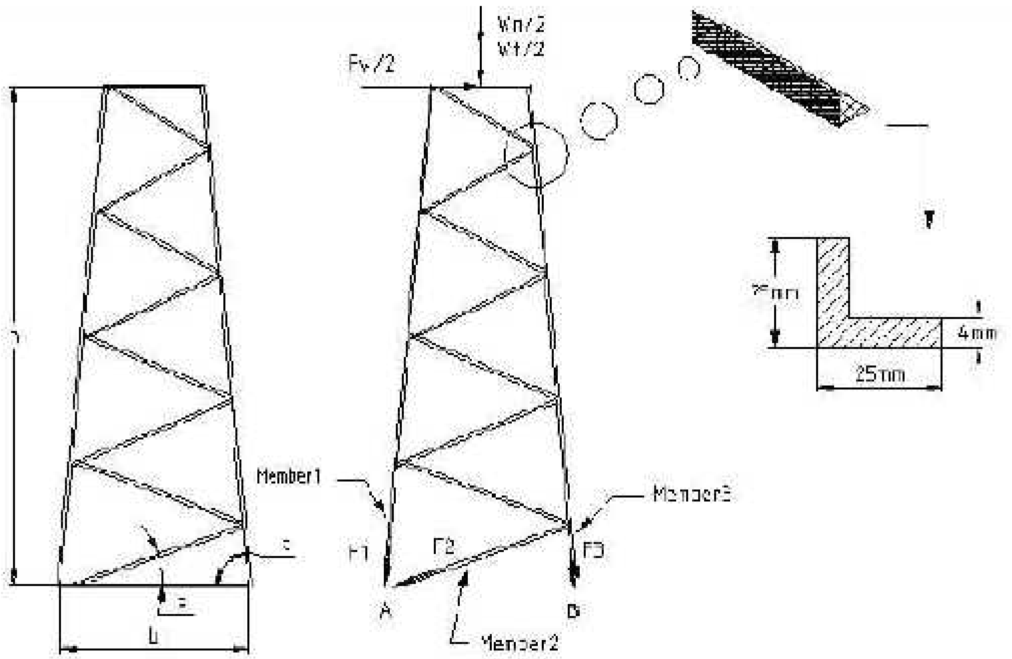

Fig 4.12 Tower free body diagram

$$\sum M_A = 0 = -F_3(b) - \frac{Wt}{2}(\frac{b}{2}) - \frac{Wn}{2}(\frac{b}{2}) - Fw(h) \quad (4.25)$$

$$\sum F_x = 0 = Fw - F_1\cos(c) - F_2\cos(a) + F_3\cos(c) \quad (4.26)$$

$$\sum F_y = 0 = -Wr - \frac{Wn}{2} - \frac{Wt}{2} - F_1\sin(c) - F_2\sin(a) - F_3\sin(c)$$

We have three equations with three unknown (F_1, F_2, F3), so we can find it.

Where:

M_A : Moment about point A (*N.m*).

F_1: Force on member 1 *(N).*

F_2: Force on member 2 *(N).*

F_3: Force on member 3 *(N).*

F_w: Force acting on the rotor area from wind (At highest wind speed =*25m/s*).

W_n: Nacelle weight *(N).*

W_t: Tower weight *(N).*

b: Tower base *(m).*

h: Tower height *(m).*

$$F_w = 3\,Blade \times \frac{1}{2} \circ AV^2\,(Cl\cos\text{¤} + Cd\sin\text{¤}\,) = 417N \quad (4.27)$$

Wn: *nacelle weight* (N) ,

Wt : *tower weight* (N),

b : *tower base* (m) ,

h : *tower height* (m)

After we find F1, F2, and F3 we can assess the safety of the tower by calculating whether the normal stresses on members 1, 2, and 3 is less than the allowable stresses or not.

The steel which we will use it is structural-steel angle, size (25x25x4)[1]

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$$\pm_1 = \frac{F1}{A1} = 49.9MPa \qquad (4.28)$$

$$\pm_2 = \frac{F2}{A2} = 30.66MPa \qquad (4.29)$$

$$\pm_3 = \frac{F3}{A3} = 49.9MPa \qquad (4.30)$$

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$$n_1 = n_3 = \frac{S_y}{\pm_1} = 5.8 \qquad (4.31)$$

$$n_2 = \frac{S_y}{\pm_2} \qquad (4.32)$$

4.4.2 Dynamic analysis:

The previous analysis refers to static analysis, now we talk about dynamic analysis. The dynamic forces which act on the turbine refer to the vibration forces. To find the natural frequency of the tower (single degree of freedom), we assume that the tower is considered as a cantilever beam, and there is a mass (nacelle) existed at the top of the tower.

We have to find the equivalent mass of the tower using the equivalence of kinetic energy and using a single degree of freedom model.

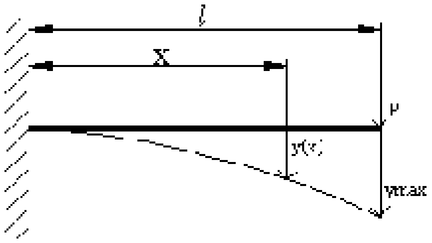

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Fig 4.13 Cantilever beam with existed force at the top

The static deflection of a cantilever beam under a concentrated end load is given by:

[1] ~~SeeTable~~See Table A-6, Joseph Shigley & Charles Mischke, Mechanical Engineering Design, 5th ed, McGraw Hill, 1989

$$y(x) = \frac{Px^2}{6EI}(3l - x) \tag{4.33}$$

$$y_{max} = \frac{Pl^3}{3EI} = 0.54183\,mm \tag{4.34}$$

Where:

l : The length of the tower (m).

