TRANSMISSION SYSTEM IN SMALL WIND TURBINE

By

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(Tn. Haji Kamal Ariff bin Zainal Abidin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(SHAHIRA EMIE LYANA MUSTAFFA)

ABSTRACT

Growing energy demand and public awareness on the environmental impact of non-renewable energy source has increase public interest in renewable energy especially wind energy. Nowadays countries like India, Germany, France, Spain, UK, USA and many more are widely using wind energy as an alternative source of power generation [1]. However, in Malaysia, wind energy is not very popular because the wind condition is variable due to the seasonal variation. The maximum wind speed in Malaysia is around 4-5 m/s annually [2]. With the right design of wind turbine, this wind speed is enough to generate power for household in order to reduce the dependency on the conventional power generation. This report is about the design and analysis of transmission system in small wind turbine. The first step is to design the transmission system for small wind turbine. With the right gear ratio, it can increase from low speed shaft into high speed shaft so that it is sufficient for generator to generate electricity. The designed transmission system is then translated into 3D drawing using CATIA V5R18 software to create a model for simulation later. ANSYS Workbench simulation software is used to simulate the static structural analysis of the transmission system to determine the equivalent (von-mises) stress, maximum shear stress, total deformation and safety factor. The results gained from the analysis are gathered and analyze to conclude the condition of the transmission system designed. Lastly, some recommendations are included for further study in the future.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Energy is one of the most important elements for socio-economic development. The rate of energy consumed by nation reflects the level of prosperity achieved by the nation [1]. Nowadays, we as human rely heavily on fossil fuel to meet our energy demand. However, fossil fuels are finite resource and will be exhausted one day. Plus, the awareness on the environmental issues has re-evoked our realization. Due to that, nowadays people are moving towards the alternative energy sources like wind, hydro, nuclear and many more. Among of all the alternative energy sources, wind power becomes one of the popular ones.

"Of all the forces of nature, I should think
the wind contains the greatest amount of power"

.... Abraham Lincoln

The wind power utilization actually starts back then, during the ancient times. During that time, people use sails to propel ships and boats. Later, wind power is used for grain grinding mills and water pumps. Along these times, the device has transformed from crude and heavy devices to today's efficient and sophisticated machines. The technology also went through various phases of development.

Nowadays human are realizing that wind energy as one of the most promising alternative energy source since it is the world's fastest growing energy source. The global wind energy capacity has increased by factor of 4.2 during last five years [1]. Global leaders in wind energy generation like Germany, United States of America, Spain and several others are increasing their utilization of wind energy for power generation causing the wind energy technology to change as well.

In Malaysia, public are starting to be conscious about wind energy, but the utilization is not really wide or popular. We can see the wind turbines are utilized only at a few places such as Perhentian Island. Wind energy is not very popular in Malaysia because the wind speed is not very high which average of 4-5m/s annually [2]. The wind speed trend is also fluctuating around the year. Even though the speed is not high and fluctuating, but with the right design of wind turbine, it can generate enough amount of energy to help reducing the dependency on conventional power generation in certain season.

The commercial wind turbine components consist of blade or rotor which converts the wind energy into rotational shaft energy, drive train, a tower and other equipments. The focus of this project is on the design of the gearing system to step up from low wind rotational speed into higher rotational speed, enough for generator to generate electricity for home use wind turbine.

1.2 Problem statement

As the world's population is increasing, the demand for energy resource is also increasing. However, the resource crisis and environmental issues due to pollution causing from resource like fossil fuel has becoming more serious day by day. Large wind turbines may produce hundreds of Megawatts (MW) of electricity, while small wind turbines can produce no more than 100 kW of electricity to be installed at home, farms and small business as backup electricity or to reduce electricity bills.

In Malaysia, the wind condition is fluctuating around the year [2]. The wind speed is also not very high compared to other country. These factors are not really favourable for the usage of wind energy in Malaysia. The main concern with the design of small wind turbine is that is it capable of increasing the wind speed enough for the generator to produce electricity? Will it be able to sustain the load/force applied to it? This entire question will be answered once this study has reached its objectives.

1.3 Objectives

The objectives of this project are:

i. To design a transmission system for small wind turbine for Malaysian low wind speed condition
ii. To determine the torque, transmitted load, forces and bending stresses acting on the gear tooth.
iii. To develop a 3D model of the transmission system
iv. To conduct a static structural analysis on the transmission system model to find equivalent (von-mises) stress, maximum shear stress, total deformation and safety factor for gears using Ansys Workbench software.

1.4 Scope of Study

In order to complete this project, several scopes of studies need to be achieved. The major scopes are as follows:

1.4.1 Understanding the fundamental of gear design and applications

- Research on the design trends in different field of gear applications. The information given helps in picking the most suitable gears for particular applications
- Research on preliminary design stage involving the consideration of kind of stresses involved, estimation of gear size and consideration of data required for gear design

1.4.2 3D design of gears using CATIA V5R18 software

- There will be a need to install CATIA V5R18 into personal computer (PC)
- Training on how to use CATIA software to develop 3D model of gears for analysis in ANSYS workbench later.

1.4.3 Static Structural Analysis using ANSYS Workbench software

- There will be a need to install ANSYS software into personal computer
- Importing the geometry from CATIA V5R18 into ANSYS Workbench for simulation purpose
- Conducting static structural analysis on the gears and pinion in order to find the Equivalent (von-mises) stress, maximum shear stress, total deformation and safety factor of the gear.

1.5 Feasibility of the project

Two semesters are required to complete this project. During the first semester, the author starts the project by researching existing design of transmission system for small wind turbine application and picking up the information required for the particular application. Then the author also starts roughly designing the transmission system

In the second semester, the author starts the detail design of the transmission system. This involved the manual calculation of the torques, stresses and forces involved and also determining the right size of the gears. Lastly is the static analysis of the gear design using ANSYS Workbench.

With the resources that are available in the University, the project shall be completed within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Wind characteristics in Malaysia

From the study been done, the wind data in Malaysia shows a seasonal effect. The maximum annual wind speed is at Mersing, Johor where the speed is 3m/s. the mean monthly wind speed in January and December varies between 4.0 m/s-5.0m/s. The average maximum speed is between 7-8 m/s in June, and varies from 4-6m/s in July. January and October shows the highest and lowest wind speed respectively.

Diurnal variation of hourly mean wind speed shows a bell shaped trend which can be seen throughout the year. This is happen due to the effect of solar heating balance, where the wind speed usually increased during the day and increase during night.

For wind energy generation, it is advantageous to generate wind energy during the day since the wind speed is higher during the day, plus the electrical consumption is usually higher at day compared to night [2].

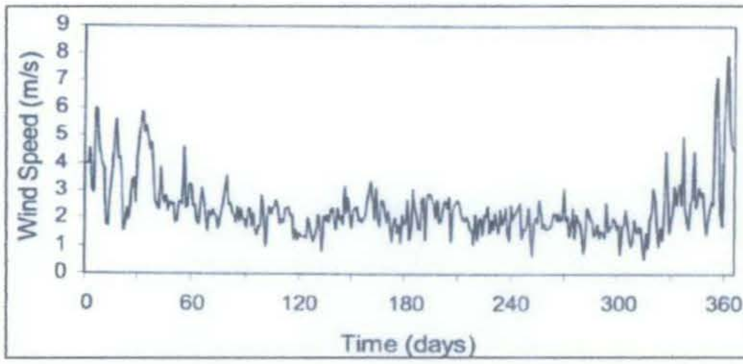

Figure 1: Mean daily wind speed values at Mersing

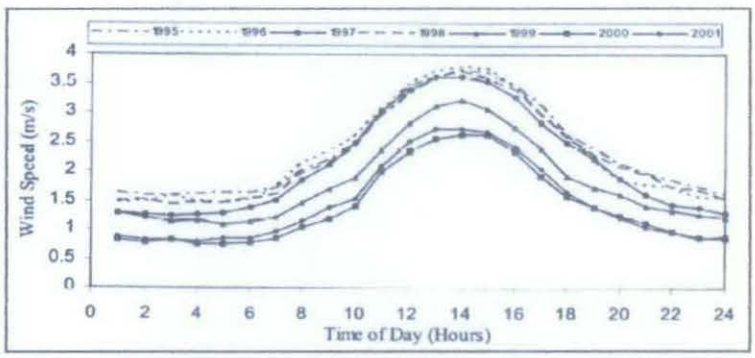

Figure 2: Diurnal wind speed variation for all individual years in Mersing

2.2 Example of the existing wind turbine

One example of small wind turbine products available in the market is Conergy SWT 7500. This small wind turbine is flexible, efficient and robust. Its application ranges from house or village electrification, water pumping to small enterprise. It is designed to withstand the extreme weather condition, where it is equipped with patented passive pitch control which enables the wind turbine to keep stable energy output in strong winds [3].

The gear configuration is required to increase the rotational speed from 75 – 125 rpm (rotor speed) into 1500 rpm (optimum speed of generator). The drive assembly of this wind turbine consist of two steps of spur gear with gear ratio of 1:12.1 (ig = 12.1).

