UNIVERSITI MALAYSIA PAHANG

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JUDUL: **OPTIMAL DESIGN OF ELECTRIC BICYCLE: BICYCLE FRAME DESIGN**

SESI PENGAJIAN: 2012/2013

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OPTIMAL DESIGN OF ELECTRIC BICYCLE:
BICYCLE FRAME DESIGN

MOHAMAD FIRDAUS BIN OMAR

Report submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechatronics Engineering

Faculty of Manufacturing Engineering
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JUNE 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MANUFACTURING ENGINEERING

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ACKNOWLEDGMENT

In the name of Allah S.W.T the Most Beneficent and the Most Merciful, infinite thanks I brace upon the Almighty for giving me the strength and ability to complete my Final Year Project.

First and foremost, I would like to thanks the respective to my Final Year Project (FYP) supervisor Prof. Ir. Dr. Shah Nor Bin Basri and my Final Year Project Panel Mr. Shaiful Hakim Bin Mohamed Noor. I also to thank a lot to all my friend who help me in finishing my FYP, Without their outstanding support and interest, this report of mine would not have been the best it would as of now.

I would also like to express my deepest appreciation to my parents and my siblings whom always supports me financially, morality and their never-ending motivations to ensure that I complete my FYP and this report with less difficulty.

Last but not least, I am also in debt to the Faculty of Manufacturing Engineering (FKP) University Malaysia Pahang, for their guidance, starting from my starting project till the end of my successful FYP. My sincere thanks go to all staff in Lab for give me guidance in using machine and also provide me the material for my project. My sincere appreciation also reaches out to all my colleagues and friends who have provided assistance at various occasions. Also to all individuals who was involved either directly nor indirectly in the completion of this report. Indeed I could never adequately express my indebtedness to all of them. Thank you a lot.

ABSTRACT

This projek discuss the suitable design for electric bicycle and also the material for the bicycle frame. With the addition of motor and battery pack on the electric bicycle, the body frame have extra load to overcome other than rider weight. Therefore an analysis by using Finite Element Analysis method will be done to determine the most efficient design and the suitable material for the electric bicycle's frame.

ABSTRAK

Projek ini membincangkan reka bentuk yang sesuai untuk basikal elektrik dan juga bahan untuk bingkai basikal. Dengan pertambahan motor dan pek bateri pada basikal elektrik, kerangka badan mempunyai beban tambahan untuk ditampung selain daripada berat badan penunggang. Oleh itu analisis dengan menggunakan kaedah Analisis Unsur Terhingga akan dilakukan untuk menentukan reka bentuk yang paling berkesan dan bahan-bahan yang sesuai untuk bingkai basikal elektrik ini.

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LIST OF SYMBOLS

F	Force
m	Mass of rider
g	Gravitational acceleration
σ	Stress
A	Area
E	Modulus of elasticity
ε	Strain
R	Radius of outer surface
r	Radius of inner surface
h	Height
a	Major radius
b	Minor radius

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
CAD	Computer Aided Design
FEA	Finite Element Analysis
TA	Titanium Alloy

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bicycle is the most efficient vehicle which had been designed by human. By comparison, it is one-tenth more efficient than jet aircraft and one-twentieth more efficient compare to the best automobile in term of cost, and energy spent in carrying a comparable load over a comparable distance. In the past, bicycle were played by the rich but then, it soon evolved into an efficient and convenient transport. However, the submerged of automobile had relegated bicycle role as main transportation means into an exerciser or a sports machine. Although the role of bicycle becomes smaller, in certain county such as China and Southeast Asia, it still use as daily transportation. But then, the bicycle had been used as a primary choice for short runs vehicle in urban areas. The efficiency of bicycle which does not pollute the atmosphere, noiseless and the important factor, its size makes it more efficient to be used in urban areas which mostly packed with other vehicle.

In 1791, a Hobby Horse the first concept two-wheeled vehicle being display at a Parisian Park. The toy-like machine was simply a wooden beam on two wheels which need to be propelled by the rider himself. The rider drove the machine by pushing his feet against the ground. In 1817, the Hobby Horse undergo improvement by Baron von Drais and his invention then being name after his own name, Draisienne (see in Figure 1.1). The invention then become popular among the rich and fashionable along the day. The important addition of the Draisienne is the steerable front wheel which change the permanent front wheel of the Hobby Horse. The addition gives the Draisienne some measures of stability. However, the awkward posture of the rider and bumpy ride on solid wheels had cause lot of hernia cases and lead to setback in the development of bicycle.

Figure 1.1: The Draisienne

A Scottish blacksmith named Kirkpatrick Macmillan had introduce the first true bicycle, Velocipede in 1839 (see in Figure 1.2). The Scottish had employed the power of the leg muscle to turn the rear wheel directly. He employed treadles-drives crank mechanism in his invention. By using two bar suspended from the front end of the frame, the lower end of these bars, known as treadles, carried pedals which were driven alternately by feet through short arcs. The two cranks were moved by the motion of these treadles which conveyed through a pair of connecting rods to the rear wheel, thus turn the push and pull motion of the rods into the rotary motion of the rear wheel. But the design never had commercial success and not many people know about his bold design. In 1863, Pierre Michaux's Velocipede was successfully commercialise. It then known as Bone-shaker (see in Figure 1.3) due to the wooden wheels on the cobbled roads that give rider such a rough side.

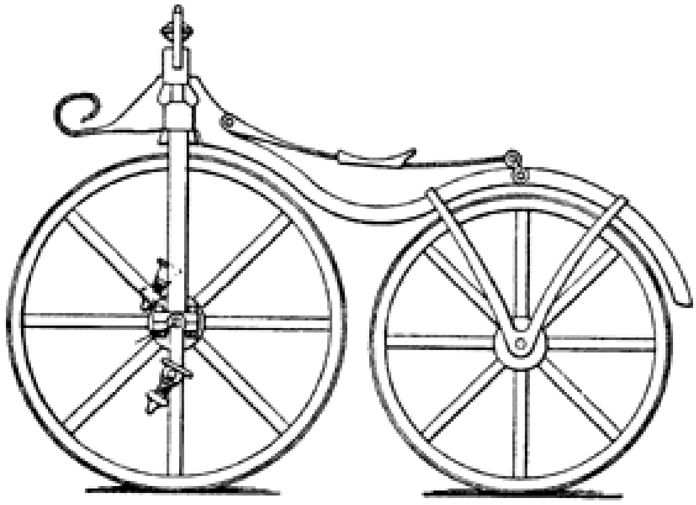

Figure 1.2: The Velocipede

Figure 1.3: The Bone-shaker

Since then, new concept and technical aspect of bicycle development show its progress rapidly. Implementation of ball bearing, spooked wheel, tubular frame, chain drive, free wheel, gears and differential mechanism had change the scene of bicycle industry. In 1980, Dunlop had introduced pneumatic tire for the bicycle which brought major change in the industry. By 1895, the bicycle had reach it peak of improvement with the development of diamond frame form, pedal power, chain drive and pneumatic tires. However, the bicycle industry had a setback between 1900 and 1950 due to the popularity of automobile. At the moment, the world focused on the development of automobile and airplane. Although bicycle industry having such difficulties at the moment, it then comes upon advantages through the development of both automobile and airplane industries. Through the research for the military and commercial airline industries, lot of material had been developed to find suitable material that could outperform steel. From the research, material such as aluminium alloy, carbon fibre, and titanium had been widely used for bicycle frame.

1.2 Problem Statements

This project is proposed in order to design the electric bicycle that use for the travelling and can be used in long distance. The designing of the electric bicycle is included of the frame design, motor control and gearing system design and the riding comfort for the rider. The customer demand for electrical bicycle increase rapidly however manufacturer only compete with each other in term of technology meanwhile neglect the most important factor in electric bicycle which is the strength of the bicycle frame. In this proposal, the design of bicycle frame and analysis of material for the bicycle frame will be proposed.

1.3 Objective

The aim for this project of making the electric bicycle which is included the designing of the frame, comfort, the way of powered and controlled it. Hence, my objective for this project is:

i. To design and analyse bicycle frame design that support load from 50kg to maximum load of 70kg.
ii. To analyse suitable material for the bicycle frame.

1.4 Scope of Study

In my part/ project task, there are two scope of study. They are:

i. Comparative study of bicycle frame design.
ii. Analysing material for the bicycle frame by using Finite Element Analysis (FEA) method.

1.5 Closure

This chapter highlighted on basic information regarding design of bicycle which had been built back then. In the next chapter an extensive literature review will be discussed about frame design, material for bicycle and finite element analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will briefly explain about relation of bicycle frame design and the material of the frame. The sources are taking from the journals, and articles and books. Literature review is helping in order to provide important information regarding previous research which related to this project. Those information are important to know before can proceed further to analysis and study later.

