DEVELOPMENT OF TWO WHEELS SPACE-FRAME PLUG-IN HYBRID ELECTRIC MOTORCYCLE CHASSIS

MUHAMMAD AKMAL BIN JAMALUDIN

Report submitted in fulfillment of the requirements for award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering

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UNIVERSITI MALAYSIA PAHANG

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EXAMINERS APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that report entitled ‘Development of Two Wheels Space-Frame Plug-In Hybrid Electric Chassis’ is written by Muhammad Akmal B. Jamaludin with matric number MH09011. I have examined the final copy of this report and in my opinion, it is adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor in Mechanical Engineering with Automotive Engineering. I herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor Engineering.

Signature:
Name of Examiner: PROF. DR. SHAHRANI BIN ANUAR
Date: 20 JUNE 2013

SUPERVISOR'S AND CO-SUPERVISOR'S DECLARATION

We hereby declare we have checked this report, which written by Muhammad Akmal B. Jamaludin, and in our opinion, this report project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Signature:
Name of Supervisor: PROF. DATO. DR. HJ. ROSLI BIN ABU BAKAR
Position: PROFESSOR
Date: 20 JUNE 2013

Signature:
Name of Co-supervisor: DR. GAN LEONG MING
Position: SENIOR LECTURER
Date: 20 JUNE 2013

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own, except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any other Degree and is not concurrently submitted for award of other degree.

Signature:
Name: MUHAMMAD AKMAL BIN JAMALUDIN
ID Number: MH09011
Date: JUNE 2013

Dedicated to my beloved parents

JAMALUDIN KADIR

KHALIJAH JIWA

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ABSTRACT

This research deals with the development and analysis of the plug in hybrid electric motorcycle frame. The significance of this project is to offer additional space on the existing conventional motorcycle models. A 304 stainless steel hybrid electric motorcycle chassis was fabricated upon the completion of the Computer Aided Design (CAD) modelling as well as a Finite Element Analysis (FEA) specifically stress analysis of the modelled chassis. SolidWorks was used to conduct both the modelling and the stress analysis. The simulation results exhibited desirable minimum factor of safety which in turn ensures the structural integrity of the chassis. Round hollow 1.5 inch and 1 inch 304 stainless steel tubes were used to from the main part of the chassis. The tubes were rolled to conform specified design and joined by means of Tungstens Inert Gas (TIG) welding and Metal Inert Gas (MIG) welding.

ABSTRAK

Kajian ini berkaitan dengan pembangunan dan analisis rangka motosikal hibrid elektrik. Kepentingan projek ini adalah untuk menyediakan ruang tambahan pada model motosikal konvensional yang sedia ada. Casis motosikal hibrid elektrik keluli tahan karat 304 dihasilkan apabila selesai model CAD serta analisis FEA khusus terhadap tekanan casis yang telah dimodelkan. SolidWorks telah digunakan untuk merekabentuk dan menganalisis tekanan. Keputusan simulasi menunjukkan faktor keselamatan melebihi tahap minimum dan memastikan integriti struktur casis. Tiub bersaiz 1.5 inci dan 1 inci jenis 304 tiub keluli tahan karat digunakan untuk bahagian utama casis. Tiub telah dibentuk dengan mematuhi reka bentuk yang telah ditetapkan dan disambungkan dengan cara kimpalan tungstens gas lengai (TIG) dan kimpalan logam gas lengai (MIG).

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LIST OF SYMBOLS

Greek symbols

ε	Strain [unitless or %]
σ	Stress [Pa]
$\sigma_{von\ Mises}$	Von Mises Stress [Pa]
σ_{limit}	Yield strength [Pa]

Symbols

ΔL	Elongation of length [m]
F	Force [N]
L	Length [m]
E	Modulus of elasticity [Mpa]
A	Surface area [m^2]

LIST OF ABBREVIATIONS

BEVs	Battery Electric Vehicle
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CVs	Conversional Vehicle
FOS	Factor of Safety
FEA	Finite Element Analysis
HEV	Hybrid Electric Vehicle
HC	Hydrocarbon
MIG	Metal Inert Gas
PHEM	Plug-in Hybrid Electric Motorcycle
PHEV	Plug-in Hybrid Electric Vehicle
TIG	Tungsten Inert Gas

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

A hybrid electric vehicle (HEV) consist of two or more power source (Gao Y et al., 2005) namely, internal combustion engine and an electric motor in order to improve its fuel efficiency (Huang KD and Tzeng S-C, 2004) and the reduction of harmful emissions (Doucette RT and McCulloch MD, 2011). A plug-in hybrid vehicle (PHEVs) is an HEV with the ability to recharge its energy storage system with the supply of electricity from the electric utility grid (Tony Markel, 2006). The terminology between PHEV and HEV can be classified further into charge-sustaining mode, charge-deleting mode, all-electric range (AER), electrified Miles, PHEVxx, SOC, degree of hybridization and utility factor (Tony Markel, 2006).