Figure 3: Conergy SWT 7500

Table 1: Technical data of Conergy SWT 750

Rotor		
	Diameter	: 6m (19.7 ft)
	Number of rotor blades	: 4
	Position	: upwind
	Speed	: 75-125 rpm
	Design of blades	: steel/fiber- glass composite structure
	Design of hub	: rigid, solid steel
Drive assembly		
	Gear unit design	: spur gear, 2 step, i=12.1
	Generator	
	Type	: Asynchronous
	Rated power	: 7.5 kW
	Speed	: 1500 rpm
	Rated voltage	: 120V, 3-phase, 75 Hz
Power characteristics		
	Rated power	: 7.5 kW
	Cut in speed	: 3 m/s (7 mph)
	Rated speed	: 11.5 m/s (25.8 mph)
	Cut out wind speed	: none
	Survival wind speed	: 60 m/s (135 mph)

2.3 Gearing system in small wind turbine

The purpose of gear is to transmit power and/or motion from one shaft to another at a constant angular velocity. Gear system is one of the most important components in the wind turbines power train. The speed of usual wind turbine rotor is between 30-50 rpm, whereas the optimum speed of generator is between 1000-1500 rpm. Hence the function of gear trains is to manipulate the speed according to the requirements of generator. An ideal gear system is designed to perform smoothly and quietly even under extreme climate and loading condition throughout the life cycle of the wind turbine.

In smaller wind turbine, the desired speed ratio is achieved by designing the gear with two or three staged system. If higher gear ratio is required, the stages of the gear can be increased. However, the gear ratios are restricted to 1:6. But if the gearbox size is limited, it is better to use planetary gear instead of spur gear as it design is more compact. Bigger wind turbines typically have primary stage planetary gears combined with secondary two staged spur gears to raise the speed to the desired level [1].

2.4 Experiences on wind energy utilization in Korea

In Korea, the study on wind energy utilization has started since 1970s. The purpose of this study is as energy source for unelectrified remote land, or as an alternative energy to diesel engine generator.

KIST (Korean Institute of Science and Technology) started the feasibility study on wind energy converter for electricity supply by operating small generators (2-5kW) since 1974. In early study, some machine show failure due to fluctuating and gusty wind. This problem is solved by using wind energy converter imported from Germany [4].

Later KIST-20 project was started with the intention to develop their own design and technology for system design and manufacturing. This project is fully funded by Korean government.

2.4.1 Project Description

i. *Site Description*

The annual mean wind speed along the south and west coast of Korean peninsula is about 4-4.5 m/s at height of 10 m. So, Wolryoung which situated on the west coast of Cheju Island was selected as the site for the project

ii. *KIST-20 project description*

The purpose of this project is to design and manufacture small scale horizontal-axis wind turbine with their own technology and this project will be the basis of the development of larger scale of wind turbine in the future.

iii. *System description*

This 20kW wind turbine has a rotor with two blades which rotates at horizontal axis. The components of this wind turbine are:

- Rotor and blades

  Each blade is 6.5m long and weight about 120kg. The blades are attached to low speed shaft which drives generator through a step-up gear

- Nacelle arrangement

  Consist of all rotating equipment for wind turbine

- Transmission system

  Consist of 2-staged gearbox which driven directly by low speed shaft by the rotor and hub. It has 1:21.43 speed-up ratio from low speed shaft to high speed shaft provided by gear

- Blade pitch control
- Electrical power system
- Control system
- Yaw system
- Tower

iv. *Technical data*

Table 2: Technical data of systems in wind turbine for KIST-20

Rotor	**Gearbox**	**Generator**
No. of blades: 2 Diameter: 14m Rotational speed: 84.7rpm Location: down wind Height: 12.5m	Type: 2 stage Gear ratio: 1:21.43 Rating: 31.3kW	Type: induction Output: 20kW Voltage: 3 x 380V

2.5 Theory

2.5.1 Equations for calculation [5], [6], [7], [8]

1. Diametral pitch

$$D = \frac{N}{P_d}$$

2. Gear Ratio

1st stage gear (1-2)

$$i_{g1-2} = \frac{N\ (gear)}{N\ (pinion)}$$

2nd stage gear (3-4)

$$i_{g3-4} = \frac{N\ (gear)}{N\ (pinion)}$$

Total gear ratio

$$i_g = \frac{product\ of\ driven\ gear\ size}{product\ of\ driving\ gear\ size}$$

3. Gear rotational speed

$$w_2 = \frac{N_1}{N_2}\, w_1$$

Where:

N: no of teeth

w: gear rotational speed

4. Tooth loads

Gear tooth load must be developed to calculate gear and shaft stresses and bearing lives.

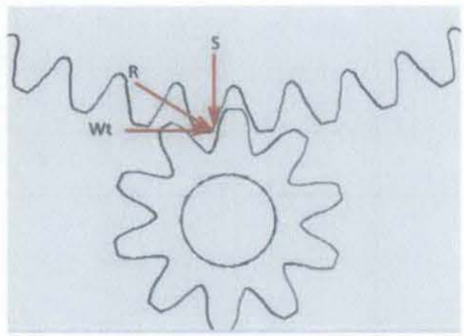

Figure 4: Forces acting on gear tooth

5. The gear torque:

$$T = \frac{63{,}025\ hp}{rpm}$$

6. Component of tangential load, W_t

$$W_t = \frac{2\,T}{D}$$

7. Strength rating

Strength rating of gear tooth itself concerns itself with bending stress in the tooth fillet, where fatigue cracks initiate and propagate resulting in fracture of teeth.

The AGMA stress equation:

$$S_t = \frac{W_t K_a}{K_v} \frac{P_d}{F} \frac{K_s K_m}{J}$$

Where,

K_a: Application factor.

K_v : Dynamic factor

K_s : Size factor

K_m : load distribution factor

F : face width, in

J : Geometry factor for bending strength

The relation between the calculated bending stress to the allowable stress of material is:

$$S_t \leq \frac{S_{at} K_1}{K_t K_r}$$

Where,

S_{at} : Allowable material stress, psi

K_1 : Life factor

K_r : Temperature factor. Usually taken s 1.0 unless oil gear blank T exceeds 250^{o}F

K_t : Reliability factor

2.5.2 Forces acting on spur gear

Gear sets are used to transmit rotary motion and power from one shaft to another. When two spur gears are meshed, there are contact points that moves along a line as the gear rotates. The line of action is also called pressure line [9].

The force that is pushing the driven gear will always be along the pressure line. The type of force is bearing (pushing) force, which applying pressure on the mating tooth. The gear force is a compressive force, which always pushing into gear teeth. The gear force can be resolved into 2 components which are:

1. *Tangential components*
   Used to transmit power

2. *Radial components*
   In radial direction directed to the gear centre and applied at pitch point. This force will cause bending of gear tooth.

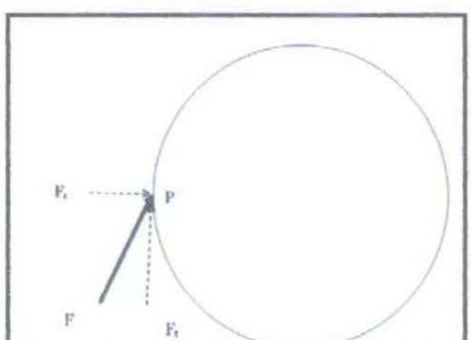

Figure 5: Radial and tangential force acting on gear tooth

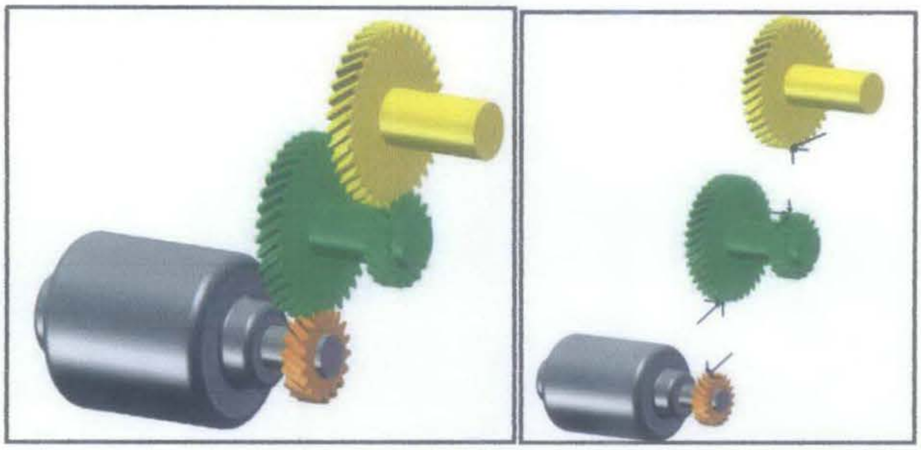

Figure 6: Free body diagram of forces acting on gear train

2.5.3 Static structural analysis

Structural analysis and design is a very old art and is known to human beings since early civilization. The aim of structural analysis is to evaluate the external reaction, the deformed shape and internal stresses in the structure [10].

Stress is a measure of internal forces acting within a deformable body. However, continuous loading on the body beyond the limit of material strength can lead to permanent shape change or structural failure.