2.2 Properties of Material

The properties of physical materials can be classified into three main groups:

- Physical -- Density, colour, electrical conductivity, magnetic permeability, and thermal expansion
- Mechanical -- Elongation, fatigue limit, hardness, stiffness, shear strength, tensile strength, and toughness
- Chemical -- Reactivity, corrosion resistance, electrochemical potential, irradiation resistance, resistance to acids, resistance to alkalis, and solubility

2.2.1 Density

Density describes the weight of a given volume of a material [1]. Different material have a different density. It is an important in searching material for bicycle frame because the material selection for the bicycle depend on it function. Some bicycle used a high density material while bicycle like mountain bike or racing bike need material with lower density. For example, titanium is about half the density of steel, aluminium is about one-third the density of steel [1]. The entire bicycle will often weigh about one tenth as much as the fully accessorized rider. Most cyclists will not notice a small difference in the weight of the frame unless they do a lot of climbing or need to lift and carry [2]

2.2.2 Stiffness

Stiffness is described by a quantity called modulus of elasticity, or Young's Modulus [1]. Imagine fixing one end of a solid bar into a clamp so tightly that it will not budge. Now apply some force to the free end of the bar, for example, by hanging some weights from the free end. For small weights, the bar will bend slightly, but if you remove the weight the tube will spring back to being perfectly horizontal. This elastic property is the stiffness of the material. Under the same weight a stiff material will bend or flex less than an elastic one [2]. For bicycle, the material always depend on the function of the bike. As an example, a cyclist interested in maximizing his performance in sprints and time trials will often prefer a stiff frame [2]. It because the elastic material will cause the frame to absorb energy that being generated to move the bike forward. Different frame materials have different levels of inherent elasticity, the stiffness of a tube is mostly determined by its diameter and length. A frame's geometry also has a significant impact on the overall stiffness of the bike [2].

2.2.3 Fatigue Strength

The fatigue strength number describes the stress required to break the specimen after a specific number of cycles [1]. Failure from fatigue is a very complicated and dynamic process that depends not only on the amount of force applied in each cycle and the number of repetitions but also on microscopic defects and anomalies that may be present in the material [2]. The lifespan of a bike frame depend on the fatigue strength of the material. Since the bike were used repeatedly, therefore the fatigue failure might happen thus the material selection is important. Steel and titanium exhibit a fatigue limit, a threshold below which a repeating load may be applied an infinite number of times without causing failure. Aluminium and magnesium don't exhibit such a limit, meaning that they will eventually fail under any repeating load, even a minimal one [1].

2.2.4 Tensile strength

"The more strength the better" is a good rule of thumb, but only if you keep close tabs on other properties at the same time [1]. Now imagine hanging more weight from the free end of a bar. At a heavy enough load the bar will no longer spring back to its original shape, it will permanently warp [2]. It's the same condition with bike frame. A brittle material such as carbon fibre will snap before they deform while flexible material such as steel will bend before it breaks at their respective breaking point. The strength of the frame material doesn't influence the performance or feel of the ride under normal conditions, but it is a significant factor in the "crash worthiness" of the frame [2]. Defining a material for the frame is crucial since a broken frame most likely be a taboo to a rider.

2.2.5 Elongation

Elongation measures how far a material will stretch before it breaks. It's a measure of the material's ductility [1]. In designing, the failure factor should be considered and need to be minimized to ensure the safety of the rider. Ductility of material is important since the material will bend before it break thus will reduce the injury risk. Shattering like a piece of glass is not an acceptable failure mode in a bicycle [1]. With the repeated force acting on the frame, the possibility of the frame to break is still there therefore a ductile material will ensure the frame to bend if the condition happen.

2.3 Materials

The first bicycle were made by wood and since then there are variety of material being used for the bicycle frame. However, there are four type of material that widely used for the bicycle frame which are steel, aluminium, carbon-fibre composite and titanium. The table below shows the typical tensile strengths of those materials:

Table 2.1: Typical tensile strengths of material

Material	Yield Strength (MPa)	Ultimate Strength (MPa)	Density (g/cm^3)
Steel, high strength alloy ASTM A514	690	760	7.8
Aluminium alloy 2014-T6	414	483	1.84
Titanium 11 (Ti-6Al-2Sn-1.5Zr-1Mo-0.35Bi-0.1Si), Aged	940	1040	4.50
Carbon fibre	N/A	1600 for Laminate, 4137 for fibre alone	1.75

2.3.1 Steel

The bicycle frame was for many years manufactured in steel, the first frames were very heavy and the angles were laid back and with a long wheel base, which made for a comfortable ride on the rough roads of the time, but would not be responsive for today's fast roads and race conditions [1]. Steel is made mostly of iron, whose atomic symbol is Fe, from the Latin ferrum. That's where get the term 'ferrous', as in ferrous and non-ferrous materials. As you may have guessed, steel is a ferrous material, and aluminium and titanium are non-ferrous [2]. The versatility of steel which it can be drawn, machined, shaped, and alloyed with other metals to accommodate a wide variety of strength and performance requirements, produce an impressive array of strong, comfortable, excellent handling, and inexpensive frames built of steel alloys. It weight which heavier than other material become one of its disadvantage [3]. Steel is also a reliable material for building bikes. It's easy to work with, can be welded or brazed, requires only simple tools for fabrication, fails in a predictable manner, and cheap [2]. Steel is durable if well painted, and the hardest, stiffest, strongest, structural material available. It varies in tensile strength from 375 to 1800 MPa. Its modulus of elasticity though, which is the measure of its stiffness or resistance to bending, is the same for all grades - about 201,000 MPa [4]. Steel tubing is the most popular bike frame material. Steel can, and usually is, butted—meaning that the walls are thinner in the center than the ends of the tubing. Thicker walls typically appear at the ends because this is where the tubing is stressed the most, and is also where the tube is welded or brazed to other frame tubes [5]. However, Steel's density and oxidation issues are its largest drawbacks. Higher strength steels (e.g., AerMet 100 or MP35N) are not yet capable of offering the performance advantages of titanium [6].

2.3.2 Aluminium

In his article, Beth Puliti had mention that aluminium is a lighter-weight material that was the first-ever alternative to the steel bicycle frame. Although its density is one-third compare to the steel but the diameter of aluminium tubes is larger than steel tubes. This is because the material is also one-third the rigidity and one-third the strength of steel [5]. It is a popular material because it is extremely lightweight, produces strong tubing and framesets, and yet is remarkably inexpensive however it lacks the durability or damage and fatigue resistance of either steel or titanium become the major setback of aluminium [3]. Mike Burrows stated in his book that this material has a lower tensile strength than steel, typically 225-750 MPa, and a considerably lower modulus of about 54,000 MPa. It is much more prone to fatigue if badly used. But it is a third the weight of steel. This is why it is what most aeroplanes are made of today, although not in tubular form. [4]. Furthermore, the aluminium is the most plentiful metal in the earth's crest, thus it become one of the resourceful material for the bike frame [7]. Aluminium MMCs are new to bicycle frame use. The most successful so far is an aluminium-oxide MMC. Unfortunately, the current tubular-form aluminium MMCs' property improvements over monolithic aluminium are not substantial [6].

2.3.3 Titanium

Titanium is very light but will give a hard ride experience to the rider, mixing titanium main tubes with carbon forks and back end would be the best for handling and for comfort [1]. Titanium actually the fourth most abundant metallic element in the earth, after aluminium, magnesium and iron, thus with the mass of material, the production of titanium frame can be done without lack of material worries [8]. Boasting one of the highest strength to weight ratios of any material, titanium is lighter than steel but equally as tough [5]. However fabricating titanium is a difficult task since titanium react aggressively to oxygen thus makes it harder for welding process. The cost to extracting the raw material and also the cost of tooling makes titanium frame expensive [3] [5]. Titanium's fatigue endurance allows the builder to create a frame with a more resilient ride than what is currently available with other bicycle-frame materials [6]. Other than frame, titanium characteristic which can flex while maintaining its shape so well makes it used as a shock absorber on some bikes [5].

2.3.4 Carbon-Fibre Composites

Tough and exceptionally lightweight, carbon-fibre is made up of a bunch of knitted carbon-fibres that are attached together with glue. This non-metallic material is also resistant to corrosion [5]. With carbon-fibre you can manipulate the carbon in certain ways to make the bike have a certain feel to it, as compared to metal [11]. Carbon as a material is pretty versatile because it can be it can be moulded and sculpted into aerodynamic forms without sacrificing strength, making it a top choice of triathletes. Then those shapes can be used to add strength where needed. It has a very strong strength to weight ratio, and is replacing aluminium in a lot of aircraft manufacturing [3] [9]. Carbon-fibre bike frames can be constructed in three different ways, they can be made in one piece, with the carbon material wrapped in different directions for strength and lightness or tubes can be made more like ordinary alloy or steel frames and then joined directly or with lugs [1]. Carbon-fibre structures are less fault-tolerant than metal structures, making good design and execution even more important than usual [10]. However, the failure rate on many composite frames has severely limited the acceptance of these products [6]. The disadvantage of the material is that in the event of cracking or damage the frame is not repairable and must be replaced. Also, a poor quality carbon fibre frame may be brittle and lack the shock absorption of top quality carbon fibre frames [3].