$y(x)$: the static deflection of the tower.

P: the force existed at the top

E : modulus of elasticity

Then

$$y(x) = \frac{y_{max}}{2l^3}(3x^2 l - x^3)$$

The kinetic energy $T = \frac{1}{2}m\dot{x}^2$

The maximum kinetic energy of the beam (T_{max}) is given by :

$$T_{max} = \frac{1}{2}\int_0^l \frac{m}{l} * \{\dot{y}(x)\}^2 dx$$

where $\frac{m}{l}$ is the mass per unit length and m is the total mass

$$\dot{y}(x) = \frac{\dot{y}_{max}}{2l^3}(3x^2 l - x^3)$$

And so T_{max} becomes:

$$T_{max} = \frac{m}{2l}\left(\frac{\dot{y}_{max}}{2l^3}\right)^2 \int_0^l (3x^2 l - x^3)^2 dx$$

After integration:

$$T_{max} = \frac{1}{2}\frac{m}{l}\frac{\dot{y}_{max}^2}{4l^6}\frac{33l^7}{35} = \frac{1}{2}m\,\dot{y}_{max}^2\frac{33}{140}$$

The maximum kinetic energy for the equivalent mass of the cantilever

$$T_{max1} = \frac{1}{2}m_{eq}\,\dot{y}_{max}^2 \tag{4.35}$$

After equating T_{max} we obtain:

$$m_{eq} = \frac{33}{140}m \tag{4.36}$$

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Where m_{eq} is the equivalent mass of the cantilever *(kg)*.

The total effective mass acting at the end of cantilever beam is given by:

$$M_{eff} = M + m_{eq} \qquad (4.37)$$

so the natural frequency of the tower :

$$w_n = \sqrt{\frac{k}{M_{eff}}} = \sqrt{\frac{k}{M + \frac{33}{140}m}} = 80\, rad/s \qquad (4.38)$$ [1]

Where:

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w_n : the natural frequency of the tower *(rad / s)* .

M: the mass of the nacelle *(kg)*.

$Where : w_n$: the natural frequency of tranverse viobration of the tower (rad / s)

M : the mass of the nacelle (kg)

By referring to the Mechanical Vibrations reference book we have adopted the following sentences as assumption to solve our problem.

"The tower can be modeled as steel of square section of side 1in for estimating its stiffness"[2].

And by referring to structural angle tables we take the properties of the used angle [3].

The Fig 4.14 illustrates the tower cross sections which depend on it to find the moment inertia for the tower.

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$$I = \frac{1}{3}\left[A_A b_1 - A_B b_2\right] = 2.6769 \times 10^{-4}\, m^4 \qquad (4.39)$$ [4]

Where:

I: moment of inertia of the tower.

A_A : Hollow area.

A_B : Angles cross section area.

[1] All vibration equation refers to Singireu S. RAO, Mechanical vibrations, 3ed Ed.

[2] See P2.36, page 170, Singireu S. RAO, Mechanical vibrations, third Ed.

[3] See Table A-6 ~~Joseph~~ Shigley & ~~Charles~~ Mischke, Mechanical Engineering Design, 5th ed, McGraw Hill, 1989.

[4] Meriam & Kraige, Engineering Mechanics Statics , 4th ed, John Wiley Inc , 1998.

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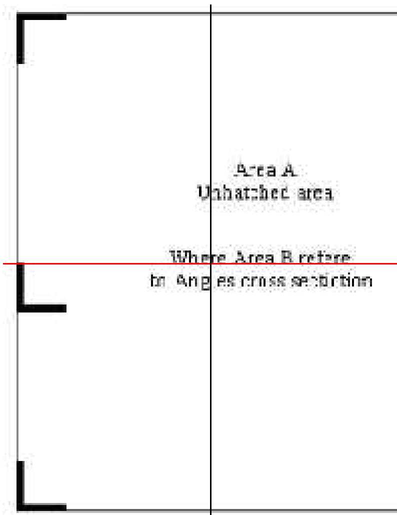

Fig 4.14 Tower cross section

$$I = \frac{1}{3}[A_A b_1 - A_B b_2] \quad (4.39)$$ [1]

Where:
I: moment of inertia of the tower.
A_A : Hollow area.
A_B : Angles cross section area.

[1] Meriam & Kraige, Engineering Mechanics Statics, 4th ed, John Wiley Inc, 1998.

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$$K = \frac{3EI}{l^3} = 769.6\,kN/m \qquad (4.40)$$

Where:
K: the stiffness of tower.
E: modulus of elasticity.
l: tower high.

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4.4.3 Eccentric force:

The wind turbine has three blades each consists of a uniform mass m and length l.

The blades are connected at the hub side with a solid steel shaft of length L and diameter D.

The mass moment of inertia of the blades about the shaft axis is given by:

$$\frac{1}{2}J_{eq}\vec{\ }^{2}_{eq} = \frac{1}{2}J_{1}\vec{\ }^{2}_{1} + \frac{1}{2}J_{2}\vec{\ }^{2}_{2} + \frac{1}{2}J_{3}\vec{\ }^{2}_{3} \qquad (4.41)$$

$$since \quad \bar{\ }_{eq} = \bar{\ }_{1} = \bar{\ }_{2} = \bar{\ }_{3}$$

$$J_{eq} = J_1 + J_2 + J_3 = 3J = 3(\frac{1}{3}ml^2) = ml^2 \quad (kg.m^2) \qquad (4.42)$$

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~~**4.4.3 Eccentric force:**~~