The stress analysis involve the process of determining the internal distribution of stresses in a structure

1. Equivalent (von-mises) stress

It is a formula to calculate whether the stresses combination at a given point will cause failure. At any point in the body, there are stresses acting in different directions and magnitude of the stress changes from point to point. Von-mises formula combines all the three forces into an equivalent stress and compares it with yield stress of material. If von-mises stress exceeds yield stress, the material is considered to be at failure condition [11].

2. Maximum shear stress

Shear stress is a stress caused by a pair of opposing forces acting along a parallel line. Failures will occur in a machine if the magnitude of the maximum shear stress in the part exceeds the material's shear strength [11].

3. Deformation

Deformation is a transformation of a body from reference configuration to current configuration. It is caused by external loads, body forces and temperature changes within the body [12]. There are two types of deformation which are:

- *Elastic deformation*: deformation which recover after stress has been removed
- *Plastic deformation*: irreversible deformation which occurs once the stress applied has attained certain threshold value known as elastic limit or yield stress.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

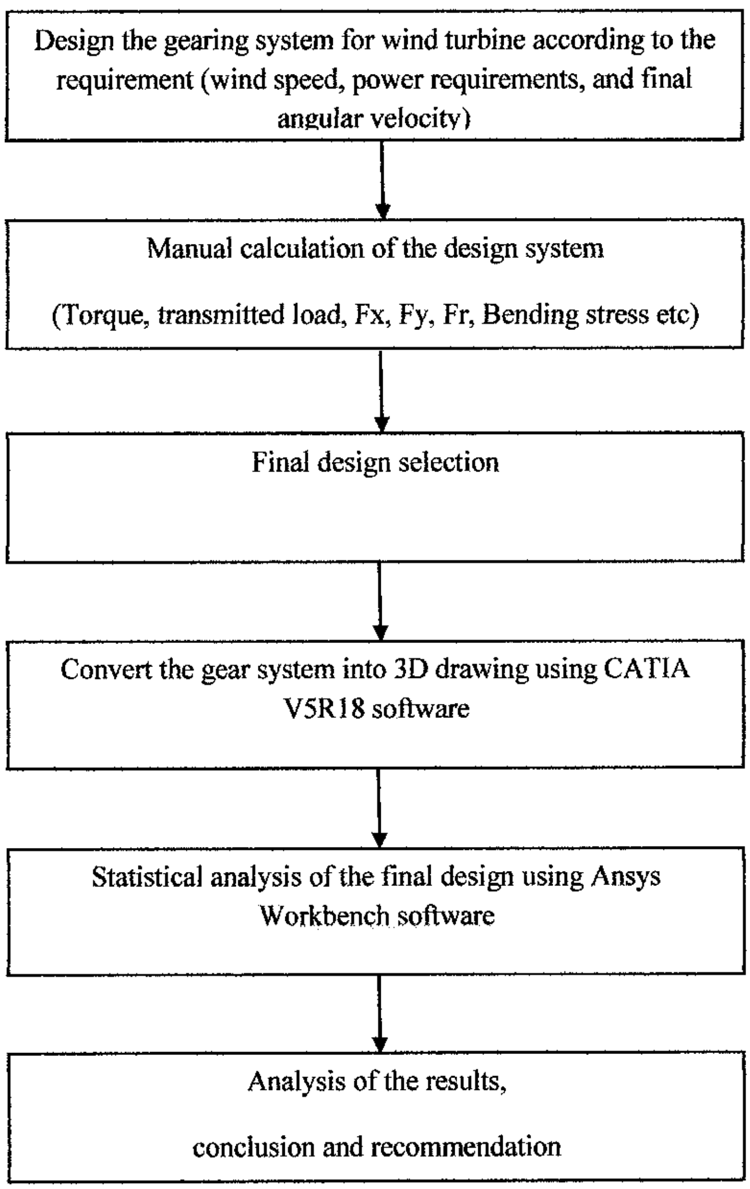

Figure 7: Project flow planning for both semesters

3.2 Work scope

3.2.1 Data gathering and research

Research and data gathering is done via books, articles, journals and websites to make sure the accuracy of the theoretical equation foe design development is acquired.

3.2.2 Designing process for transmission system

Involve the process of determining the output rpm required to generate electricity. From that, we can design the transmission system according to the gear ratio required. Also involve the process of determining the size and dimension of the gears, and calculations to determine transmitted load, forces acting on the gears, torques, and bending stresses. Also translating the design into 3D model using CATIA software

3.2.3 Static analysis of the gears using ANSYS Workbench

The 3D model of the gear design is imported into ANSYS Workbench for static structural analysis to determine the:

- Equivalent (von-mises) stress
- Maximum-shear stress
- Total deformation
- Safety factor

Data received is analyzed for further study in the future.

3.3 Tools and equipments required

3.3.1 CATIA V5R18

This software is one of the advanced CAD software for product development. The benefit of this product is we can see full product development process from detail basic. It also provides product concept specification till product in service. The components available in CATIA software are shape design and styling, product synthesis, equipment and system engineering, analysis and machining.

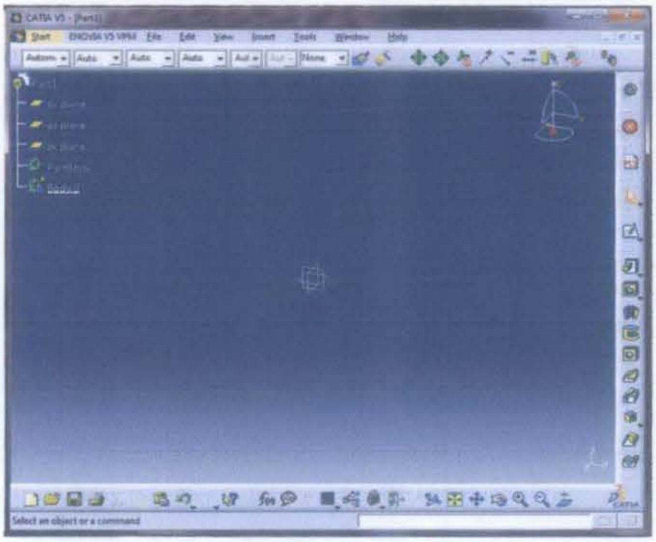

Figure 8: CATIA V5R18 workbench

For this project, 3D model of gear and pinion is developed using part design under shape design and styling components. The first procedure is sketching a gear tooth, and then padding it for 1.5inch. After that is the process to array the gear tooth according to the number of teeth required. Lastly is to create the inside volume of the gear.

3.3.2 ANSYS Workbench

ANSYS Workbench software is a platform for engineering simulation. It allows us to construct models or structures, machine components or system. It also allows for the study of physical responses, such as stress levels, temperature distribution, pressure and etc. This software allows the evaluation of a design without having to build and destroy multiple prototypes for testing. ANSYS Workbench has variety of design analysis application ranging from everyday items to highly sophisticated system.

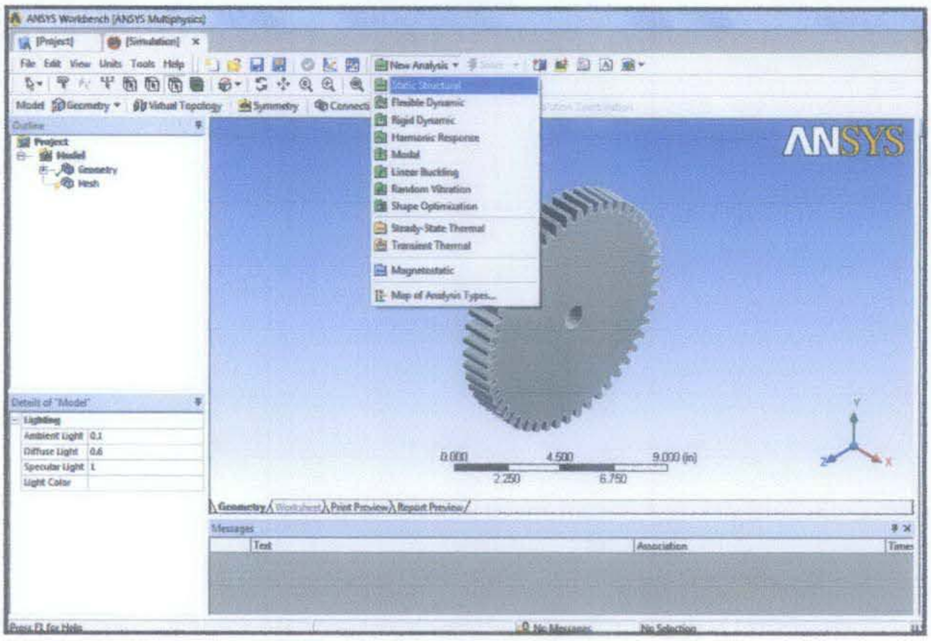

Figure 9: ANSYS Workbench simulation

ANSYS Workbench software is used in this project for static structural analysis simulation of the gear and pinion to determine the total deformation, Equivalent (von-mises) stress, and maximum shear stress and safety factors.