2.4 Frame Design

The frame is the heart and soul of a bicycle. It translates pedal effort into forward motion, guides the wheels in the direction selected, and helps to absorb the road shock. How well the frame does these various jobs is determined by the materials from which it is built, the design, and the method of construction [5]. The tubing on most conventional bike frames is designed to form a diamond shape. This arrangement goes back at least a hundred years to the earliest safety bicycles and hasn't changed much since [14].

2.4.1 The Diamond Frame

In the diamond frame, the main "triangle" is not actually a triangle because it consists of four tubes: the head tube, top tube, down tube and seat tube. The rear triangle consists of the seat tube joined by paired chain stays and seat stays. The head tube contains the headset, the interface with the fork. The top tube connects the head tube to the seat tube at the top. The top tube may be positioned horizontally (parallel to the ground), or it may slope downwards towards the seat tube for additional stand-over clearance. The down tube connects the head tube to the bottom bracket shell. The rear triangle connects to the rear fork ends, where the rear wheel is attached. It consists of the seat tube and paired chain stays and seat stays. The chain stays run connecting the bottom bracket to the rear fork ends. The seat stays connect the top of the seat tube (often at or near the same point as the top tube) to the rear fork ends [15].

2.4.2 Design Requirement

Ron Nelson in his article had stated the foremost design requirement for bike frame are light weight and high lateral stiffness [16]. The light weight bike frame contribute in minimizing energy consumption up hills or during acceleration. Both up hills and acceleration need more energy compare to cruise ride because it need to overcome the gravitational force during up hills and need to turn the pedal more faster during acceleration. By using light weight bike frame, those action can be done more smoothly since the load from the frame had been reduced. The light weight also helps the rider to experience more responsive feel to their movement meanwhile the high lateral stiffness provides a stable feel to the rider whenever descending or cornering, thus provide confidence in the frame’s response to rider action [16]. Furthermore, the ability of the frame to damp road vibrations and provide vertical compliance to absorb shock are also important in designing bike frame [16]. Below are the requirement that need to be consider in bike frame design

i. Strength Requirement

Strength of bike frame is a major requirement in designing a bike frame. From a rider perspective, they would never want experiencing bike frame malfunction. Thus, reliability producing high static and fatigue strength is essential to minimize service failures which affect profitability, product image and can produce legal liabilities [16].

ii. Geometry and Interface Requirement

The functionality of bike frame is to hang all equipment on it. The frame provided the key interface for all the other componentry which compromise the bicycle [16]. The geometry of the tube centrelines must be exact because it can affect the rider position and handling dramatically. Equipment such as wheels, front fork, steer tube and bearing assembly, each of the equipment had its own clearance and operational dimension constraint to meets the interface requirement. The frame material selection also affect the design of the frame considerably [16]

2.5 Finite Element Analysis (FEA)

Finite element analysis can be known as a finite element method and is the basis of a multibillion dollar per year industries. FEA is one of the numerical solutions and important in introductory treatments of Mechanics of Materials. It is used in a new product design, and existing product refinement to analyse for specific result. In case of structural failure like a wrinkling, FEA may be used to help determine the design modifications to meet the new condition and optimize the parameters. There are generally two types of analysis that are used in industry: 2-D modelling, and 3-D modelling. While 2-D modelling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modelling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modelling schemes, the programmer can insert numerous algorithms which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture. FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. FEA is used to optimize mass, volume, temperature, strain energy, stress strain, force, velocity and others. In this project FEA is study in terms of displacement.

2.6 Closure

This chapter highlighted on literature review regarding the material and also design requirement of bicycle frame design and finite element analysis. In the next chapter, a methodology for this project will be discussed about the parameter of bicycle frame and also the analysis method for the bicycle. Analysis set up and procedure also will be discussed on the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will described about the procedures of designing bicycle frame and analysis of material for the frame. Research methodology is a set of procedures or methods used to conduct research. Methodology is needed for a guideline in order to ensure the result is accurate based on objective. There are several steps need to be followed to ensure the objective of the research can be achieve starting from finding literatures until submitting the final report.

3.2 Flow Chart of Methodology

Flowchart is represents a process by showing the steps as box of various kinds, and their orders by connecting with arrows. Flowchart is important in doing research by helping viewer to understand a process flow and help to visualize what is going on. Flow chart methodologies were constructed related to the scope of product as a guided principal to formulate this research successfully, in order to achieve the objectives of the project research. This is important to ensure the research experiment is on the right track. The terminology of work and planning for this research was shown in the flow chart below.

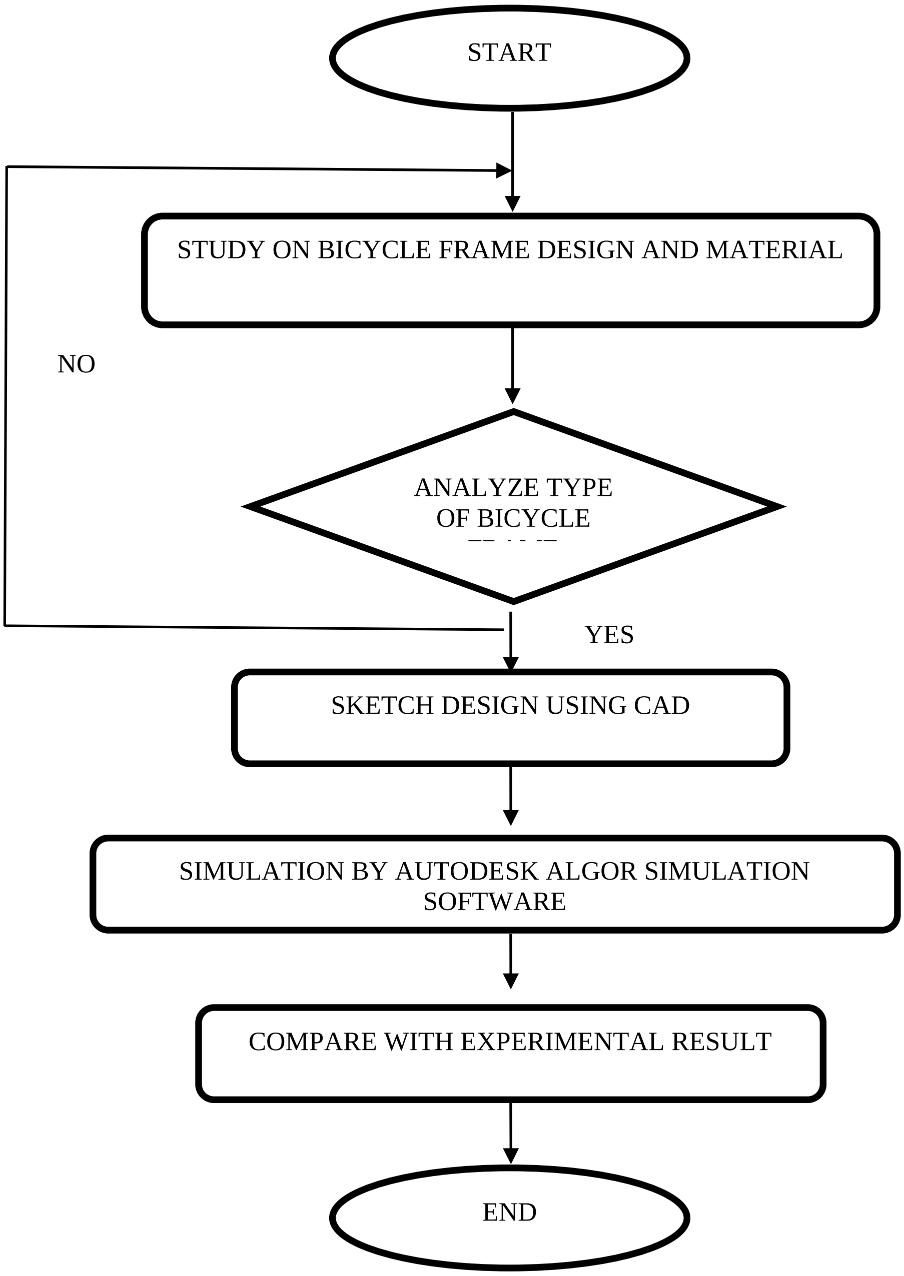

Figure 3.1: Project flow chart

3.3 Design of Bicycle Frame

The design of the frame will be using the diamond shape frame. There will be two different shape of bicycle design which are tube frame design, shown in Figure 3.2 and ellipse frame design shown in Figure 3.3. The diamond shape frame were choose because it was widely compare to other type of frame. Besides that, this frame were easily made compare to others which give an advantage for a mass production.