The hybrid electric motorcycle are introduced as motorcycles are the major mode of transportation especially in South Asia and Asia region (Yuan-Yong Hsu, 2009). Motorcyles are favoured due to limited space, short daily trip distances, population density, easy operation and maintenance (Shaik Amjad, 2010). The number of motorcycles has increased by 0.35 million per year for domestic sales and 1 million for export into South Asia market (Chia-Chang Tong, 2007). The development of hybrid electric motorcycles are driven by the ‘go green’ technological push, economic sense as well as to reduce harmful exhaust emissions (Yuan-Yong Hsu, 2009).

In the design of plug-in hybrid electric motorcycle (PHEM), the chassis plays a significant role as it supports the powertrain components, drivetrain parts and rider. A chassis is essentially the skeleton of a motorcycle. It must be straight to provide a secure mounting for the steering apart from proper wheel alignment. The frame must be structurally sound to support the weight of the rider, the engine and the other components attached to it (Edward Abdo, 2009).

One of the chassis design types of the street motorcycles is the chopper or feet forward type. This type of chassis is characterized by the footrests being forward from the seat, long forks and low seat height. The handlebars may be higher as compared to the seat which is often positioned low. The riding position is as such that the legs of the rider are extended forward.

1.2 PROBLEM STATEMENT

The integration of a plug-in hybrid electric motorcycle (PHEM) components in a limited space of a motorcycle frame is indeed a challenging task. Therefore, the design of the chassis is important to ensure enough space is provided to mount all the components well.

The chassis design should also provide enough strength to support the powertrain components, rider and other forms of weight contributors. Plug-in hybrid electric motorcycle (PHEM) in essence are heavier compared to conventional motercycles. Therefore it is essential that the chassis could withstand the a fore mentioned contributing loads apart from providing adequate support.

Hence, the combination of the above mentioned aspects as well as other factors such as ergonomics, economics and aesthetic sense are commendable in the design of such chassis.

1.3 OBJECTIVES

The objectives for this project are as follows

a. To develop a stainless steel hybrid electric motorcycle chassis
b. To analyze the stress and strain distribution of proposed chassis design