3.4 Design process of transmission system

The transmission system for small wind turbine is designed to overcome the problem of low wind speed and the fluctuating wind condition in Malaysia which is unfavourable to generate electricity for home usage. The designing process involves several steps which are:

1. Design calculation based on information gained from researches
2. 3D modelling using CATIA V5R18 software
3. Static structural analysis using ANSYS Workbench software.

3.4.1 Design calculation

Before design calculation is done, several important parameters for transmission system design are determined first form researches and studies:

Wind speed: 5m/s @63.66rpm
Types of generator: Asynchronous generator
Rated power: 7.5kW @ 10.06 horsepower
Final angular speed required: 1500 rpm

From there we can design the gear system with gear ratio that can step-up from 63.66rpm input into 1500rpm output angular speed. Then, gear types, size and dimension of the gears can be determined. The material used for the gears are also determined at this stage.

The next step involve the calculation process to determine gear torques, transmitted load, forces, bending stresses and material bending stress. All the equations required for the calculation is available in section 2.5.1

3.4.2 3D modelling using CATIA V5R18

All the calculated sizes and dimensions of the gear are then translated into 3D model using CATIA V5R18.

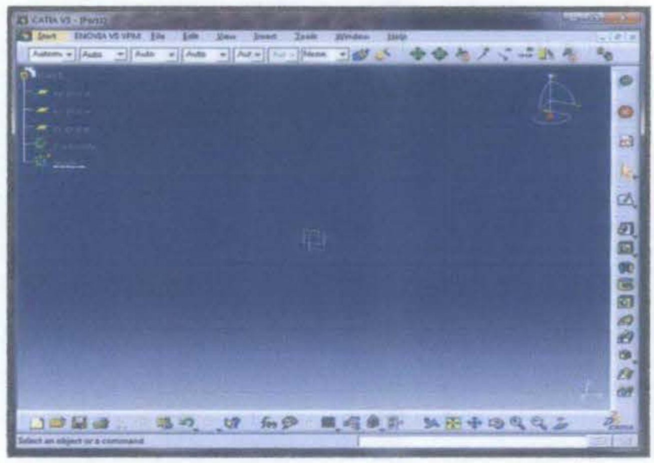

Figure 10: CATIA V5R18 workbench

The steps involved in sketching the gears are:

1. Sketch a gear tooth
2. Pad the gear tooth for the dimension of 1.5in
3. Array the padded gear tooth in a circular pattern to the number of teeth required
4. Sketching the volume of the gears and the pad it at the dimension of 1.5 in

3.4.3 Geometry static structural analysis using ANSYS Workbench software

The processes involved in conducting static structural analysis simulation using ANSYS Workbench are:

1. *Importing 3D model from CATIA V5R18 into ANSYS Workbench*

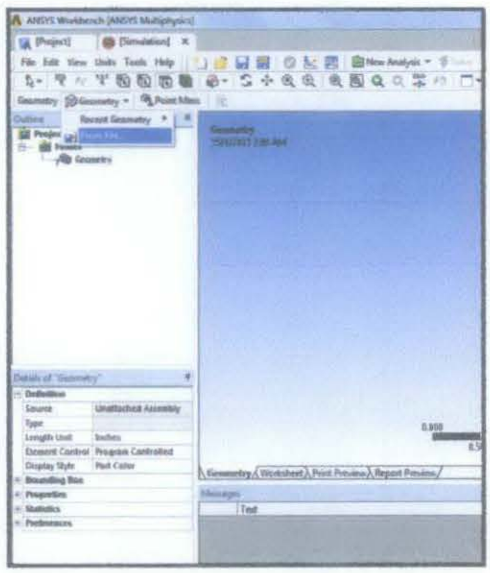

Figure 11: Importing external files into ANSYS workbench

2. *Meshing*

In meshing process, we can determine the type or method of meshing needed for the simulation

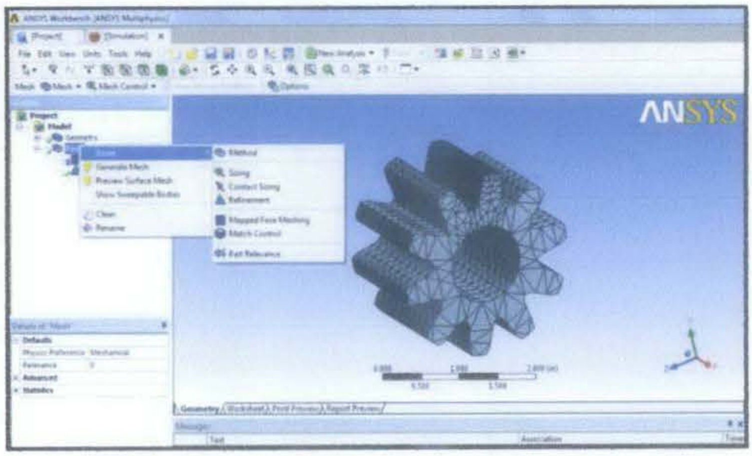

Figure 12: Meshing in ANSYS Workbench

3. Static structural analysis

After done with meshing, the next step is to conduct the static structural analysis simulation. Static structural icon is selected and it will show various selection of analysis required.

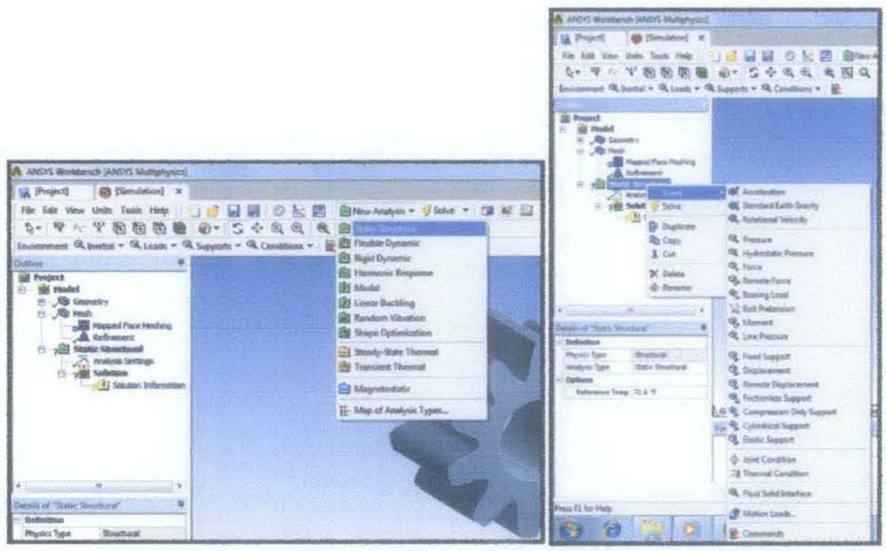

Figure 13: Types of static structural analysis in ANSYS Workbench

From there, several types of inputs such as loads, supports, conditions and inertial can be choose. For this project, the input chosen are fix support and force. First of all, for the fix support it requires to select the geometry faces to apply the fix support. Below is the figure of faces chosen as fix support in the gear.

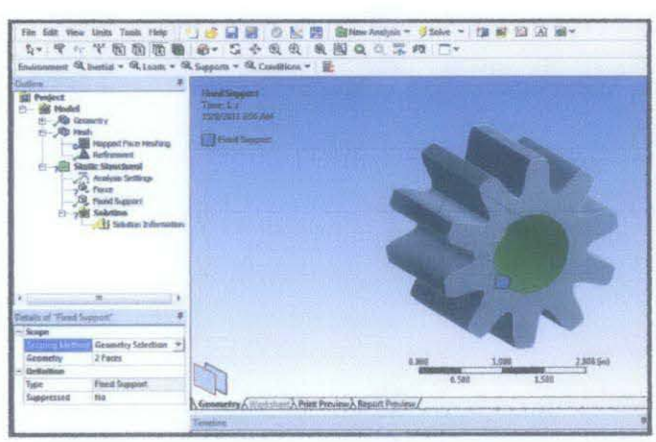

Figure 14: Selecting geometry faces for fix support

The next step is to determine the face to apply force. For this model, the force is applied at one of the gear teeth on the line of action or pitch line. Below stated the magnitude of forces applied on each gears and a figure to show where the force applied on gear tooth.