Figure 3.2: Tube frame design

Figure 3.3: Ellipse frame design

3.4 Material Selection

The material that will be in the analysis are aluminium alloy and titanium alloy. These material will be define to the bicycle frame in the Autodesk Algor Simulation software. Table 3.1 below shows the properties of both material

Table 3.1: Properties of analyse material

Material	Aluminium Alloy 2014 T6	Titanium Alloy 6Al-4V
Modulus of Elasticity (GPa)	75.152	113.763
Mass Density (g/cc)	2.789	4.382
Poisson's Ratio	0.4	0.35

3.5 Computer Aided Design (CAD)

The CAD software that will be used for this project is Catia. Figure 3.4 shows the part of bicycle frame design which consist of head tube, seat tube, top tube, down tube, seat stays, chain stays and lastly bottom bracket shell. The bicycle frame will be design according to a specific parameter shown in Table 3.2 for tube frame design and Table 3.3 for ellipse frame design. These parameters were taken from a bicycle manufacturer frame's geometry.

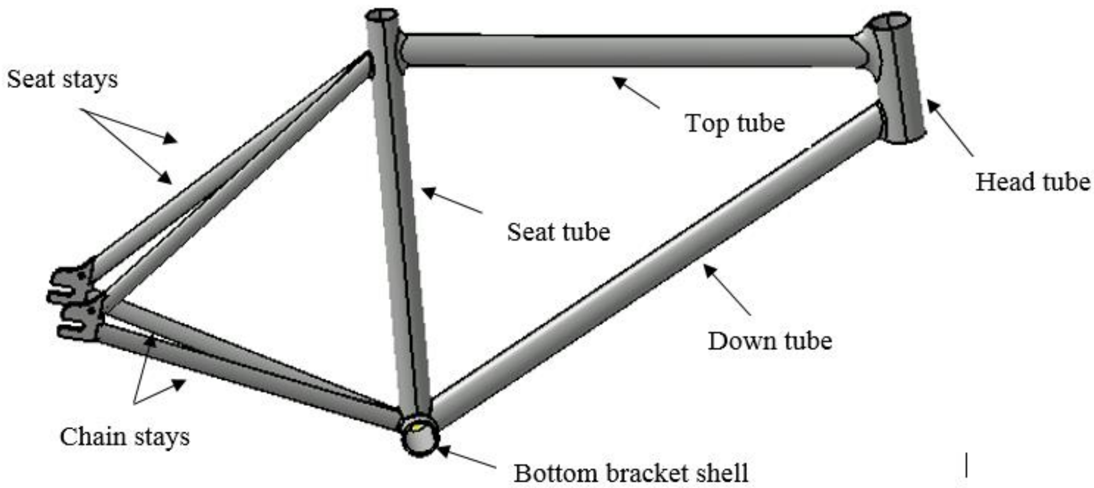

Figure 3.4: Graphical representation of the parameter

Table 3.2: Geometry values for the tube frame design

Parameter	Value
Head tube angle	71°
Seat tube angle	73.5°
Seat tube length	470 mm
Top tube length	559 mm
Down tube length	632 mm
Seat stay length	443 mm
Chain stay length	405 mm
Head tube length	130 mm
Bottom bracket shell drop length	70 mm
Wheel base length	977.5 mm
Seat tube inner diameter	31.8 mm
Seat tube outer diameter	34.9 mm
Head tube inner diameter	42 mm
Head tube outer diameter	46 mm
Top tube inner diameter Down tube inner diameter	30.9mm
Top tube outer diameter Down tube outer diameter	34 mm
Seat stay inner diameter Chain stay inner diameter	14.9mm
Seat stay outer diameter Chain stay outer diameter	18 mm

Table 3.3: Geometry values for the ellipse frame design

Parameter	**Value**
Head tube angle	71°
Seat tube angle	73.5°
Seat tube length	470 mm
Top tube length	559 mm
Down tube length	632 mm
Seat stay length	443 mm
Chain stay length	405 mm
Head tube length	130 mm
Bottom bracket shell drop length	70 mm
Wheel base length	977.5 mm
Seat tube inner diameter	31.8 mm
Seat tube outer diameter	34.9 mm
Head tube inner diameter	42 mm
Head tube outer diameter	46 mm
Top tube inner major radius Down tube inner major radius	15.45 mm
Top tube inner minor radius Down tube inner minor radius	10.45 mm
Top tube outer major radius Down tube outer major radius r	17 mm
Top tube outer minor radius Down tube outer minor radius	12 mm
Seat stay inner major radius Chain stay inner major radius	8.45 mm
Seat stay inner minor radius Chain stay inner minor radius	4.45 mm

Seat stay outer major radius Chain stay outer major radius	10 mm
Seat stay outer minor radius Chain stay outer minor radius	6 mm

3.6 Autodesk Algor Simulation Software

ALGOR Simulation is a general-purpose multiphysics finite element analysis software package developed by ALGOR Incorporated for use on the Microsoft. Windows and GNU/Linux computer operating systems. It is distributed in a number of different core packages to cater to specifics applications, such as mechanical event simulation and computational fluid dynamics.

3.7 Closure

This chapter highlighted on methodology for this project will be discussed about the parameter of bicycle frame and also the analysis method for the bicycle and also analysis set up and procedure. In the next chapter, result and discussion will be discussed.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the results, finding and the analysis of the project. The outcome of this research will be discussed in detail by the next topic.

4.2 Results and Findings

The calculation of stress and strain will be done for the seat tube. Figure 4.1 below show the force exerted on the seat tube. Since the seat tube have a force exerted on to it therefore the area will be the most important part in determining the toughness of the bicycle frame. As for the material, aluminium alloy and titanium alloy will be used as the analyse material for the bicycle frame. The properties for the material had been shown in Table 3.1. Both result of theoretical calculation and finite element analysis will be compare to choose which one of the design and material more suitable to be used for the bicycle frame.

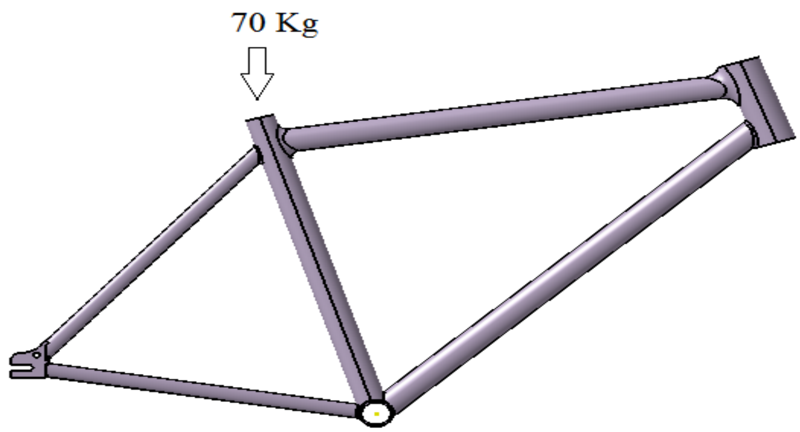

Figure 4.1: Force displacement for the bicycle frame

From the figure above, its shows the weight of the rider being exerted on to the seat tube. By using the force formula in equation 4.1, the force exerted on to the seat tube can be calculate. The maximum weight of the rider will be 70 kg therefore the force applied on the seat tube can be calculated as below:

$$F = mg \tag{4.1}$$

Where

m = Mass of rider

g = Gravitational acceleration

Since the force exerted in downward direction, therefore the acceleration, a will be the gravitational acceleration which is 9.81 m/s therefore, the force acting on the seat tube will be

$$F = 70 \times 9.81$$

$$F = 686.7N$$

In this analysis, two factor are consider which stress and strain on the bicycle frame. The stress and strain cause by the force at the seat tube on to the bicycle frame will be analyse and will be compare with the result from the finite element analysis results.

For the stress, σ calculation, this formula will be use:

$$\sigma = \frac{F}{A} \tag{4.2}$$

Where:

F = Force,

A = Area

As for the strain, ε calculation, the Hooke's Law will be use:

$$\sigma = E\varepsilon \tag{4.3}$$

Therefore,

$$\varepsilon = \frac{\sigma}{E} \tag{4.4}$$

Where:

E = Modulus of elasticity

The Modulus of elasticity, E will be determine from the material selection.

From equation above, the area of the tube is one of the most important aspect in calculating the stress. For the tube frame design, since the tube is hollow cylinder therefore the surface area formula of hollow cylinder will be used:

$$A = 2\pi rh + 2\pi Rh + 2(\pi R^2 - \pi r^2) \tag{4.5}$$

Where

R = Radius of outer surface

r = Radius of inner surface

h = Height

Meanwhile for the eclipse frame design, the surface area formula of hollow ellipse tube will be used:

$$A = \left(2h\pi\sqrt{\frac{1}{2}(a^2 + b^2)} + 2\pi ab\right)_o - \left(2h\pi\sqrt{\frac{1}{2}(a^2 + b^2)} + 2\pi ab\right)_i \tag{4.6}$$

Where

h = Height

a = Major radius

b = Minor radius

4.3 Theoretical Calculation

In this analysis, two design were being analyse which are tube and ellipse frame design. Both frame will be calculated for its shear and stress and the result will be compared.

4.3.1 Tube Frame Design

For tube design, equation 4.5 will be used to calculate the area of the tube. Each tube will be calculated its stress by using equation 4.2 and the strain occur at the tube will be calculate by using equation 4.1.