1.4 SCOPES

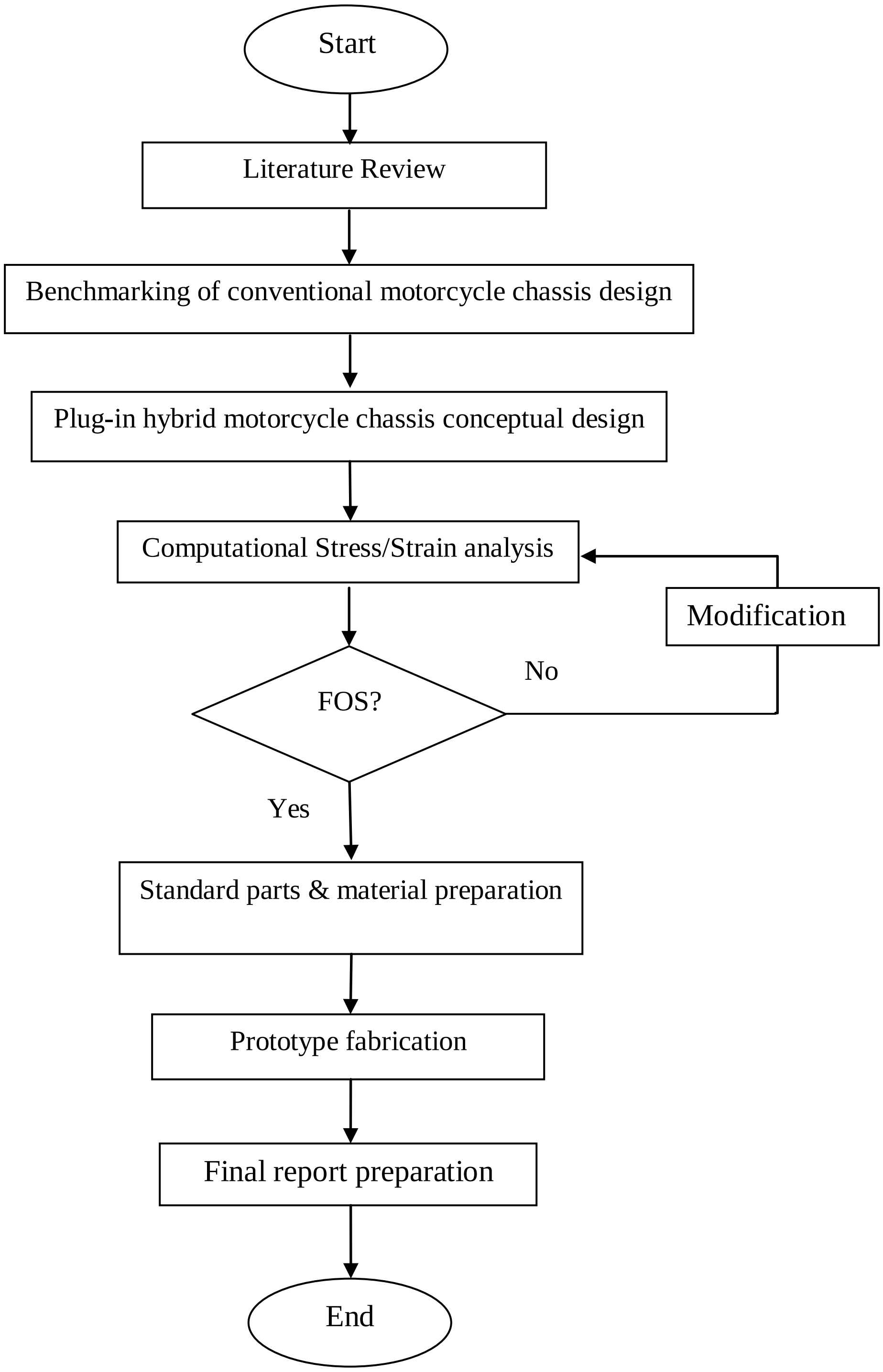
The scopes for this project is as follows

a. Benchmark study on the conventional motorcycle chassis designs.
b. Plug-in hybrid electric motorcycle chassis conceptual design.
c. Computation of the stress and strain analysis by means of FEA.
d. Standard component preparation.
e. Chassis fabrication.

1.5 HYPOTHESIS

Plug-in hybrid electric motorcycle chassis fabricated could fulfill the design considerations specified and a working prototype could be built.

1.6 FLOW CHART



1.7 GANTT CHART

Refer to APPENDIX A.

CHAPTER 2

LITERATURE REVIEW

2.1 DEVELOPMENT OF PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)

Plug-in hybrid electric vehicles (PHEVs) have been proposed as a next step in the evolution of transportation technologies towards increased energy efficiency and less pollution (Romm and Frank, 2006;Suppes, 2006). They are similar to current hybrid gasoline-electric vehicles but have larger batteries and if their owners choose, charge their batteries from the electric grid and operate for some number of miles in all-electric mode. Ordinary hybrid vehicles have proven popular as sales in the U.S. have grown by over 80% annually since 2000, despite questions about the value of their fuel savings relative to the additional costs of the vehicles (see www.hybridcars.com and Lave and MacLean, 2002). Several companies now offer to convert ordinary hybrid vehicles into PHEVs and plan to sell retrofit kits, while at least one PHEVs is being evaluated for sale in Europe

In a sense, PHEVs have two fuel tanks: they may use gasoline like a hybrid electric vehicle, or they may charge their batteries from the electric grid and run in all-electric mode until low battery charge leads the vehicle to switch to the gasoline-fueled hybrid electric mode. PHEVs promise to link the separate gasoline and electricity markets through the repeated marginal decisions of automotive fuel choice. As a result, PHEV owners should be more responsive than BEV owners to gasoline and electricity price signals, and unlike BEVs, the loads PHEVs place on the electric power system are discretionary because a PHEV can always operate on gasoline. In addition, because PHEVs are much more similar to conventional gasoline vehicles (CVs) than to BEVs in terms of technology and consumer experience, and are likely to be have a smaller cost premium than BEVs, consumers may adopt PHEVs more readily. However, the flexibility PHEVs display in operation makes their implications for energy markets less straightforward to estimate.