Table 3: Magnitude of force applied at each gears

No. of gears	Force applied (lbf)
1	2.12
2	1991.93
3	398.39
4	898.39

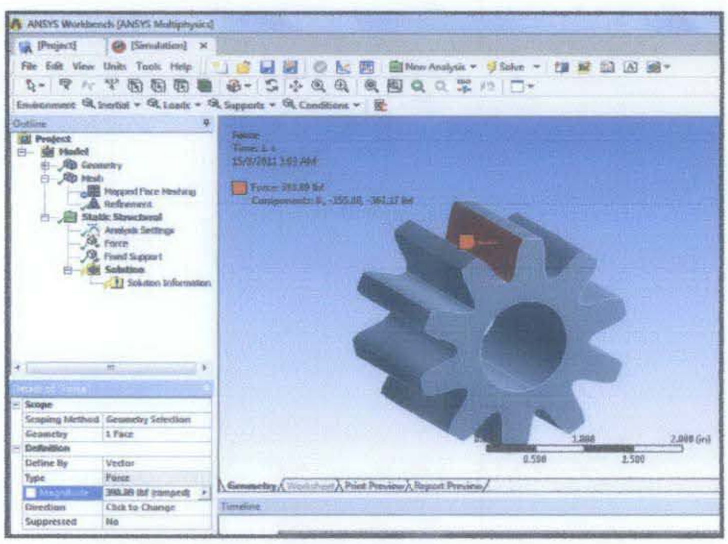

Figure 15: Selecting geometry face to apply force

After that, select the output analysis wanted. There are several options are given for the output analysis ranging from stress tool, deformation, strain, stress, fatigue and etc. However for this simulation, the output analysis chosen are:

1. Total deformation
2. Von-mises stress
3. Maximum shear stress
4. Safety factor

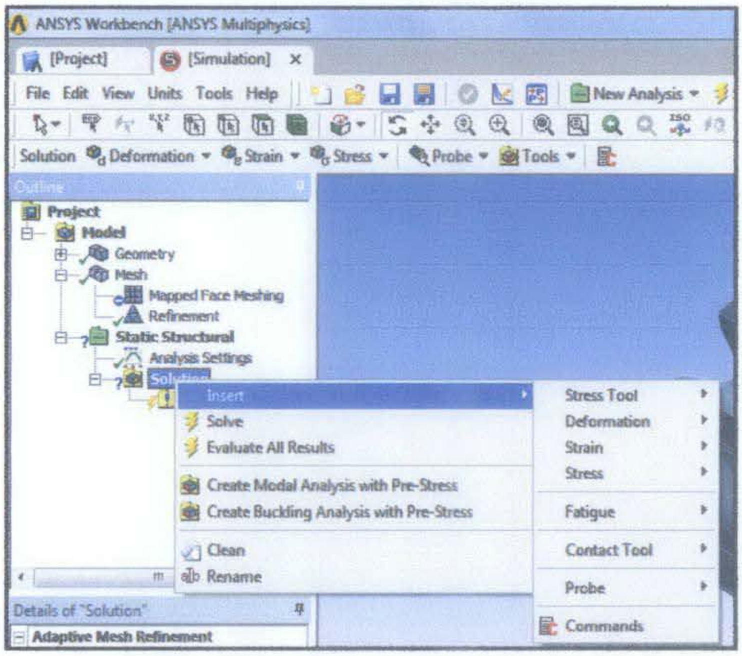

Figure 16: Static structural analysis

After putting all the information and input needed, lastly we can solve this simulation. To do that, click on 'solve' tab, and the computer will solve the problems according to the input given. We can see the simulation result as the figure below

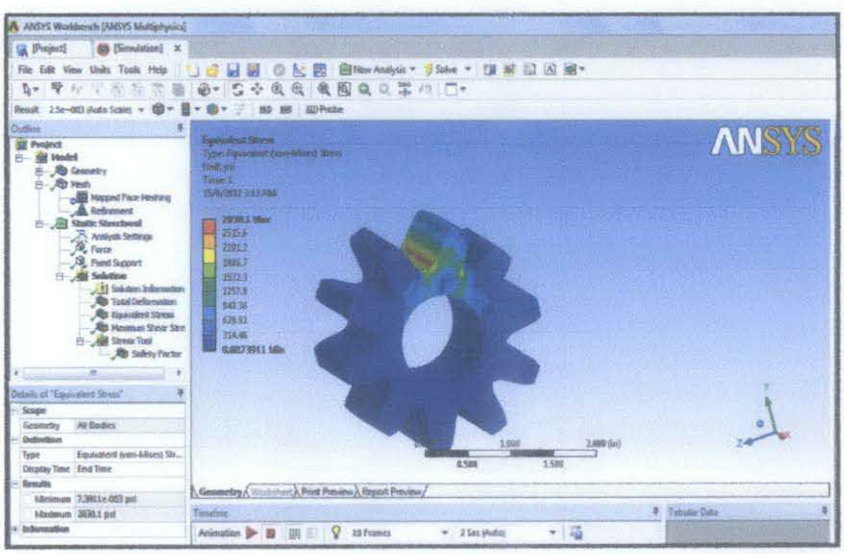

Figure 17: Simulation result for Equivalent (von-mises stress)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Gear design

The transmission system is designed based on the set up parameters which are:

Wind speed: 5m/s @63.66rpm
Types of generator: Asynchronous generator
Rated power: 7.5kW @ 10.06 horsepower
Final rotational speed required: 1500 rpm

The final designs of the gears are:

The drive assembly consist of four spur gears, which are 2 gears and 2 pinions. It is divides into two stages, which are stage 1 and stage 2. The gear ratio for 1st stage gear assembly is 5(ig=5) and the same goes to the 2nd stage gears. So the total gear ratio of this two staged gear assembly is ig=25.

The final output this drive assembly can produce with the given wind speed is 1591.5rpm which exceed the minimum requirement for the generator to generate electricity.

Below is the isometric figure of the 2 staged gear assembly for small wind turbine.

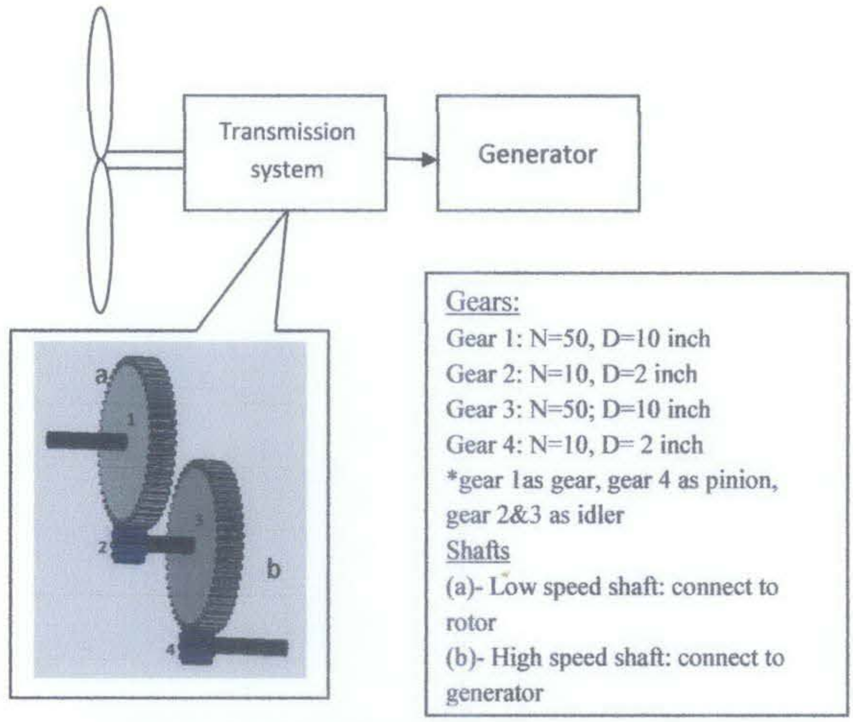

Figure 18: Design of a 2-staged transmission system for wind turbine

Table 4: Technical data for designed transmission system

Gearbox	Generator
Spur gear, 2 step, ig = 25	Types: Asynchronous
N1: 50	Rated power: 7.5kW @
N2: 10	10.06 hp
N3: 50	Rotational speed: 1500 rpm
N4: 10	
Material: Steel carburized Rc 60,	
Sat= 55 000 – 65 000 psi	

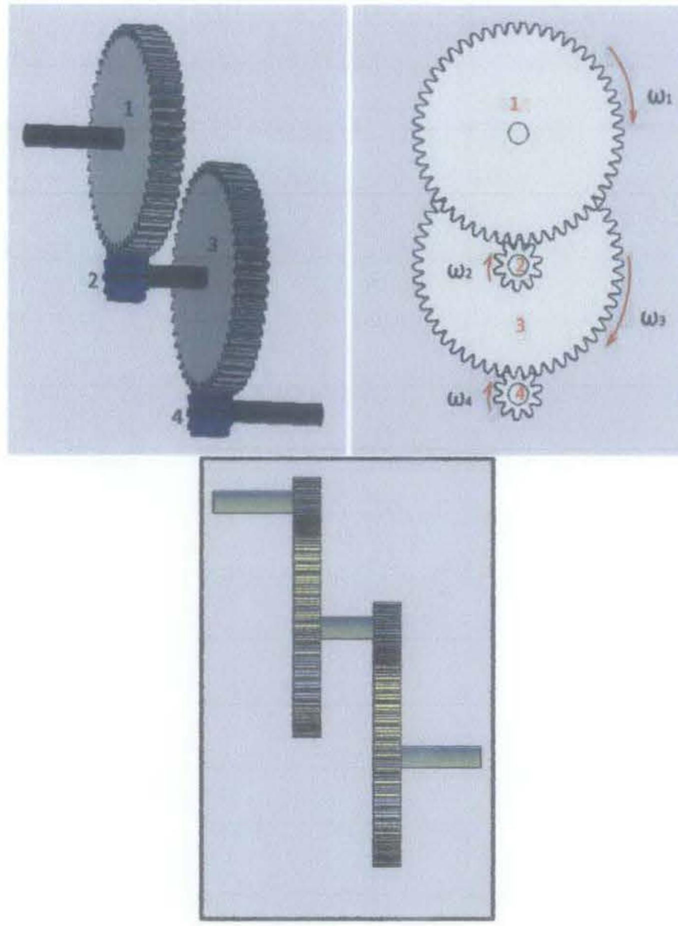

Figure 19: Isometric, front and side view of drive assembly design

From the calculation that had been done based on the gear size and dimensions, the torques, transmitted load, forces and bending stress for each gear are acquired.