For stress calculation:

1. **Seat tube**

$$A = 2\pi(15.9)(470) + 2\pi(17.45)(470) + 2\left[\left(\pi(17.45^2)\right) - \left(\pi(15.9^2)\right)\right]$$
$$A = 98810.9mm^2$$

$$\sigma = \frac{686.7}{98810.9}$$
$$\sigma = 6.9497 \times 10^{-3}\ N/mm^2$$

2. **Top tube**

$$A = 2\pi(15.45)(559) + 2\pi(17)(559) + 2\left[\left(\pi(17^2)\right) - \left(\pi(15.45^2)\right)\right]$$
$$A = 114290.2mm^2$$

$$\sigma = \frac{686.7}{114290.2}$$
$$\sigma = 6.0084 \times 10^{-3}\ N/mm^2$$

3. Down tube

$$A = 2\pi(15.45)(632) + 2\pi(17)(632) + 2\left[\left(\pi(17^2)\right) - \left(\pi(15.45^2)\right)\right]$$
$$A = 12.9174.1mm^2$$

$$\sigma = \frac{686.7}{12.9174.1}$$
$$\sigma = 5.3161 \times 10^{-3}\, N/mm^2$$

4. Seat stay

$$A = 2\pi(7.45)(443) + 2\pi(9)(443) + 2\left[\left(\pi(9^2)\right) - \left(\pi(7.45^2)\right)\right]$$
$$A = 45947.98mm^2$$

$$\sigma = \frac{686.7}{45947.98}$$
$$\sigma = 0.01495\, N/mm^2$$

5. Chain stay

$$A = 2\pi(7.45)(405) + 2\pi(9)(405) + 2\left[\left(\pi(9^2)\right) - \left(\pi(7.45^2)\right)\right]$$
$$A = 30569.25mm^2$$

$$\sigma = \frac{686.7}{30569.25}$$
$$\sigma = 0.02246\, N/mm^2$$

Therefore, for strain calculation:

- For Aluminium Alloy 2014 T6 where it's Modulus of Elasticity, E is 75.152GPa.

1. **Seat tube**

$$\varepsilon = \frac{6.9497 \times 10^{-3}}{75.152}$$
$$\varepsilon = 9.248 \times 10^{-5}\, mm/mm$$

2. **Top tube**

$$\varepsilon = \frac{6.0084 \times 10^{-3}}{75.152}$$
$$\varepsilon = 7.995 \times 10^{-5}\, mm/mm$$

3. **Down tube**

$$\varepsilon = \frac{5.3161 \times 10^{-3}}{75.152}$$
$$\varepsilon = 7.0738 \times 10^{-5}\, mm/mm$$

4. **Seat stay**

$$\varepsilon = \frac{0.01495}{75.152}$$
$$\varepsilon = 1.9893 \times 10^{-4}\, mm/mm$$

5. **Chain stay**

$$\varepsilon = \frac{0.02246}{75.152}$$
$$\varepsilon = 2.9886 \times 10^{-4}\, mm/mm$$

- For Titanium Alloy 6Al-4V where it's Modulus of Elasticity, E is 113.763GPa.

1. Seat tube

$$\varepsilon = \frac{6.9497 \times 10^{-3}}{113.763}$$
$$\varepsilon = 6.1089 \times 10^{-5}\, mm/mm$$

2. Top tube

$$\varepsilon = \frac{6.0084 \times 10^{-3}}{113.763}$$
$$\varepsilon = 5.2815 \times 10^{-5}\, mm/mm$$

3. Down tube

$$\varepsilon = \frac{5.3161 \times 10^{-3}}{113.763}$$
$$\varepsilon = 4.6730 \times 10^{-5}\, mm/mm$$

4. Seat stay

$$\varepsilon = \frac{0.01495}{113.763}$$
$$\varepsilon = 1.3141 \times 10^{-4}\, mm/mm$$

5. Chain stay

$$\varepsilon = \frac{0.02246}{113.763}$$
$$\varepsilon = 1.9743 \times 10^{-4}\, mm/mm$$

4.3.2 Ellipse Frame Design

For ellipse design, equation 4.6 will be used to calculate the area of the ellipse tube. Each tube will be calculated its stress by using equation 4.2 and the strain occur at the tube will be calculate by using equation 4.1.

For stress calculation:

1. **Seat tube**

$$A = 2\pi(15.9)(470) + 2\pi(17.45)(470) + 2\left[\left(\pi(17.45^2)\right) - \left(\pi(15.9^2)\right)\right]$$
$$A = 98810.9mm^2$$

$$\sigma = \frac{686.7}{98810.9}$$
$$\sigma = 6.9497 \times 10^{-3}\, N/mm^2$$

2. **Top tube**

$$A = \left(2(559)\pi\sqrt{\frac{1}{2}(17^2 + 12^2)} + 2\pi(17)(12)\right) - \left(2(559)\pi\sqrt{\frac{1}{2}(15.45^2 + 10.45^2)} + 2\pi(15.45)(10.45)\right)$$
$$A = 5623.008mm^2$$

$$\sigma = \frac{686.7}{5623.008}$$
$$\sigma = 0.1221\, N/mm^2$$

3. Down tube

$$A = \left(2(632)\pi\sqrt{\frac{1}{2}(17^2 + 12^2)} + 2\pi(17)(12)\right) - \left(2(632)\pi\sqrt{\frac{1}{2}(15.45^2 + 10.45^2)} + 2\pi(15.45)(10.45)\right)$$

$$A = 6322.41mm^2$$

$$\sigma = \frac{686.7}{6322.41}$$

$$\sigma = 0.1086\, N/mm^2$$

4. Seat stay

$$A = \left(2(443)\pi\sqrt{\frac{1}{2}(10^2 + 6^2)} + 2\pi(10)(6)\right) - \left(2(443)\pi\sqrt{\frac{1}{2}(8.45^2 + 4.45^2)} + 2\pi(8.45)(4.45)\right)$$

$$A = 4297.11mm^2$$

$$\sigma = \frac{686.7}{4297.11}$$

$$\sigma = 0.1598\, N/mm^2$$

5. Chain stay

$$A == \left(2(405)\pi\sqrt{\frac{1}{2}(10^2 + 6^2)} + 2\pi(10)(6)\right) - \left(2(405)\pi\sqrt{\frac{1}{2}(8.45^2 + 4.45^2)} + 2\pi(8.45)(4.45)\right)$$

$$A = 3940.58mm^2$$

$$\sigma = \frac{686.7}{3940.58}$$

$$\sigma = 0.1743\, N/mm^2$$

Therefore, for strain calculation:

- For Aluminium Alloy 2014 T6 where it's Modulus of Elasticity, E is 75.152GPa.

1. **Seat tube**

$$\varepsilon = \frac{6.9497 \times 10^{-3}}{75.152}$$
$$\varepsilon = 9.248 \times 10^{-5}\, mm/mm$$

2. **Top tube**

$$\varepsilon = \frac{0.1221}{75.152}$$
$$\varepsilon = 1.625 \times 10^{-3}\, mm/mm$$

3. **Down tube**

$$\varepsilon = \frac{0.1086}{75.152}$$
$$\varepsilon = 1.445 \times 10^{-3}\, mm/mm$$

4. **Seat stay**

$$\varepsilon = \frac{0.1598}{75.152}$$
$$\varepsilon = 2.126 \times 10^{-3}\, mm/mm$$

5. **Chain stay**

$$\varepsilon = \frac{0.1743}{75.152}$$
$$\varepsilon = 2.319 \times 10^{-3}\, mm/mm$$

- For Titanium Alloy 6Al-4V where it's Modulus of Elasticity, E is 113.763GPa.