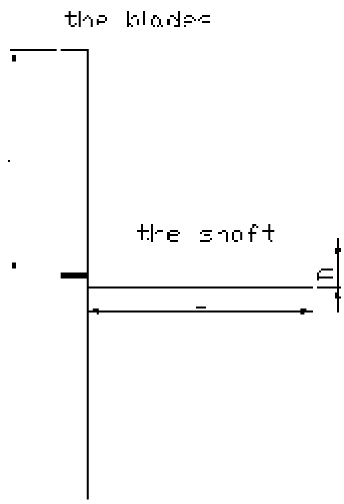

Fig 4.15 Shaft of the rotor

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The mass of inertia of the cross-sectional area of the steel is given by:

~~The wind turbine has three blades each consists of a uniform mass m and length *l*. The blades are connected at the hub side with a solid steel shaft of length L and diameter D.~~

~~The mass moment of inertia of the blades about the shaft axis is given by:~~

$$J = \frac{\text{®}}{32} D^4 \qquad (4.43)$$

The tortional stiffness of the shaft :

The tortional stiffness of the shaft:

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$$k_t = \frac{\text{®} G}{32L} D^4 \qquad (4.44)$$

The natural frequency of tortional oscillation is given by:

$$w_n = \sqrt{\frac{k_t}{J_{eq}}} = \sqrt{\frac{\text{®} GD^4 / 32L}{ml^2}} \quad (rad / s) \qquad (4.45)$$

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If there is an unbalance in the rotor then we can find the maximum amplitude *X*:

~~if there is an imbalance in the rotor then we can find the the maximum amplitude using :~~

$$X = \frac{mew^2}{k - Mw^2} = \frac{mew^2}{k(1 - r^2)} \qquad (4.46)$$

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If X is known then we can find K_t & then determine the diameter of the shaft.

4.5 Base bolts design:

The Fig 4.15 shows the base of nacelle which is connected to the tower base using special bolts to strengthen the connection.

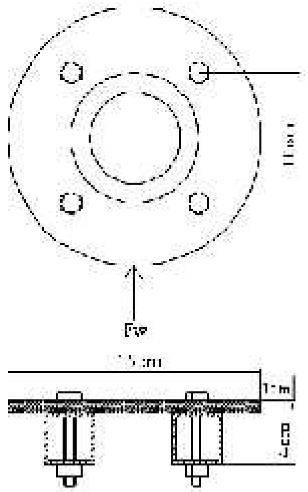

Fig 4.16 Base of the Nacelle

The bolt type which has been used is M12, which has minimum S_y = 240 MPa.

~~The bolt type which has been used is M12, which has minimum S_y = 240 MPa[1].~~

The shear reaction V = Fw, and the primary shear load per bolt can be given by,

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$$F' = \frac{V}{\# of\ bolts} = 104.25\,N \qquad (4.47)$$

Now the bolt shear stress is

[1] ~~See Table 8-6, Joseph Shigley & Charles Mischke, Mechanical Engineering Design, 5th ed, McGraw Hill, 1989.~~ See Table 8-6, Shigley & Mischke, Mechanical Engineering Design, 5th ed, McGraw Hill, 1989.

$$2 = \frac{F'}{A} = 0.921 MPa \qquad (4.48)$$

$Where : A :$ The bolt shear stress area.

The factor of safety for the bolts is given by,

$$n_{bolt} = \frac{S_y}{22} = 32 \qquad (4.49)$$ [1]

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[All calculation results for this chapter were listed in Table 4.3]

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[1] The calculation results performed in this Chapter are listed in table 4.3

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Table 4.1 Available data

Symbol	~~Description~~Definition	Quantity	Unit
$TSR(\lambda)$	Tip speed ratio	5	-
V	Max Wind speed	11	m/s
D	Rotor Diameter	3.9	m
R	Rotor radius	1.95	m
α	Angle of attack	5	Degree
e	Blade length/2	0.975	m
c	Outer Chord width	260	mm
t	Outer thickness	35	mm
L	Inner Chord width	253	mm
h	Inner thickness	28	mm
$S_{y(Blade)}$ [1]	Yield strength of fiber glass	103.5	MPa
$S_{y(Shaft)}$	Yield strength of cold drawn steel	580	MPa
$S_{ut(Shaft)}$	Tensile strength	690	MPa
Wn	Nacelle weight	980	N
Wt	Tower weight	833	N
b	Tower base width	60	cm
h	Tower high	6	m
$A1$	Cross section area of 1	1.85	cm^2
$A2$	Cross section area of 2	0.925	cm^2
$A3$	Cross section area of 3	1.85	cm^2
S_y	Yield strength of steel	290	MPa
E	Modulus of elasticity	207	GPa

[1] William D. Callister Jr, Materials Science & Engineering, 4th Ed, John Wiley & Sons Inc, 1996.