According to the IEEE-USA Energy Policy Committee classification,a plug-in hybrid electric vehicle (PHEV) has at least a 4 kWh battery energy storage system; could run a 16.1 km length in electric-drive mode only; and has means to recharge the energy storage system from an external electricity source (see www.ieeeusa.org/policy). Electric cars are characterized by the use of one or more electric motors connected to a mechanical shaft or directly to the wheels. They have an energy storage system, but still have low autonomy. The hybrid ones also feature an internal combustion engine, smaller, which can provide power to the electric motor, pull the vehicle, or only work at higher speeds (K. Clement-Nyns et al., 2007). There are many PHEVs with different configurations.

The main differences refer to motor/engine coupling to powertrain, which could be a series or parallel hybrid (A. Emadi et al., 2008) and battery energy storage system models. Regarding the electric motors, it’s more common to use synchronous units with permanent magnets and rated power varying from 50 kW to 160 kW. As electric motor development continues, some of the key areas are identified, such as multiple motor design concepts including variable-voltage traction motors and sintered or bonded magnets for permanent magnet motors. Besides increasing performance, research efforts are being made to reduce materials, parts, and manufacturing costs (G. Wirasingha et al,. 2008).

2.2 DEVELOPMENT IN PLUG-IN HYBRID ELECTRIC MOTORCYCLE (PHEM)

In a many urban areas of Asia especially India, two wheelers are quite popular mode of transportation because of limited space, short daily trip distance, easy in operation and maintenances (Sheu Kuen-Bao and Hsu Tsung-Hua, 2005). Statistics show that the number of two wheelers has multiplied by a factor of three times during this period and account for nearly two-third of the total vehicle population (Sheu Kuen-

Bao and Hsu Tsung-Hua, 2006). The pollutants, such as carbon monoxide (CO) and hydrocarbons (HC), produced by motorcycles account for approximately 10% of the total annual amount of pollution emissions in Taiwan (Yuan-Yong Hsu, 2010). In order to reduce emissions and go green technology of two wheelers, development in hybrid technology in two wheelers has been introduced (Yuan-Yong Hsu, 2010).

The Environmental Protection Administration of the ROC has implemented some policies to reduce air pollution, such as the strict exhaust standards for gasoline vehicles, an electric motorcycle development action plan, and a subsidy for purchasing electric scooters (Sheu Kuen-Bao and Hsu Tsung-Hua, 2005). To facilitate this, the government and industry have been applying fuel-cell technology to power scooters (Wang JH et al., 2000). However, the goal of replacing polluting combustion-engine motorcycles with battery powered ones has not been successful in Taiwan (Tso C and Chang S-Y, 2003).

Another approach to reduce both pollution and get better performance is to utilize a hybrid concept of internal-combustion engine and battery at this stage. Over the past few years, hybrid electric vehicles (HEVs), primarily automobiles, have been actively developed and marketed (Brown LT et al., 2001). This study considers the design of a hybrid power-transmitting system that is suitable for motorcycles. In 1997, Honda Motors released a hybrid two-wheeler concept in the Tokyo motor show with the key goals of a 60% reduction in carbon dioeide (CO_2) emission and 2.5 times better fuel-efficiency. In this system, a water-cooled 49 cc gasoline engine is packed with a DC brushless electric-motor together driving the rear wheel. The gasoline engine delivers power for high-speed performance and for hill climbing while the electric motor engages for low-speed cruising.

In 1999, AVL Company proposed a hybrid system that used a 50 cc carbureted lean-burn two-stroke engine with a 0.75 kW electric motor mounted on the engine crankshaft mainly to provide increased torque during acceleration (Sheu Kuen-Bao and Hsu Tsung-Hua, 2005). Matsuto and Wachigai also proposed a motorcycle hybrid-drive system (Matsuo T et al., 2000). The main components of this system consists of the two power sources of an engine and an electric motor, a traction drive continuously-variable transmission (CVT), a final reduction drive and three clutches. The transmission shaft and the electric motor shaft are coaxial in series in the longitudinal direction of the vehicular body and in parallel with the crank shaft of the engine.

2.3 IMPORTANCE OF CHASSIS IN VEHICLE

Basically chassis is considered as a framework to support the body, engine and other parts which make up the vehicle. Chassis lends the whole vehicle support and rigidity. Chassis usually includes a pair of longitudinally extending channels and multiple transverse cross members that intersect the channels. The transverse members have a reduced cross section in order to allow for a longitudinally extending storage space. The chassis has to contain the various components required for the motorcycle as well as being based around a rider position. Chassis play the important role in hybrid electric motorcycle to support weights. The hybrid electric motorcycle has an extra size in chassis compared with standard motorcycle design.