1. **Seat tube**

$$\varepsilon = \frac{6.9497 \times 10^{-3}}{113.763}$$
$$\varepsilon = 6.1089 \times 10^{-5}\, mm/mm$$

2. **Top tube**

$$\varepsilon = \frac{0.1221}{113.763}$$
$$\varepsilon = 1.073 \times 10^{-3}\, mm/mm$$

3. **Down tube**

$$\varepsilon = \frac{0.1086}{113.763}$$
$$\varepsilon = 9.546 \times 10^{-4}\, mm/mm$$

4. **Seat stay**

$$\varepsilon = \frac{0.1598}{113.763}$$
$$\varepsilon = 1.400 \times 10^{-3}\, mm/mm$$

5. **Chain stay**

$$\varepsilon = \frac{0.1743}{113.763}$$
$$\varepsilon = 1.532 \times 10^{-3}\, mm/mm$$

4.4 Finite Element Analysis Result

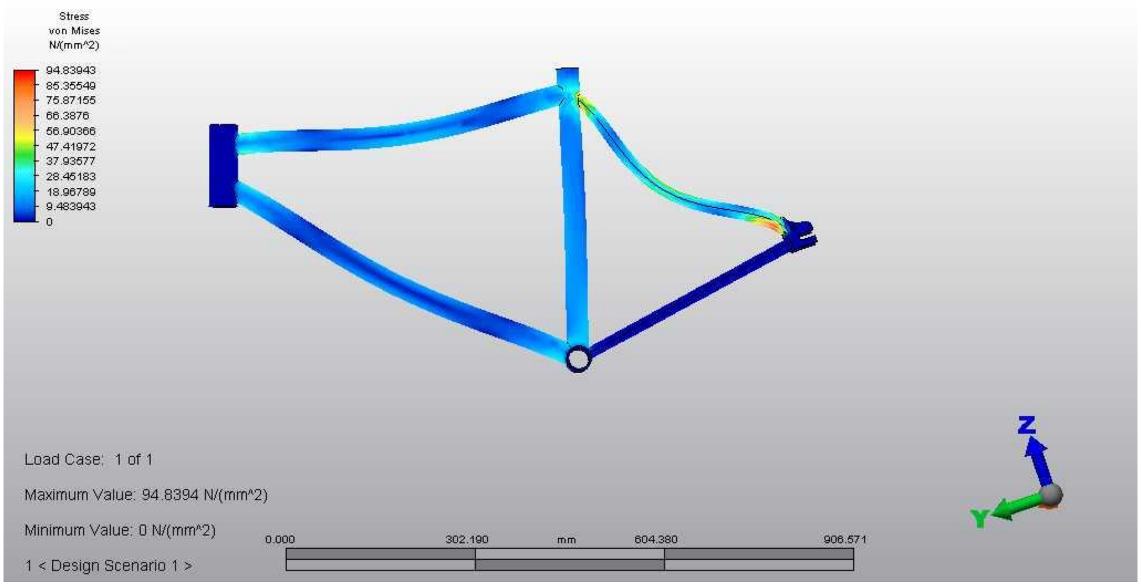

Figure 4.2: The result of stress for aluminium tube frame

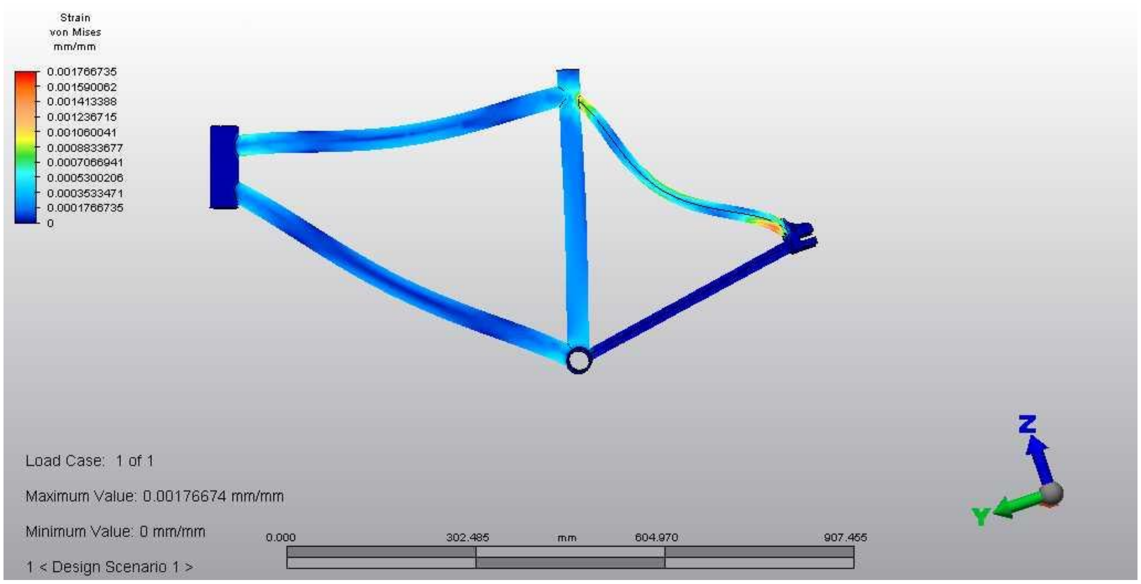

Figure 4.3: The result of strain for aluminium tube frame

In the Figure 4.2 and Figure 4.3, it shows that the design of the bicycle frame being simulated. The material used for this bicycle frame is Aluminium Alloy 2014 T6. The force or load will be exerted on the seat tube (downward) which is -686.7N. In addition, this design will be analysed in term of stress and strain

From the simulation done, the design's maximum stress recorded was 94.8394 N/mm² and the maximum strain recorded was 0.00176674 mm/mm.

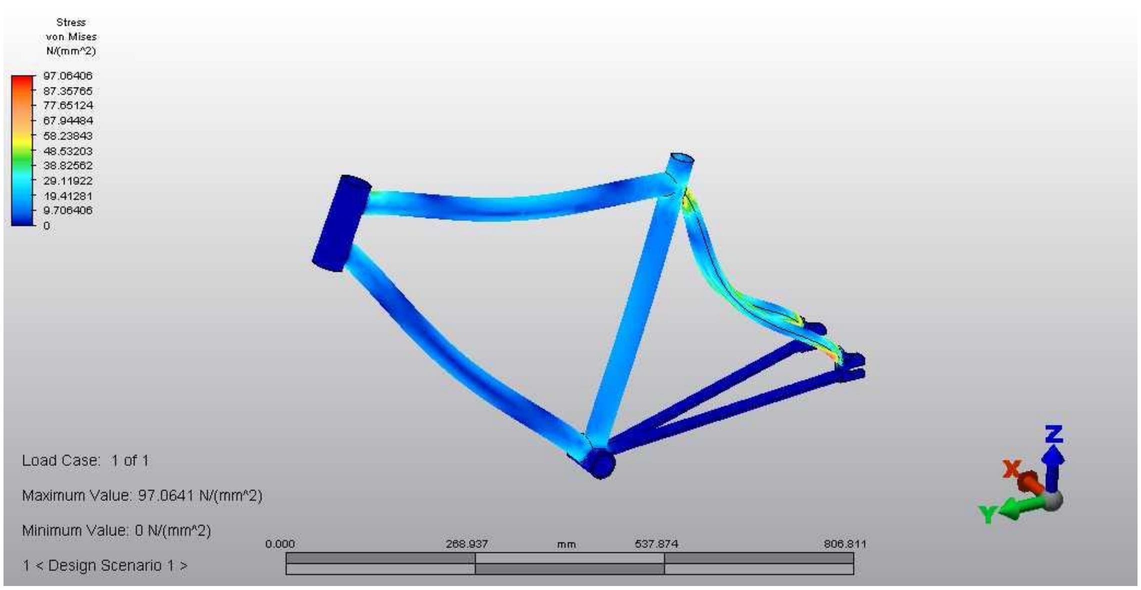

Figure 4.4: The result of stress for titanium tube frame

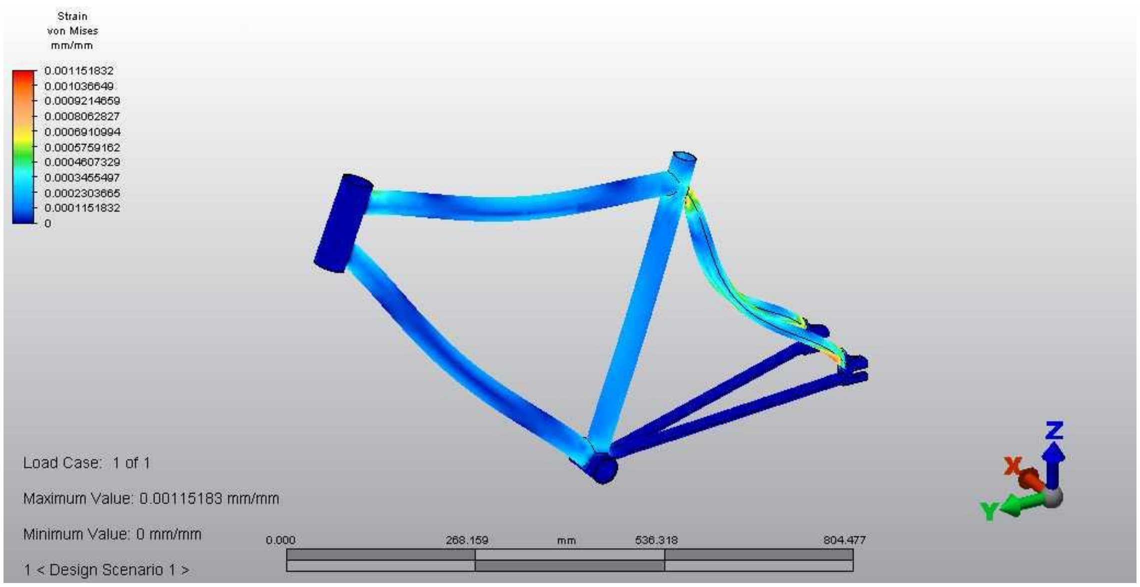

Figure 4.5: The result of strain for titanium tube frame

In the Figure 4.4 and Figure 4.5, it shows that the design of the bicycle frame being simulated. The material used for this bicycle frame is Titanium Alloy 6Al-4V. The force or load will be exerted on the seat tube (downward) which is -686.7N. In addition, this design will be analysed in term of stress and strain

From the simulation done, the design's maximum stress recorded was 97.0641 N/mm^2 and the maximum strain recorded was 0.00115183 mm/mm.