Table 4.2 Blade calculation results

Blade station	Local radius *(m)*	Chord width *(m)*	Beta *(degree)*	Drop *(m)*
1	*0.15*	*0.260*	*9.66*	*0.0443*
2	*0.20*	*0.257*	*9.44*	*0.0427*
3	*0.25*	*0.253*	*9.23*	*0.0411*
4	*0.30*	*0.249*	*9.01*	*0.0395*
5	*0.35*	*0.245*	*8.80*	*0.0379*
6	*0.40*	*0.241*	*8.59*	*0.0364*
7	*0.45*	*0.237*	*8.37*	*0.0349*
8	*0.50*	*0.234*	*8.16*	*0.0336*
9	*0.55*	*0.230*	*7.94*	*0.0321*
10	*0.60*	*0.226*	*7.73*	*0.0307*
11	*0.65*	*0.222*	*7.52*	*0.0293*
12	*0.70*	*0.218*	*7.30*	*0.0279*
13	*0.75*	*0.214*	*7.09*	*0.0266*
14	*0.80*	*0.211*	*6.87*	*0.0254*
15	*0.85*	*0.207*	*6.66*	*0.0242*
16	*0.90*	*0.203*	*6.45*	*0.0229*
17	*0.95*	*0.199*	*6.23*	*0.0217*
18	*1.00*	*0.195*	*6.02*	*0.0206*
19	*1.05*	*0.191*	*5.80*	*0.0194*
20	*1.10*	*0.188*	*5.59*	*0.0184*
21	*1.15*	*0.184*	*5.38*	*0.0173*
22	*1.20*	*0.180*	*5.16*	*0.0163*
23	*1.25*	*0.176*	*4.95*	*0.0152*
24	*1.30*	*0.172*	*4.73*	*0.0142*
25	*1.35*	*0.169*	*4.52*	*0.0134*
26	*1.40*	*0.165*	*4.31*	*0.0124*
27	*1.45*	*0.161*	*4.09*	*0.0115*
28	*1.50*	*0.157*	*3.88*	*0.0106*
29	*1.55*	*0.153*	*3.66*	*0.00979*
30	*1.60*	*0.149*	*3.45*	*0.00898*
31	*1.65*	*0.146*	*3.24*	*0.00826*
32	*1.70*	*0.142*	*3.02*	*0.00749*

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33	*1.75*	*0.138*	*2.81*	*0.00677*
34	*1.80*	*0.134*	*2.59*	*0.00606*

Table 4.3 Mechanical design calculations results

Symbol	~~Description~~Definition	Quantity	Unit	Eq # :
N	Shaft speed	*300 (max)*	*RPM*	**4.1**
B	# of blade	*3*	-	**4.2**
Φ	Apparent angle	*11.45* at R/r =2	*Degree*	**4.5**
F	Thrust force at wind speed =25 m/s	*139*	*N*	**4.12**
M	Moment	*33.8*	*N.m*	**4.13**
σ	Stress	*20.5*	*MPa*	**4.14**
I	Moment of inertia	1.4765×10^{-6}	m^4	**4.16**
n_{Blade}	Factor of safety of blade	*5*	-	**4.17**
T	Rotor torque	*39.4*	*N.m*	**4.18**
S'_e	Endurance limit of test	*374.8*	*MPa*	**4.20**
K_a	Surface factor	*0.798*	-	**4.21**
K_b	Size factor	*0.9544*	-	**4.22**
Se	Endurance limit	*264.89*	*MPa*	**4.19**
τ	Shear stress	*73.16*	*MPa*	**4.23**
n_{Shaft}	Factor of safety of shaft	*4*	-	**4.24**
$F3$	Force of member 3	*9.24*	*kN*	**4.25**
$F2$	Force of member 2	*677.3*	*N*	**4.26**
$F1$	Force of member 1	*9.24*	*kN*	~~-4.27~~
Fw	Rotor force	*417*	*N*	**4.~~28~~27**
$\sigma1$	Stress on 1	*49.9*	*MPa*	**4.~~29~~28**
$\sigma3$	Stress on 3	*49.9*	*MPa*	**4.~~31~~30**
$\sigma2$	Stress on 2	*30.66*	*MPa*	**4.~~30~~29**
n_{Tower}	Tower factor of safety	*5.8*	-	**4.~~32~~31**
y_{Max}	Max deflection of tower	*0.54183*	*mm*	**4.34**
w_n	Natural frequency of tower	*80*	rad/s	**4.38**

I	Moment inertia of tower	2.6769×10^{-4}	m^4	***4.39***
k	Stiffness of tower	*769.6*	kN/m	***4.40***
F'	Shear load per bolt	*104.25*	N	***4.47***
2_{Bolt}	Bolt shear stress	*0.921*	MPa	***4.48***
n_{Bolt}	Factor of safety of Bolts	*32*	-	***4.49***

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Chapter Five

Chapter Five

Power Output and Energy Storage System

Power Output and Energy Storage System

The Power Output and Energy Storage System

5.1 The Power Output

5.1.1 Wind Turbine Generator:

The generator converts mechanical energy into electrical energy. When magnets are moved near a wire, an electric current is generated in that wire.

In a wind turbine, the wind pushes against the turbine blades, causing the rotor to rotate, turning the copper armature inside the generator and generating an electric current.

Generators are either DC generators or Alternative (Ac) generators. Choosing a suitable generator depending on the type of usage, probably the most suitable type for small wind turbine is a permanent magnet DC generator.

Permanent magnetic are most powerful and cost effective solution for building a small wind turbine. There low rpm performance is excellent, huge power output possible, extremely sturdy construction. Therefore it is suitable for our small wind turbine.

5.1.2 Betz law & Wind output power:

According to Betz law unfortunately we can't capture all of the wind power,. Betz' law says that *"you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine*". So C_p (Turbine coefficient) can't be greater than 0.59; and so the mechanical power (captured) is given as follow.

$$P_{mech} = 0.5 \times \text{°} \times A \times V^3 \times C_p \qquad (5.1)$$

Where: C_p : coefficient of wind turbine

P_{mech} : Power coming out from blades at the shaft (W).

ρ: air density (typically 1.225) (kg/m^3).

A: rotor swept area (m^2) $\left(A = \frac{\text{®}}{4} \times D^2, \textit{ where } D : \textit{rotor diameter}(m)\right)$.

V: Velocity of the wind (m/s).

5.1.2 Electrical Power Output

The generator we have installed is a used one with low efficiency η_g and by considering the generator's efficiency, power output could be written as follow:

$$P_{elect} = 0.5 \times \rho \times A \times V^3 \times C_p \times \eta_g \qquad (5.2)$$

Where: P_{elect} : power coming out from the generator (W).