2.4 MOTORCYCLE CHASSIS DESIGN

During development of the first motored bicycles, e.g. a steam powered Velociped Michaux-Perraux, emphasis was put on neither comfort nor driving stability. Only at the beginning of the 20th century, when the internal combustion engine has been patented by Dr. Otto, his assistant G. Daimler commenced to inquire into issues of driving stability and handling of a single-track vehicle in particular (Jakub Smiraus and Michal Richtar, 2011). Since then, the motorbike has been inexorably developed into more and more perfect machine with driving dynamics surpassing that of the majority of contemporary cars, which resulted in the occurrence of periods when engine power significantly outperformed capabilities of the chassis.

In chassis design, the most important thing that must be constraint is about the reference geometry on that chassis. The importance of reference chassis geometry is to produce new chassis in fully characteristic in design such as ergonomically, stability, maneuverability and safety consideration. Figure 2.1 shows the main parameter of reference motorcycle chassis geometry.

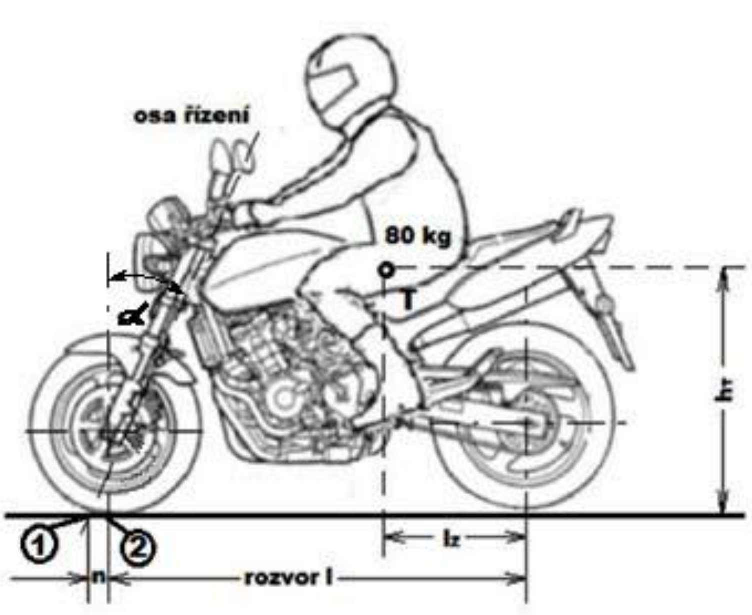


Figure 2.1: Main parameters of motorcycle chassis geometry

Source: Jakub Smiraus and Michal Richtar (2011)

Table 2.1: Symbols and parameters of motorcycle chassis geometry

Symbols	**Parameters**
α	Rake angle
1	Point of wheel contact
2	Steering axis and ground intersection
n	Trail
ℓ	Wheel-base
h_T , l_Z	Center of gravity location

Source: Jakub Smiraus and Michal Richtar (2011)

The rake angle of the front fork indicates the angle between the steering axis and the ground plane. A smaller rake angle of the front fork results in a greater stabilizing effect on the front fork. The rake angle (angle of steering axis) lies within about 24° to 30° to the ground. Steering axis and ground intersection is the point of contact with the ground is indicated as wheel axis intersection perpendicular to the base of a stationary bike at a point of their intersection. Trail is the distance between the steering axis and ground intersection and the point of wheel contact. The trail has a significant impact on the stability and handling of a motorcycle. The wheelbase is the distance between the rotation axis of the wheels in a straight-line drive. Center of gravity is determined by vertical and horizontal position.

The driving characteristics can be significantly affected by modification of the basic parameters. Therefore, if to customize the driving stability of an already constructed motorcycle, it must have the following options. Position can be adjusted the of centre of gravity. This can be achieved by change of a riding posture, which is, however, limited by placement of control and support elements of the motorcycle. Nevertheless, these changes are not always easy to control properly because it is impossible to encompass all the variety of passengers' weights. Further parameters of chassis are: wheel base, trail, rake or steering axis angle.

These dimensions are set, but if they were adjusted according to the driving conditions the overall driving stability as well as the steering response to the initiative of the driver could be influenced. Lengthening of both wheelbase and trail would result in an increased straight line stability, which would help to improve the comfort of long distance driving at higher speed. The opposite is assumed to be true as well. Shortening the latter mentioned parameters would lead to a decreased stability, yet at the same time a better handling, which is advantageous in the conditions of e.g. urban traffic. Such is the theory of these features impact on the motorcycle handling and driving characteristics.