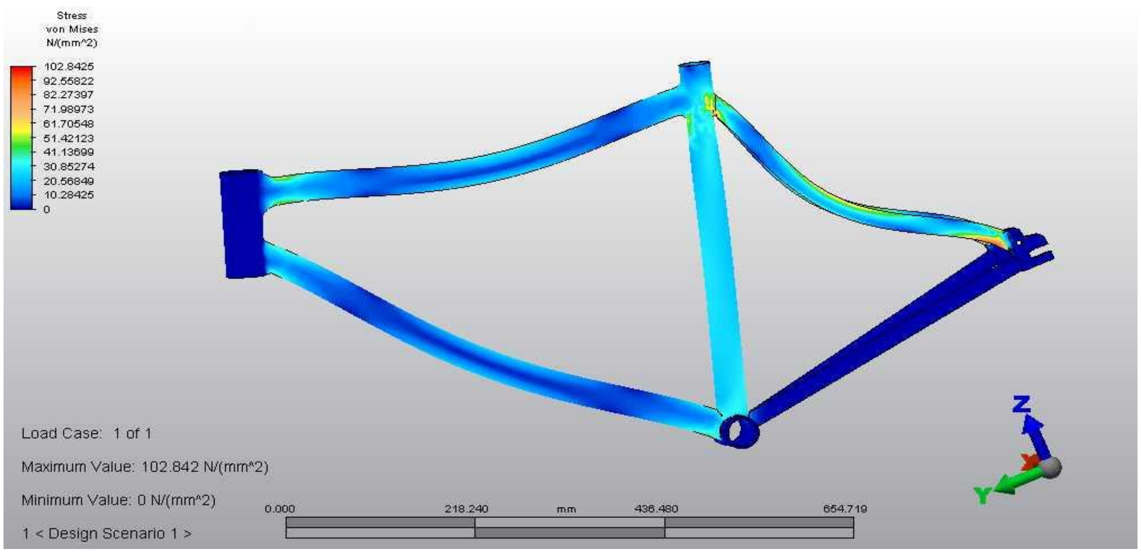

Figure 4.6: The result of stress for aluminium ellipse frame

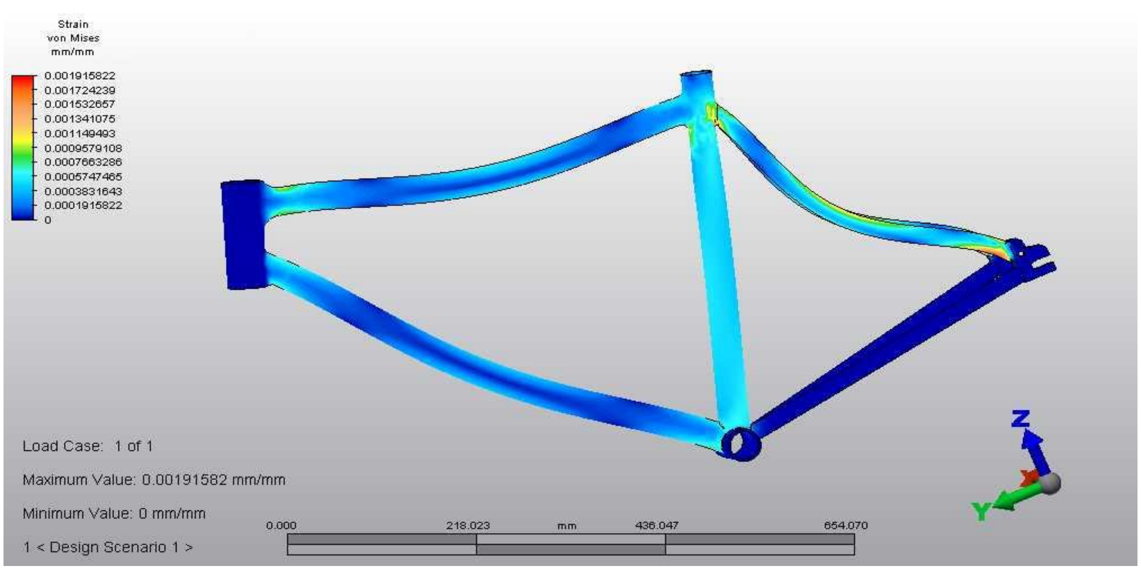

Figure 4.7: The result of strain for aluminium ellipse frame

In the Figure 4.6 and Figure 4.7, it shows that the design of the bicycle frame being simulated. The material used for this bicycle frame is Aluminium Alloy 2014 T6. The force or load will be exerted on the seat tube (downward) which is -686.7N. In addition, this design will be analysed in term of stress and strain

From the simulation done, the design's maximum stress recorded was 102.842 N/mm² and the maximum strain recorded was 0.00191582 mm/mm.

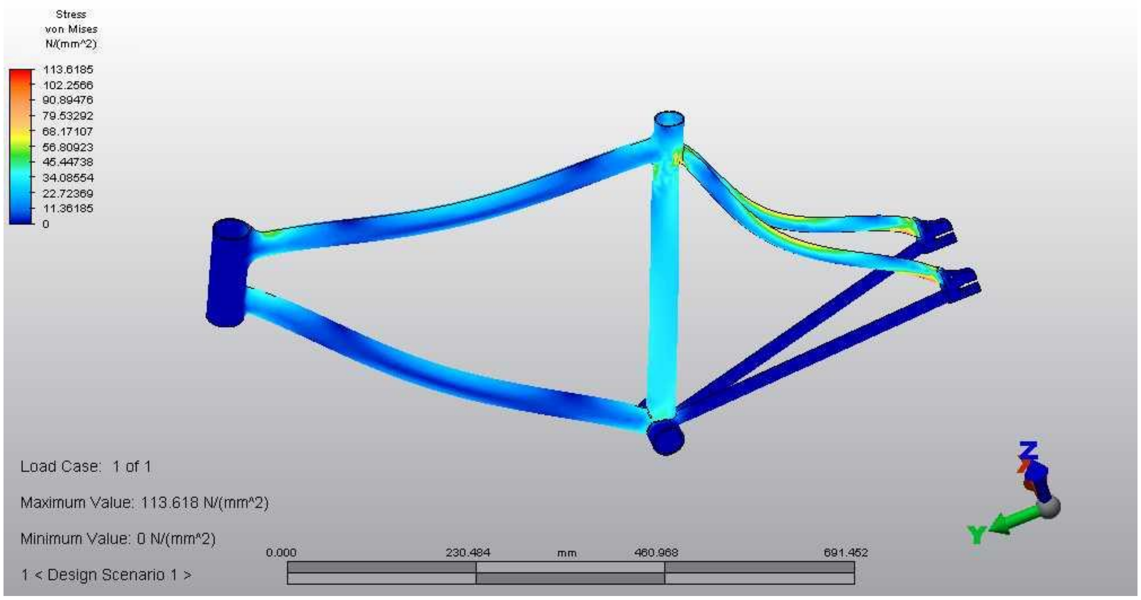

Figure 4.8: The result of stress for titanium ellipse frame

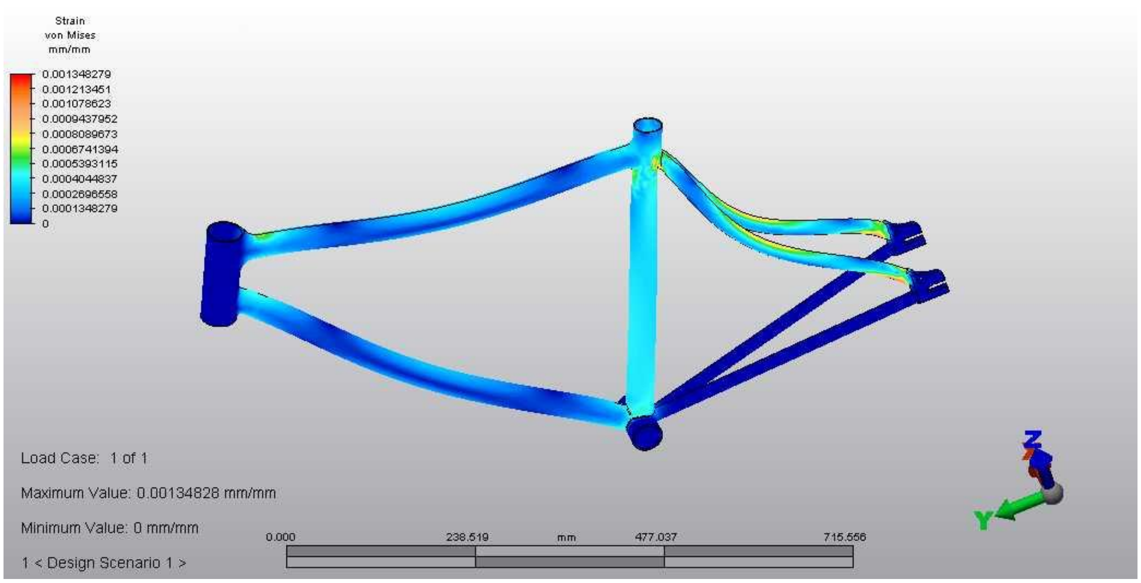

Figure 4.9: The result of strain for titanium ellipse frame

In the Figure 4.8 and Figure 4.9, it shows that the design of the bicycle frame being simulated. The material used for this bicycle frame is Titanium Alloy 6Al-4V. The force or load will be exerted on the seat tube (downward) which is -686.7N. In addition, this design will be analysed in term of stress and strain

From the simulation done, the design's maximum stress recorded was 113.618 N/mm^2 and the maximum strain recorded was 0.00134828 mm/mm.