Fig 5.1 Show the relation between wind speed & wind power ~~(mechanical output power).~~(P_{mech}).

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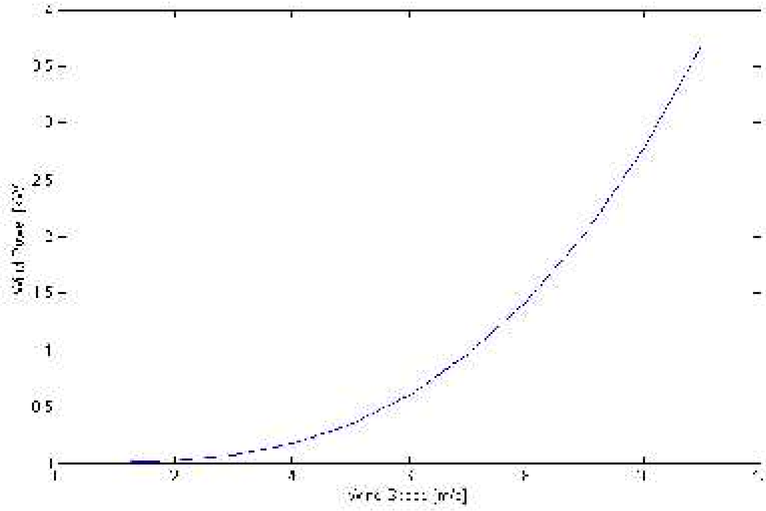

Fig 5.1 Wind power versus wind speed

5.1.3 Output voltage:

The output voltage (Terminal voltage) from the generator is given using Equations 5.3. Figure 5.2 Shows expected generator performance.

$$V_T = E_g - I_a r_a \qquad (5.3)$$

Where : E_g : The electromot ive force voltoge

V_T : The terminal voltage I_a : the armature current

r_a : Armeture resistance

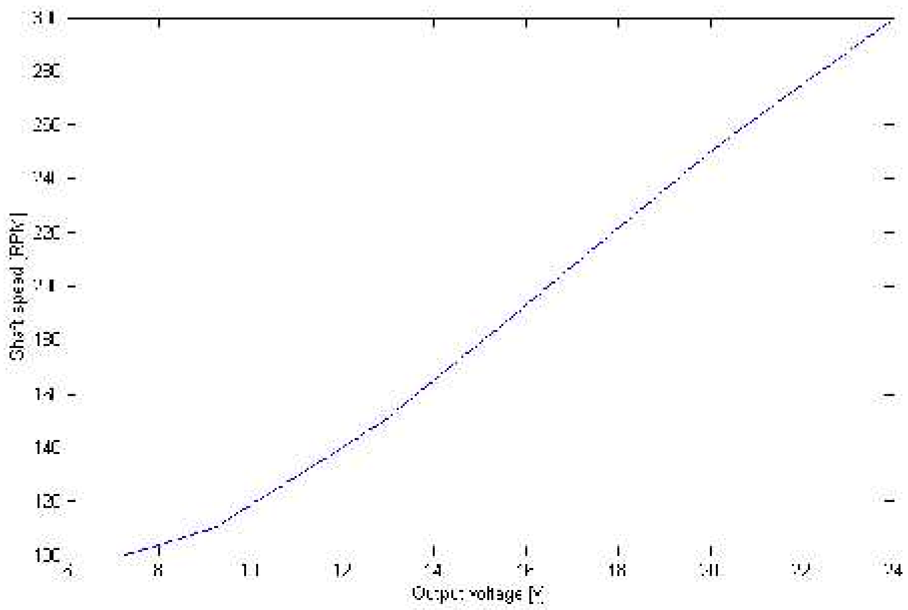

Fig 5.2 Generator performance

5.2 The energy storage system

The energy storage system is an essential part in Small ~~wind~~ Wind ~~turbine~~ Turbine ~~energy system~~which ~~needed~~ needed to maintain fixed alternative output current and voltage. After having a DC output voltage from the generator it will pass by a regulator and then flows to a battery cells, then to inverter and finally to the designed load. But because we have an alternative voltage and current we will use a DC shopper in order to having a fixed voltage and varied current. The following are an explanation to these components:

5.2.1 The regulator:

It is a charge controller that charges batteries, whether the power source is ~~PV,~~ wind, hydro, fuel, or utility grid. Its purpose is to keep batteries properly fed and safe for the long term.

The basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge, protect from electrical overload, and/or display battery status and the flow of power.

5.2.2 DC Chopper:

In many industrial applications it is required to convert a variable voltage DC source to a fixed voltage DC source. A DC chopper converts directly from DC to DC and is also known as a DC-to-DC converter. A chopper can be considered as Dc equivalent to a transformer with a continuously variable turn's ratio. Like a transformer, it can be used to step-down or step-up a Dc voltage source. In our project we used a step up Dc voltage. Fig 5.3 shows a Dc chopper which is used to step up a Dc voltage and an arrangement for step up operation. When switch SW which is implemented by a power MOSFET is closed for time t1, the inductor current rises and energy is stored in the inductor L1. if the switch is opened for time t2, the energy stored in the inductor is transformed to loud through diode D2~~1~~ and the inductor current falls, Fig 5.3 Show the simple construction for the Dc-Chopper where Fig 5.4 show the electronic circuit for the Dc-Chopper.