2.5 MATERIAL SELECTION

2.5.1 Stainless steel 304

Stainless steel 304 is the ferrous metal and heat resistance categories. It comes from Austenitic Cr-Ni stainless steel. The characteristic of stainless steel 304 is a better corrosion resistance than Type 302. It also has a high ductility, excellent drawing, forming, and spinning properties. Essentially non-magnetic, becomes slightly magnetic when cold worked. It is having a low carbon content means less carbide precipitation in the heat-affected zone during welding and a lower susceptibility to intergranular corrosion. Table 2.2 shows the mechanical properties of stainless steel 304.

Table 2.2: Stainless steel 304 mechanical properties

Mechanical Properties	Metric	Comments
Hardness, Brinell	123	Converted from Rockwell B hardness
Hardness, Knoop	138	Converted from Rockwell B hardness
Hardness, Rockwell B	70	Converted from Rockwell B hardness.
Tensile Strength, Ultimate	505 MPa	
Tensile Strength, Yield	215 MPa @Strain 0.200 %	
Elongation at Break	70 %	
Modulus of Elasticity	193 - 200 GPa	
Poissons Ratio	0.29	
Shear Modulus	86.0 GPa	
Charpy Impact	325 J	

Source: www.matweb.com (2013)

2.6 STRESS AND STRAIN ANALYSIS

Stress analysis is important in fatigue study and parts' life prediction where it aims to determine the critical point which has the highest stress (A. Rahman, 2008). Safety factor is used to provide a design margin over the theoretical design capacity. This allows consolidation of uncertainties in the design process. It is recommended by the conditions over which the designer has no control on the sources that are accounted for the uncertainties involved in the design process. In this study, safety factor rate with respect to design loading that is applied on the chassis has been investigated.

According to the journal of Design and Analysis on Eco Challenge Car Chassis by Mohd Hanif Mat (Mohd Hanif Mat, 2012), the chassis was modeled as beam elements with square and circular hollow sections using ABAQUS software. The chassis was simulated by using five different type of loading conditions. There are static load (dead load) of vehicle supported at its wheel base, 4g load on the main hoop, 1.5g acceleration, 1.5g deceleration (braking) and 2500 Nm/degree of torsional loading.

2.6.1 Stress And Strain Analysis on Motorcycle

An analysis of the frame's components and their interactions is needed to obtain a lighter frame and improve its mechanical behaviour. The first functional prototype of the motorcycle frame was used using a traditional design approach, that is, to use manual intervention to fine tune the design parameters and run the simulation iteratively (Caldenjn. B. Diseiio, 2004).

However, this analysis can be done programmatically, simulating the performance of the frame using a FEA based software as a "black box" coupled with an optimization algorithm. In this study, they compared the latter approach with the traditional one based on manual "optimization' cycles. The FEA simuiation models the mechanical behavior of the frame under an extreme load case to evaluate its performance according to the previously mentioned criteria.. Figure 2.2 shows the load case distribution on the motorcycle frame.

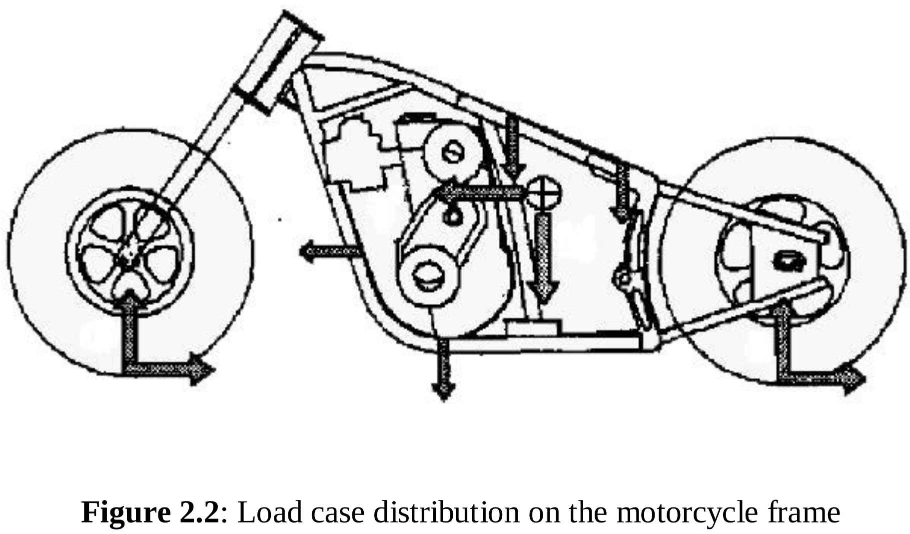


Figure 2.2: Load case distribution on the motorcycle frame

Source: Jorge E. Rodriguez el at., 2005

2.7 FAILURE CRITERIA

Failure of engineering materials can be broadly classified into ductile and brittle failure. Most metals are ductile and fail due to yielding. Hence, the yield strength characterizes their failure. Ceramics and some polymers are brittle and rupture or fracture when the stress exceeds certain maximum value. Their stress–strain behavior is linear up to the point of failure and they fail abruptly.