4.5 Comparison of Analysis Result

Table 4.1: Result of FEA analysis

Frame Design	**Stress (N/mm^2)**	**Strain (mm/mm)**
Tube (Aluminium Alloy)	94.8394	0.00176674
Tube (Titanium Alloy)	97.0641	0.00115183
Ellipse (Aluminium Alloy)	102.842	0.00191582
Ellipse (Titanium Alloy)	113.618	0.00134828

Table 4.1 above shows the result of the analysis after the analysis done for the both model. It had been identify that the ellipse model is much better in term of stress and strain, which is the design can stand a higher stress compare to the tube model. Besides the result of strain from the analysis shows the ellipse model result is much lower compare to tube design. Thus it can be conclude that the ellipse frame design is much better rather than tube design. As for material, the titanium alloy is proven much stronger compare to aluminium alloy, for both design, titanium allow had an advantage rather than aluminium alloy. It's due to its properties which can be compare in Table 4.2 below:

Table 4.2: Comparison of Aluminium Alloy and Titanium Alloy

Material	**Aluminium Alloy 2014 T6**	**Titanium Alloy 6Al-4V**
Modulus of Elasticity (GPa)	75.152	113.763
Shear Modulus (GPa)	28	44
Tensile Strength: Ultimate (MPa)	483	950
Mass Density (g/cc)	2.789	4.382
Poisson’s Ratio	0.4	0.35

4.6 Closure

This chapter highlighted on result and discussion for the stress and strain of both design of bicycle frame design by comparing result from theoretical analysis and also finite element analysis result. In the next chapter conclusion and recommendation for future works will be discussed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, this project had achieve its overall target. In this project, there is two domain objective that need to be achieve which are to design and analyse bicycle frame design and to analyse suitable material for the bicycle frame

For the first objective which to design and analyse bicycle frame, two design of bicycle frame had been done. Both design also had undergo static stress with linear material model analysis to test the durability of both frame design. As we all know, electric bicycle need to be sturdy because it had more burden to be hold compare to normal bicycle. With the addition of battery and control kit, the force exerted by the frame will be higher therefore the frame need to be sturdy enough to ensure the lifetime of the frame. By using FEA analysis, the simulation of force exerted on the frame can be shown thus it will help in identify the problem of the frame design before doing an experiment with real frame.

For the second objective which to select material for the bicycle frame, the material selection is important in order to obtain a study bicycle frame. Different material have different properties, thus with a right selection of material will ensure the sturdiness of the bicycle frame. In FEA analysis, different material can be tested and analyse therefore it can save lot of investment in producing different type of bicycle frame with different type material.

From this project analysis, it can be concluded that the ellipse design much more suitable to be used as the bicycle frame for the electric bicycle. In the results, it shows this frame can stand much higher stress which the most important factor in building electric bicycle. As for the material, the titanium alloy much suit to be use because of its strong properties.

5.2 Recommendation

Recommendation for this project:

- In this project, there is only main design of frame which is the traditional diamond frame design. For further project, the diamond frame design should be redesign so that it will have a better force distribution system.
- For the material, there different kind of material had been discover by the scientist. One of material that been popular in bike industry is carbon fibre composite. This type of material can be used as analyse material since it became one of the popular bike frame in the industry.

REFERENCE

[1] N. Scot, “Metallurgy for Cyclists I: The Basics”. Internet: http://www.63xc.com/scotn/metal.htm, 1994, [Nov 18, 2012]

[2] http://www.brightspoke.com/c/understanding/bike-frame-materials.html

[3] http://www.bikecyclingreviews.com/frames.html

[4] N. Scot, “Metallurgy for Cyclists II: Steel is Real”. Internet: http://www.63xc.com/scotn/steel.htm, 1994, [Nov 18, 2012]

[5] K. Elif, “Engineering Concepts in Industrial Product Design with a Case Study of Bicycle Design,” M.S. thesis, Dept. Industrial Design, İzmir Institute of Technology İzmir, Turkey, 2004

[6] B. Mike. “Material and Processes”. Internet: http://www.cyclorama.net/viewArticle.php?id=255, [Nov 18, 2012]

[7] P. Beth. “Types of Mountain Bike Frame Materials: Understanding the different materials for mountain bikes”. Internet: http://mountainbike.about.com/od/technologyinnovations/a/Types-Of-Mountain-Bike-Frame-Materials.htm, [Nov 18, 2012]

[8] V. Robert. “Opportunities for the Titanium Industry in Bicycles and Wheelchairs”. Industrial Insight, JOM, pp. 24-27, June 1997

[9] N. Scot, “Metallurgy for Cyclists III: Aluminium's Future is Bright and Shiny”. Internet: http://www.63xc.com/scotn/alumin.htm, 1994, [Nov 18, 2012]

[10] N. Scot, "Metallurgy for Cyclists IV: The Titanium Advantage". Internet: http://www.63xc.com/scotn/titan.htm, 1994, [Nov 18, 2012]

[11] T. Dan. "Material World". Internet: http://www.rodbikes.com/articles/material-world.html, 2009, [Nov 18, 2012]

[12] N. Scot, "Metallurgy for Cyclists V: Carbon Fiber Boasts Tremendous Potential". Internet: http://www.63xc.com/scotn/carbon.htm, 1994, [Nov 18, 2012]

[13] B. Maureen. "Carbon Fiber Lightens up Bicycle Racing". JOM. pp. 80, Feb. 2005

[14] S. Soni, "Frame Design". Internet: http://www.netplaces.com/bicycle/bicycle-technology/frame-design.htm, [Nov18, 2012]

[15] http://en.wikipedia.org/wiki/Bicycle_frame

[16] N. Ron. "Bike frame races carbon consumer goods forward". REINFORCEDplastics. pp. 36-40, July/August 2003

APPENDIX

APPENDIX A

CAD MODELLING

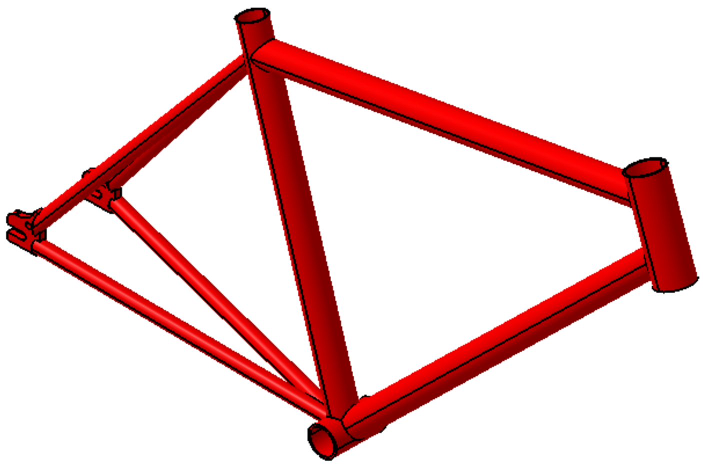

Figure A1: CAD modelling of tube frame design

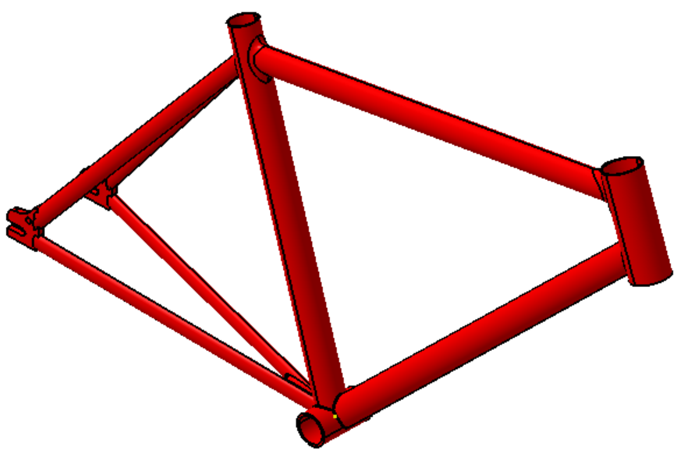

Figure A2: CAD modelling of ellipse frame design

APPENDIX B

GANTT CHART

Table B1: Gantt chart for FYP