<u>1st stage gear, ig=5</u>

Table 5: Gears configuration for 1st stage gear assembly

Gear 1	Gear 2
N :50	N :10
ω_1: 63.66 rpm	ω_2: 318.3 rpm
T_1: 10.06 lbf.in	T_2: 1991.93 lbf.in
W_{t1}: 2.012 lb	W_{t2}: 1991.931 lb
S_{t1}: 60.07 psi	S_{t2}: 59472.6 psi

2nd stage gear, ig=5

Table 6: Gears configuration for 2nd stage gear assembly

Gear 3	Gear 4
N :50	N :10
ω_1: 318.3 rpm	ω_2: 1591.5 rpm
T_1: 1991.95 lbf.in	T_2: 398.38 lbf.in
W_{t1}: 398.38 lbf	W_{t2}: 398.98 lbf
S_{t1}: 27618.24 psi	S_{t2}: 27618.24 psi

4.2 Static structural Analysis of gears

4.2.1 Gear 1 (Force: 2.12 lbf)

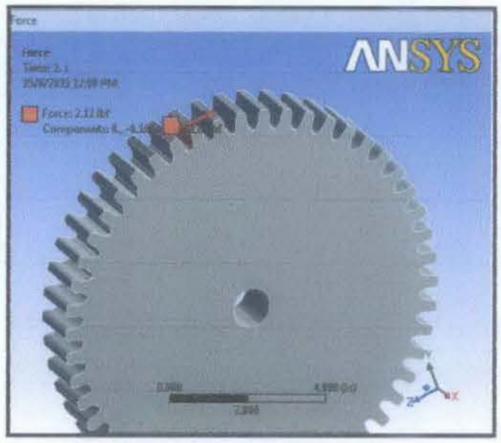

Figure 20: Free Body Diagram of force applied on gear 1

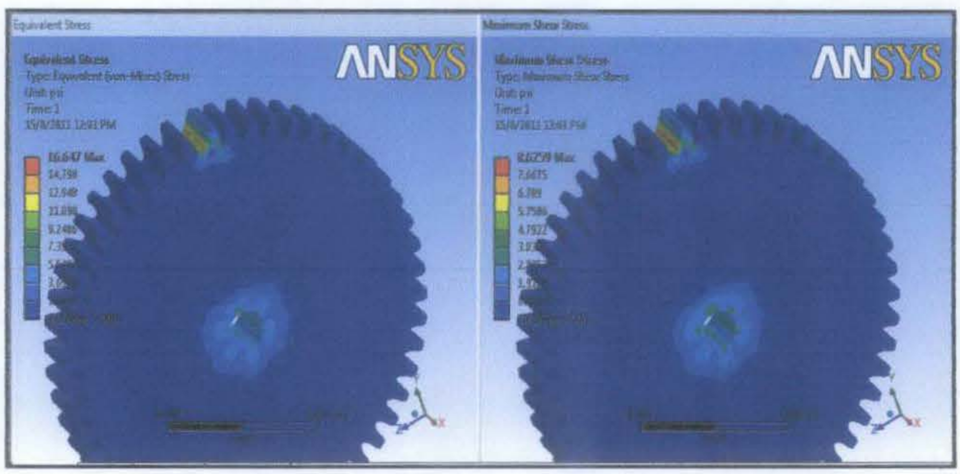

Figure 21: Equivalent (von-mises) stress and maximum shear stress on gear 1

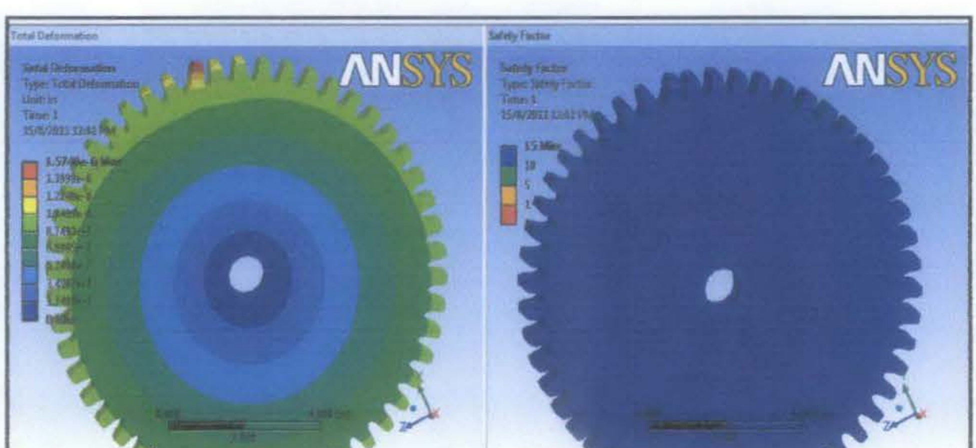

Figure 22: Total deformation and safety factor of gear 1

Table 7: Static structural simulation result for gear 1

Maximum Equivalent (von-mises) stress	16.647 psi
Maximum shear stress	8.6259 psi
Total deformation	1.5740 e-6
Safety factor	Max : 15

The result gained from the simulation shows the value of maximum equivalent (von-mises) stress is 16.647 psi, and maximum shear stress is 8.6259 psi. Both values do not exceed the material's yield strength value which is 36259 psi. As a result, this gear is not considered to be at failure condition and the deformation occurs is elastic deformation, not plastic deformation.