The stress required to break the atomic bond and separate the atoms is called the theoretical strength of the material. It can be shown that the theoretical strength is approximately equal to E/3 where, E is Young's modulus (T.L. Anderson, 2006). However, most materials fail at a stress about one–hundredth or even one–thousandth of the theoretical strength. For example, the theoretical strength of aluminum is about 22 GPa. However, the yield strength of aluminum is in the order of 100 MPa, which is 1/220th of the theoretical strength.

In ductile material yielding occurs not due to separation of atoms but due to sliding of atoms (movement of dislocations). Thus, the stress or energy required for yielding is much less than that required for separating the atomic planes. Hence, in a ductile material the maximum shear stress causes yielding of the material.

In brittle materials, the failure or rupture still occurs due to separation of atomic planes. However, the high value of stress required is provided locally by stress concentration caused by small pre-existing cracks or flaws in the material. The stress concentration factors can be in the order of 100 to 1,000. That is, the applied stress is amplified by enormous amount due to the presence of cracks and it is sufficient to separate the atoms. When this process becomes unstable, the material separates over a large area causing brittle failure of the material.

Although research is underway not only to explain but also quantify the strength of materials in terms of its atomic structure and properties, it is still not practical to design machines and structures based on such atomistic models. Hence, we resort to phenomenological failure theories, which are based on observations and testing over a period of time. The purpose of failure theories is to extend the strength values obtained from uniaxial tests to multi-axial states of stress that exists in practical structures. It is not practical to test a material under all possible combinations of stress states. In the following, we describe some well-established phenomenological failure theories for both ductile and brittle materials.

2.8 GOVERNING EQUATION

2.8.1 Stress

The term stress is used to express the loading in terms of force applied to a certain cross-sectional area of an object. From the perspective of loading, stress is the applied force or system of forces that tends to deform a body. From the perspective of what is happening within a material, stress is the internal distribution of forces within a body that balance and react to the loads applied to it. The stress distribution may or may not be uniform, depending on the nature of the loading condition. For example, a bar loaded in pure tension will essentially have a uniform tensile stress distribution. However, a bar loaded in bending will have a stress distribution that changes with distance perpendicular to the normal axis.

Simplifying assumptions are often used to represent stress as a vector quantity for many engineering calculations and for material property determination. The word *"vector"* typically refers to a quantity that has a "magnitude" and a "direction". For example, the stress in an axially loaded bar is simply equal to the applied force divided by the bar's cross-sectional area.

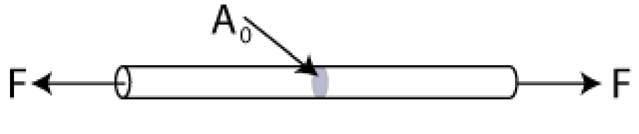


Figure 2.3: Stress diagram

Source: http://www.ndt-ed.org (2013)

$$\sigma = \frac{F}{A} \tag{2.1}$$

Where, σ is stress [Pa]

F force [N]

A surface area [m^2]

2.8.2 Strain

Strain is the response of a system to an applied stress. When a material is loaded with a force, it produces a stress, which then causes a material to deform. Engineering strain is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material. This results in a unit less number, although it is often left in the unsimplified form, such as inches per inch or meters per meter. For example, the strain in a bar that is being stretched in tension is the amount of elongation or change in length divided by its original length. As in the case of stress, the strain distribution may or may not be uniform in a complex structural element, depending on the nature of the loading condition.