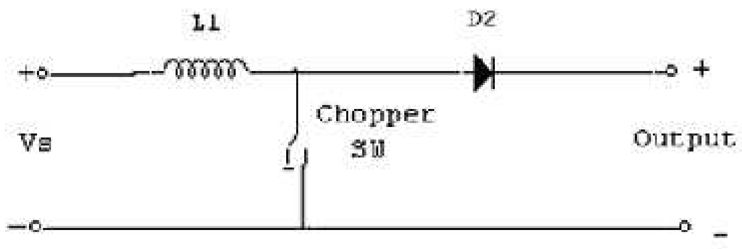

Fig 5.3 Step up arrangement

5.2.3 Batteries:

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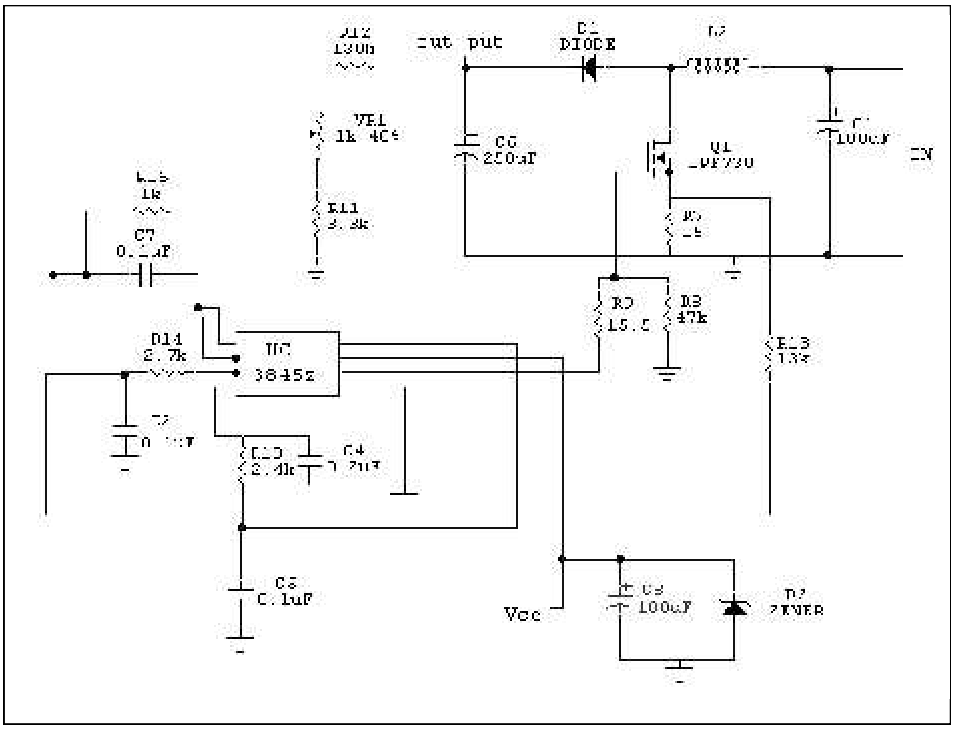
The function of the batteries is to store the energy when the wind generator is supplying energy and to provide it to the system when the coming energy from the wind generator is under the needed amount of the energy and this function need a special kind of batteries according to the nature of the system from the daily repeated



charging and discharging of the batteries.

Fig 5.4 Dc Chopper electronic circuit

~~**5.2.3 Batteries:**~~

~~The function of the batteries is to store the energy when the wind generator is supplying energy and to provide it to the system when the coming energy from the wind generator is under the needed amount of the energy and this function need a special kind of batteries according to the nature of the system from the daily repeated charging and discharging of the batteries.~~ In the natural systems one battery can't hold with the needed power of the system so we can connect two or more electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels.

5.2.4 Inverter:

DC - to-Ac converter is known as inverter. The function of an inverter is to change a DC input voltage to a symmetrical ~~ac~~ Ac output voltage of desired magnitude and frequency. Output voltage could be fixed or variable at a fixed or variable frequency.

An inverter is the device that takes the low DC voltage & high ~~DC~~ current from ~~your~~ the batteries~~y~~ and changes it into 220 volt Ac power. An inverter is essentially the exact opposite of a battery charger.

The output voltage waveform of ideal inverter should be sinusoidal. However, the waveform of practical inverter are non sinusoidal and contains certain harmonics.

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Chapter Six

Design of Control Systems

Design of Control Systems

6.1 Variable Pitch Wind Turbine Control System:

Variable pitch control can be used to shed the aerodynamic power generated by the wind turbine. Thus, the aerodynamic power produced by the wind turbine can be controlled by adjusting the pitch angle of the wind turbine. Figure 6.1 shows the effect of pitch control on power flow in wind turbine generation.

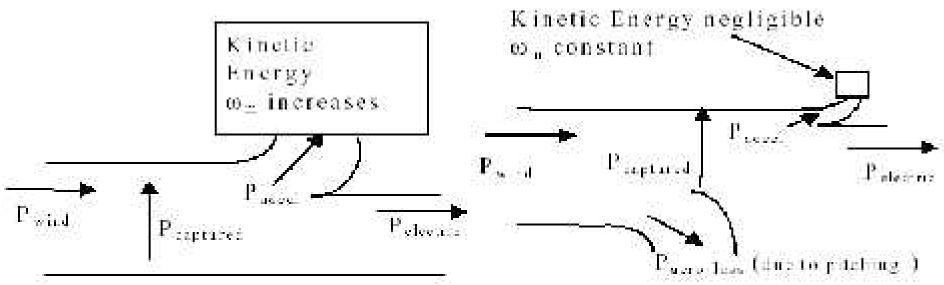


Fig 6.1(a) pitch constant **Fig 6.1(b) pitch to feather**

Figure 6.1 Effect of pitch control on power flow in Wind turbine generation

With pitch control, the power captured, $P_{captured}$, from the wind power P_{wind} can be controlled by a pitch actuator. The acceleration and deceleration is the result of the difference between the input power to the generator and the aerodynamic power captured by the wind turbine. Theoretically, at constant electric load, the acceleration and deceleration can be made zero if the pitch can be controlled fast enough to react to the wind speed such that the power captured from the wind is equal to the electric power ($P_{captured} = P_{electric}$). For example, in the high wind speed region when the rotor speed limit is reached, the pitch can be controlled to keep the rotor rpm from exceeding its limit.