4.2.2 Gear 2 (Force: 1991.93 lbf)

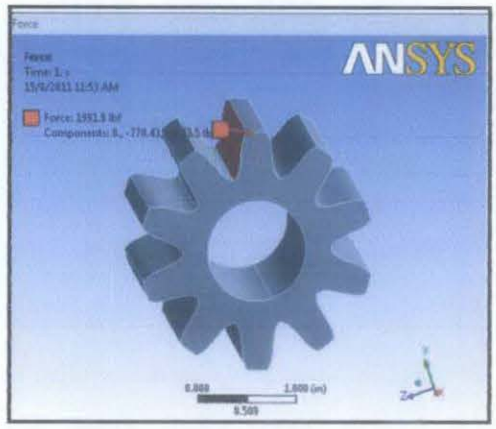

Figure 23: Free Body Diagram of force applied on gear 2

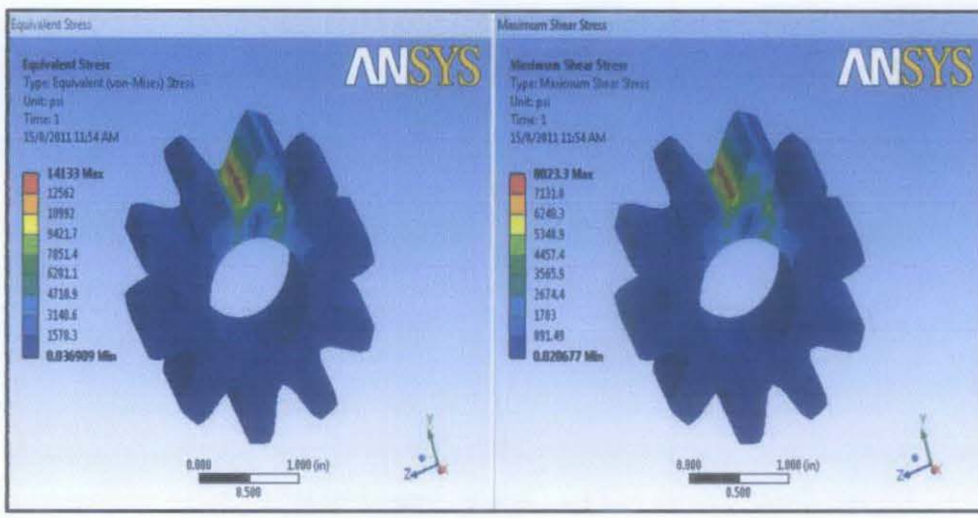

Figure 24: Equivalent (von-mises) stress and maximum shear stress on gear 2

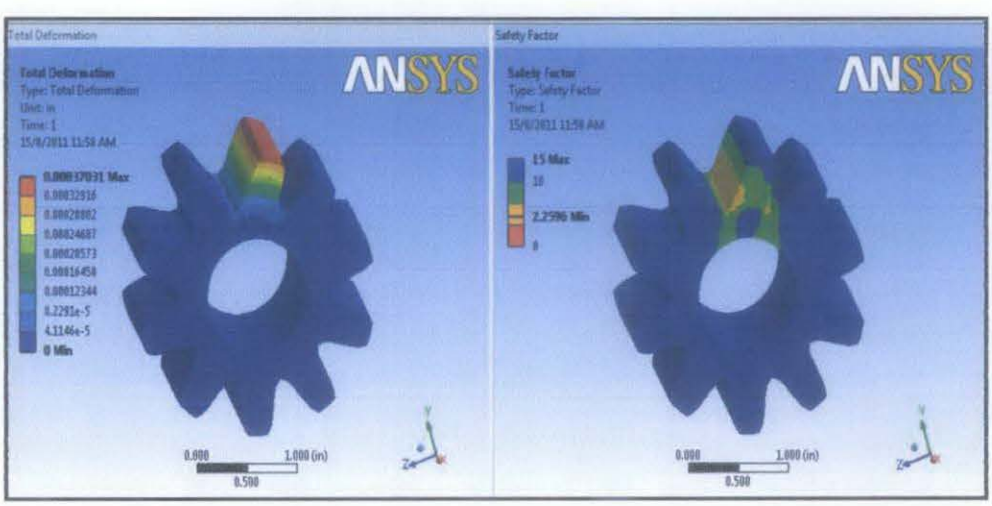

Figure 25: Total deformation and safety factor of gear 2

Table 8: Static structural simulation result for gear 2

Maximum equivalent (von-mises) stress	14133 psi
Maximum shear stress	8023.3 psi
Maximum total deformation	0.00037031 inch
Safety factor	Max: 15 Min: 2.2596

The result gained from the ANSYS simulation shows the value of maximum equivalent (von-mises) stress is 14133 psi, and maximum shear stress is 8023.3 psi. Both values do not exceed the material's yield strength value which is 36259 psi. As a result, this gear is not considered to be at failure condition and the deformation occurs is elastic deformation, not plastic deformation.

4.2.3 Gear 3 (Force: 398.39 lbf)

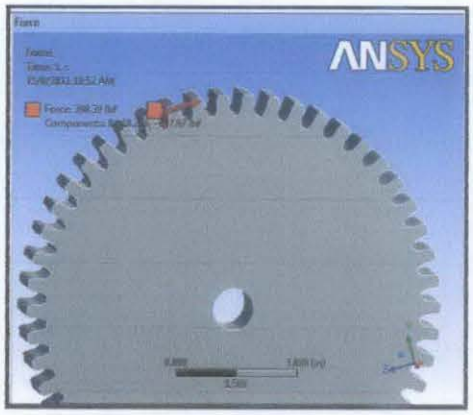

Figure 26: Free Body Diagram of force applied on gear 3

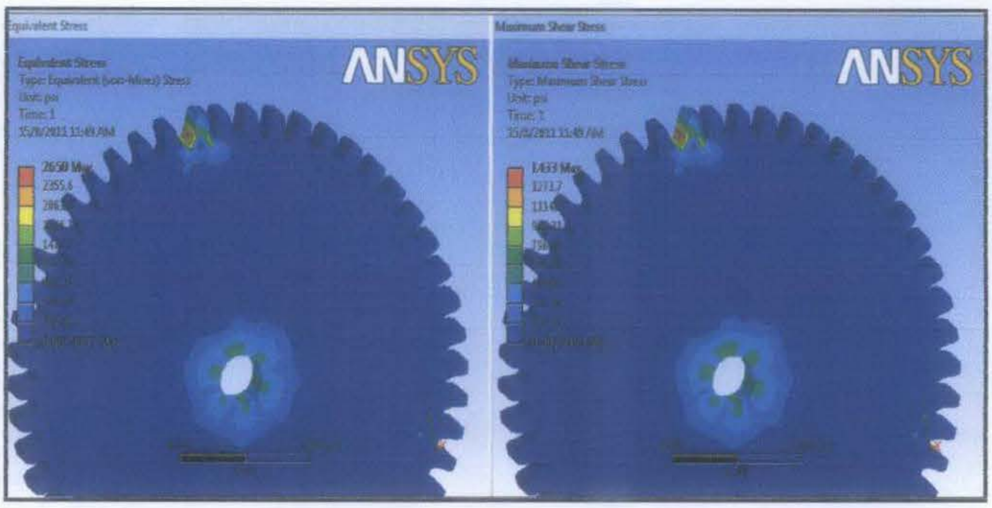

Figure 27: Equivalent (von-mises) stress and maximum shear stress on gear 3

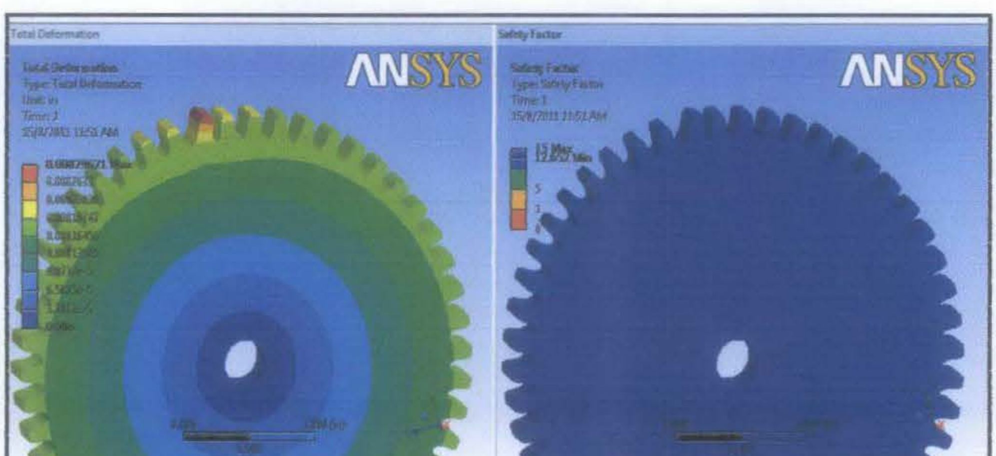

Figure 28: Total deformation and safety factor of gear 3

Table 9: Static structural simulation result for gear 3

Maximum equivalent (von-mises) stress	2650 psi
Maximum shear stress	1433 psi
Maximum total deformation	0.00029621 inch
Safety factor	Max: 15 Min:12.652

The result gained from the ANSYS simulation shows the value of maximum equivalent (von-mises) stress is 2650 psi, and maximum shear stress is 1433 psi. Both values do not exceed the material's yield strength value which is 36259 psi. As a result, this gear is not considered to be at failure condition and the deformation occurs is elastic deformation, not plastic deformation.