In Figure 6.2, the change of the Cp-TSR curve as the pitch angle is adjusted is also shown. In low to medium wind speeds, the pitch angle is controlled to allow the wind turbine to operate at its optimum condition. In the high wind speed region, the pitch angle is increased to shed some of the aerodynamic power. Where the total power given by:

$$P_{elect} = 0.5 \times \rho \times A \times C_p \times \eta_g \times \left[\frac{R}{\lambda}\right]^3 \times \omega^3 \qquad (6.1)$$

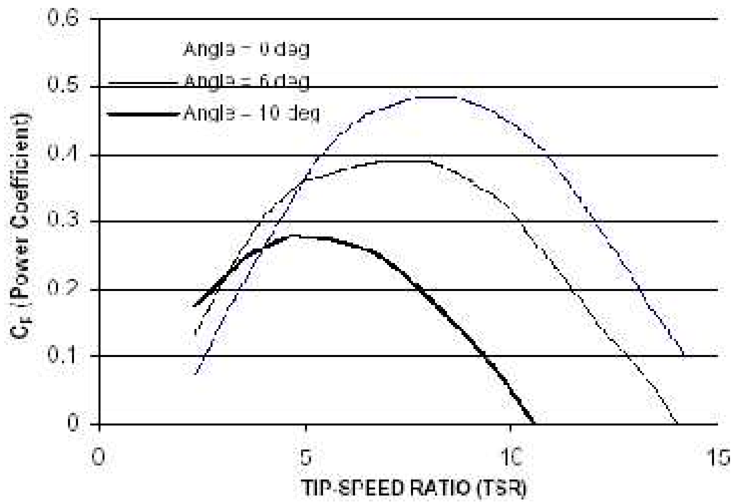
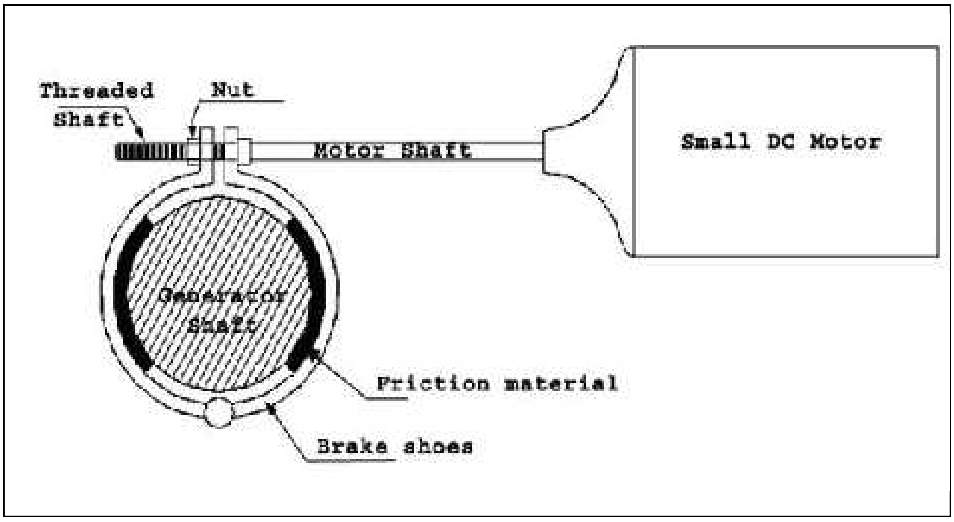


Figure 6.2 Power coefficients for different Pitch angle

6.2 Mechanical Braking Control System:

Variable Pitch Control System are complicated ,expensive and suitable for large wind turbine so we replace it with mechanical brake system to control of the shaft



speed , the Fig 6.3 below describes the theory of braking system.

Fig 6.3 Mechanical Braking System

Fig 6.4 show the block diagram for closed loop feedback control system which implies the mechanical brake control system for Wind turbine.

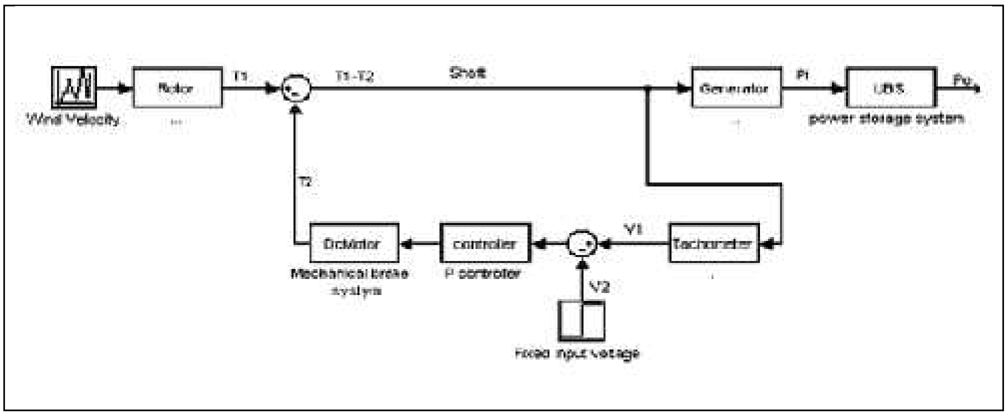
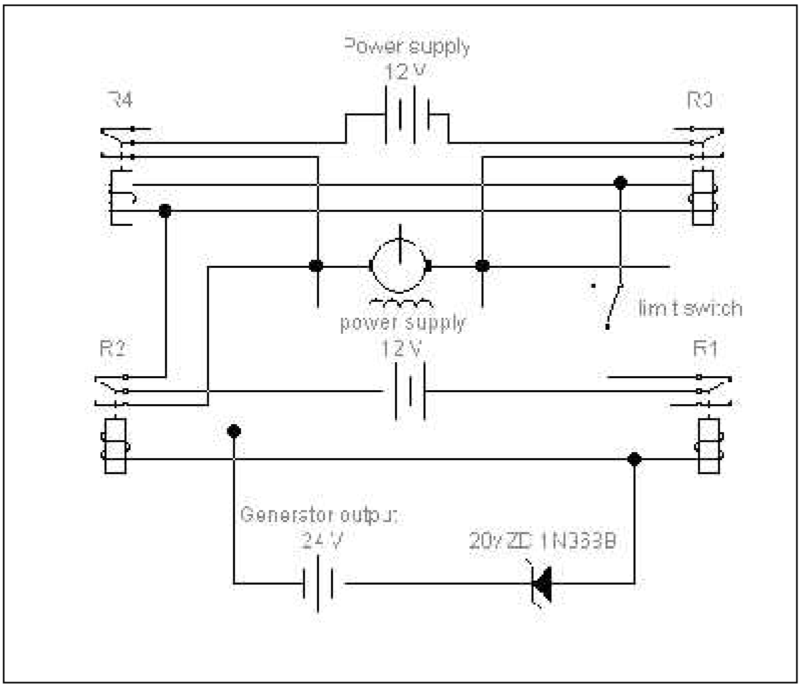


Fig 6.4 Block diagram for closed loop feedback control system

Where the electronic circuit which implies the mechanical brake control system is



showen in Fig 6.5.

Fig 6.5 Control electronic circuit

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Future Work and Recommendations

Future Work ~~and~~ & Recommendations

In the course of implementing our graduation project, we have encountered several problems and shortcomings. These persistent problems have affected the progress and hence the pilot project we have built. These problems are:

1. The closing of the university premises during the last eight months which made it impossible for us to test the performance of the wind energy system components, such as the generator.
2. Lack of references dealing with the manufacturing of the turbine blades. All available references seem to keep this specific part as classified. This situation has forced us to try to use a primitive way of manufacturing.
3. When using the polystyrene foam for manufacturing the blades, some serious problems ~~that~~ concern~~ed~~ing handling of the material arose.
4. The ~~lack~~lack of a wind map reference for the city of Hebron that help us assess the utilization of wind energy and its expected performance.
5. The lack of references dealing with wind energy engineering in general and its application in particular at the PPU library.

The project will be installed at the top of ~~the~~ Building A at Wadi Harrieh. We would urge colleagues at the department of Mechanical engineering and other departments to develop and upgrade the system based on the following recommendations:

1. Designing a gear box to increase the speed of generator's shaft utilizing the large torque produced.
2. In order to ~~absorb all power from the rotor~~increase the conversion efficiency we suggest building permanent DC generator with ~~high~~ optimal number of poles.
3. Building the pitch angle control system ~~as braking system~~for controlling braking the turbine.
4. Develop a manufacturing process for producing a finer turbine blades with material and finishing that help increasing the performance of the system.

Conclusion:

In conclusion, we would stress that renewable energy in general and wind energy in particular have a promising future in Palestine. The utilization of such energy resources needs, however, more researches and public awareness and acceptance. Wind energy utilization need to be based on a wind resource maps and assessments that shows the allocation and the potential of these systems in Palestinian. The use of hybrid systems, wind, solar and conventional resources, could also be a good solution that would ease the bourdon on the Palestinians.

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Note: Most of the web pages take Hugh Piggott's book, Windpower Workshop, as a reference.

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dices

Appendices

Project Budget

#	Name	# of Pieces	Cost (NIS)
1	Blades	3	370
2	Generator	1	250
3	Tower	1	320
4	Bearings	1	35
5	Hub	1	75
6	Printing& binding the thesis	-	100
7	Wind vane & Nacelle	1	400
8	UPBS	1	850
9	Small DC motors	1	50
10	Wires	-	150
11	Controller & Electronic devices	1	150
12	Bolt ,Washer &Nuts	-	100
13	Transportations		200
Total Cost			3050 NIS

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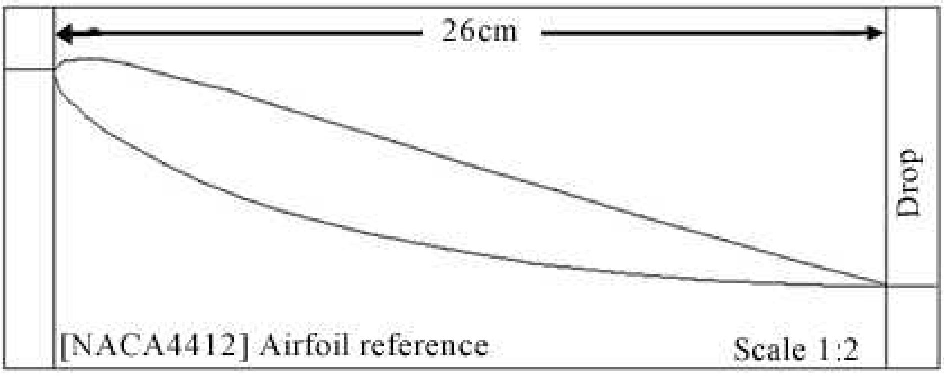
Appendix B
The blade template cross sections



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