4.2.4 Gear 4 (Force: 398.39 lbf)

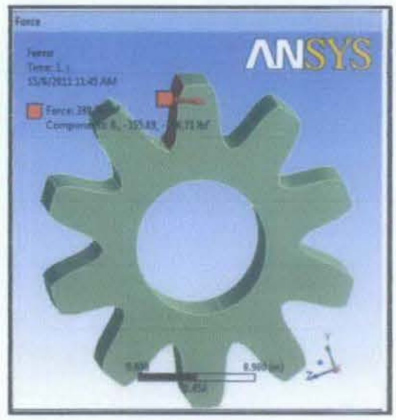

Figure 29: Free body diagram of applied force at gear 4

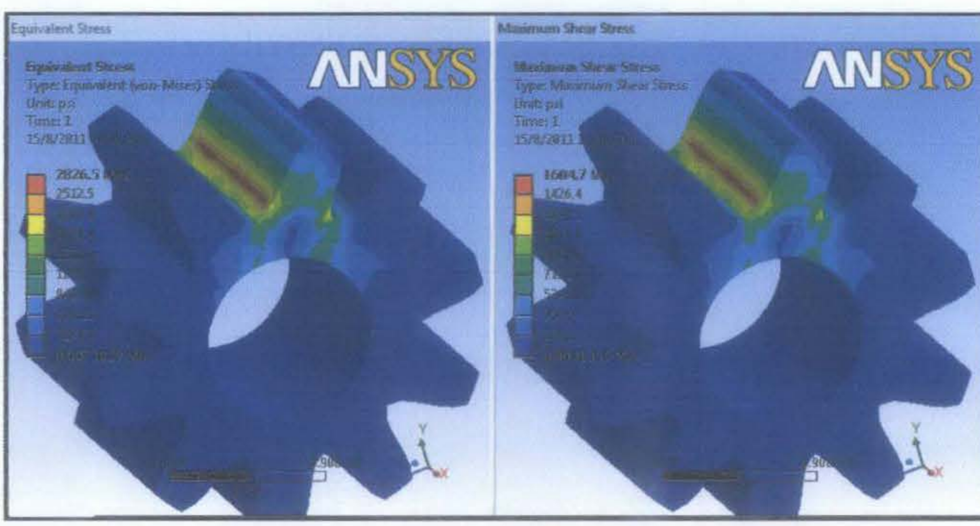

Figure 30: Equivalent (von-mises) stress and maximum shear stress on gear 4

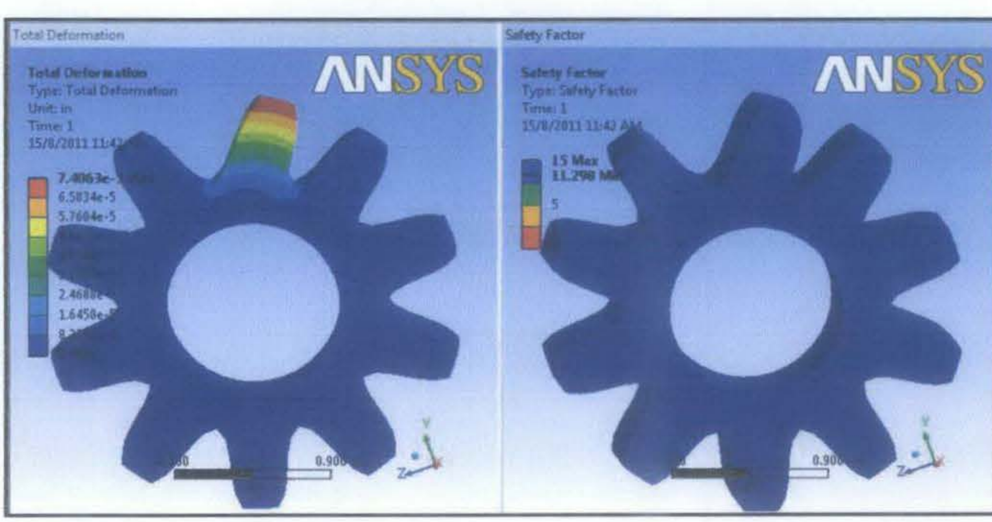

Figure 31: Total deformation and safety factor of gear 4

Table 9: Static structural simulation result for gear 4

Maximum equivalent (von-mises) stress	2826.5 psi
Maximum shear stress	1604.7 psi
Maximum total deformation	7.4063 e-5 in
Safety factor	Max: 15 Min : 11.298

The result gained from the ANSYS simulation shows the value of maximum equivalent (von-mises) stress is 2826.5 psi, and maximum shear stress is 1604.7 psi. Both values do not exceed the material's yield strength value which is 36259 psi. As a result, this gear is not considered to be at failure condition and the deformation occurs is elastic deformation, not plastic deformation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In a nutshell, author concludes that the transmission system designed for small wind turbine is a success. The designed transmission system is able to step-up from low rotational velocity input to the required final rotational velocity output for electricity generation by the generator. From the structural analysis done, it also proves that the design is safe, no material failure and no plastic deformation occur on the gear tooth. This transmission system is a help to the public to use wind energy as their source of alternative energy.

5.2 Recommendations

Improvement on the static structural analysis of the gears can be done by further by studying on the effect of undercutting on the gear. Then the gear analysis can be improved further by studying the modal analysis and fatigue analysis.

CHAPTER 6

REFERENCES

6.1 References

[1] Sathyjith Mathew: Wind Energy Fundamentals, Resource Analysis and Economics - Springer

[2] Shamshad Ahmad*, Wan Hussin W. M. A., Bawadi M. A., Mohd Sanusi. A.: Analysis of Wind Speed Variations and Estimation of Weibull Parameters for Wind Power Generation in Malaysia [journal]

[3] Conergy: Conergy SWT 750 Dc [product technical data]

[4] C.S Lee, K.H Kim and H.C Choi Division of Mechanical/Control System of Korea Institute of Science and Technology (KIST): Experiences of Wind Energy utilization in Korea [Journal]

[5] Richard G. Budynas, J.Keith Nisbet: Shingley's Mechanical Engineering design [Book] - Mc Graw Hill eight edition

[6] Peter Lynwander: Gear Drive System Design and Application [Book] – by Dekker

[7] Darle W.Dudley: Handbook of Practical Gear Design [Book] – by CRC Press

[8] Jones and Ryffel: Gear Design Simplified [Book] – by Industrial Press Inc. New York, NY, Third Edition

[9] Shih-Ling (Sid) Wang: Free Body Diagram of gear Trains [Journal] – Department of Mechanical and Chemical Engineering, North Carolina A&T State University Greensbrow, North Carolina 27411

[10] Version 2 CE IIT, Kharagpur: Module 1-Energy Methods in Structural Analysis

[11] http://www.differencebetween.net/science/difference-between-yield-strength-and-tensile-strength/

[12] http://en.wikipedia.org/wiki/Deformation_(mechanics)

APPENDICES

Calculation Result

1st stage spur gear:

N1	D1 (in)	N2	D2 (in)	ig 1-2	w2 (rpm)	PLV (1st stage)	kv	T (1-2), (in.lb)	Wt (lb)	St (psi)
50	10	10	2	5	318.3	166.577	0.466362021	1991.930569	1991.930569	59472.55745
49	9.8	11	2.2	4.45454545	283.5763636	163.24546	0.470535093	2235.840434	2032.582213	60148.06987
48	9.6	12	2.4	4	254.64	159.91392	0.47480617	2489.913211	2074.927676	60848.82592
47	9.4	13	2.6	3.61538462	230.1553846	156.58238	0.479179022	2754.797595	2119.075073	61576.37808
46	9.2	14	2.8	3.28571429	209.1685714	153.25084	0.483657618	3031.198691	2165.141922	62332.41172
45	9	15	3	3	190.98	149.9193	0.488246146	3319.884281	2213.256187	63927.97462
44	8.8	16	3.2	2.75	175.065	146.58776	0.492949029	3621.691943	2263.557464	65598.13151
43	8.6	17	3.4	2.52941176	161.0223529	143.25622	0.497770934	3937.537171	2316.198336	66473.44273
42	8.4	18	3.6	2.33333333	148.54	139.92468	0.502716799	4268.422647	2371.345915	65680.59923
41	8.2	19	3.8	2.15789474	137.3715789	136.59314	0.507791848	4615.448879	2429.18362	68340.25254
40	8	20	4	2	127.32	133.2616	0.513001615	4979.826422	2489.913211	69337.38158

Ka = 1.0 (no overload anticipated)

Ks = 1.0

Km = 1.1

2nd stage spur gear

N3	D3	N4	D4	ig (3-4)	w3 (rpm)	w4 (rpm)	PLV (2nd stage)	kv	T(3-4). (in.lb)	Wt (lb)	st (psi)
50	10	10	2	5	318.3	1591.5	832.885	0.200850886	398.3861137	398.3861137	27618.24217
49	9.8	11	2.2	4.454545	283.5763636	1263.2038	727.1843217	0.217226134	501.9233628	456.2939662	29248.13953
48	9.6	12	2.4	4	254.64	1018.56	639.65568	0.233724608	622.4783027	518.7319189	30903.24788
47	9.4	13	2.6	3.615385	230.1553846	832.100237	566.1055277	0.250385936	761.9652923	586.1271479	32594.73841
46	9.2	14	2.8	3.285714	209.1685714	687.268163	503.5384742	0.267242847	922.5387323	658.9562374	34773.51286
45	9	15	3	3	190.98	572.94	449.7579	0.284322546	1106.628094	737.7520625	36592.93256
44	8.8	16	3.2	2.75	175.065	481.42875	403.11634	0.301647624	1316.978888	823.1118052	38981.70953
43	8.6	17	3.4	2.529412	161.0223529	407.291834	362.3539681	0.319236659	1556.700742	915.706319	40977.49581
42	8.4	18	3.6	2.333333	148.54	346.593333	326.49092	0.337104589	1829.323992	1016.291106	42515.91629
41	8.2	19	3.8	2.157895	137.3715789	296.433407	294.7536178	0.355262938	2138.866554	1125.719239	45267.045
40	8	20	4	2	127.32	254.64	266.5232	0.373719914	2489.913211	1244.956605	47589.36759

Ka = 1.0 (no overload anticipated)

Ks = 1.0

Km = 1.1

APPENDIX C
Gantt Chart for first semester

No	Details	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■							MID SEMESTER BREAK							
2	First meeting with my supervisor		■													
3	Preliminary Research work															
	a) Research wind turbine working principle			■	■	■	■									
	b) research on transmission system					■	■	■								
4	Preliminary Report preparation			■												
5	Submission of Preliminary Report				●											
6	Progress report preparation						■	■								
7	Submission of Progress Report									●						
8	Seminar (compulsory)									●						
9	Project work continues									■	■	■	■	■	■	■
	a)preliminary design									■	■	■	■	■	■	■
10	Submission of Interim Report Final Draft															●
11	Oral Presentation preparation													■	■	
12	Oral Presentation (during study week)														■	■

● Suggestion milestone ■ Process

Gantt Chart for second semester

No	Details	Week 1	2	3	4	5	6	7	MID SEMESTER BREAK	8	9	10	11	12	13	14
1	Acquire data required	■														
2	Design calculation		■													
3	Detail design of transmission system		■													
4	Develop 3D drawings			■												
5	Learning ANSYS Workbench software				■	■										
6	Static structural analysis						■	■								
7	Data analysis						■	■								
8	Progress Report									■						
9	Poster/Pre EDX												■			
10	Dissertation and Technical Paper														■	
11	Oral Presentation															■
12	Final Report (Hard bound)															■

Process ■