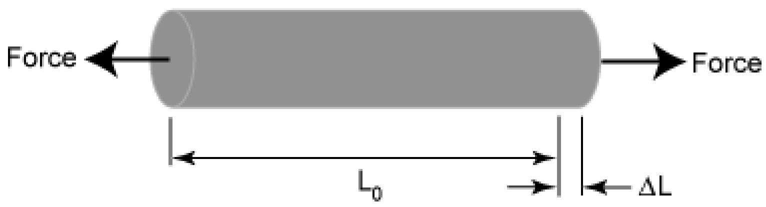


Figure 2.4: Strain diagram

Source: http://www.ndt-ed.org (2013)

$$\varepsilon = \frac{\Delta L}{L} \tag{2.2}$$

Where ε is strain [unitless or %]

ΔL elongation of length [m]

L length [m]

2.8.3 Modulus of Elasticity

The modulus of elasticity (Young's modulus) E is a material property, that describes its stiffness and is therefore one of the most important properties of solid materials. Mechanical deformation puts energy into a material. The energy is stored elastically or dissipated plastically. The way a material stores this energy is summarized in stress-strain curves. Stress is defined as force per unit area and strain as elongation or contraction per unit length. When a material deforms elastically, the amount of deformation likewise depends on the size of the material, but the strain for a given stress is always the same and the two are related by Hooke´s Law (stress is directly proportional to strain).

From the Hook's law the modulus of elasticity is defined as the ratio of the stress to the strain :

$$E = \frac{\sigma}{\varepsilon} \tag{2.3}$$

where σ is stress [MPa]

E modulus of elasticity [MPa]

ε strain [unitless or %]

CHAPTER 3

METHODOLOGY

3.1 STUDY AND CONCEPTUAL CHASSIS DESIGN

Based on study of motorcycle type, chopper design has been selected as a design reference in building plug-in hybrid electric motorcycle (PHEM). Plug-in hybrid electric motorcycle has more components compared to standard motorcycle, therefore the project prototype will use chopper chassis design because it has more space. MODENAS Jaguh 175cc is revised as a reference chopper concept in order to making idea for chassis design.

As we know that chopper design is like to be old school and over the century but when it is assembled with hybrid electric system, it will be revolutionary and futuristic. Hence, the design of the chassis should come with futuristic design. After dismantling all components and parts, all of them will be drawn in 3D drawing using CAD software especially in powertrain and drivetrain component in order to get the suitable dimension of chassis.

Figure 3.1: Modenas Jaguh 175cc.

Source: http://han2ride.blogspot.com/2010/06/cerite-motorku.html (2013)

Design work in this project uses CAD SolidWorks software developed by Dissault Systemes SolidWorks Corp. The software is easy to handle compare with other CAD software. The expression of 3D view also easier to view and configuration of this software gives the advantage in designing of the chassis. The icon arrangement in this software is placed in the perfect place and helps the user in handling it.

In design the chassis of plug-in hybrid electric motorcycle, space of all components is the main parameter that should be considered. Before chassis design is started, all components from MODENAS Jaguh 175cc which is head engine, gearbox and the others such as electric motor and battery will be drawn in Solidworks software to implement in 3D drawing of chassis design in order to get the suitable measurement of chassis.

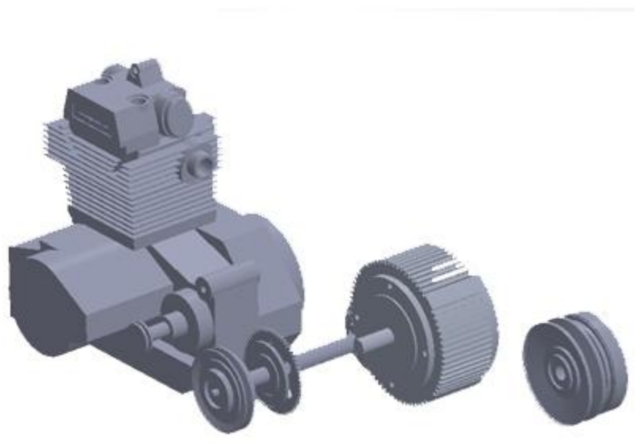


Figure 3.2: Isometric view of components assembly in CAD software

The plug-in hybrid motorcycle chassis is made from AISI 304 stainless steel hollow cylinder with two type of dimension which are 1.5 inch of diameter, 1.2mm thickness and 1 inch diameter, 1mm thickness. The material is strong and corrosion resistance. According to comparison of cost of AISI 304 stainless steel and other materials, AISI 304 stainless steel only bumps cost up 37% in that analysis (Norm Ellis, 2009). The steel is less costly compared to other materials but reliable in the long term.

3.2 COMPUTATIONAL STRESS AND STRAIN ANALYSIS

The prototype chassis design is built in SolidWorks software and will be analyzing the strength of the chassis using SolidWorks Simulation. SolidWorks is a complete software with CAD and CAE software version that contains a core package in it such as easy-to use, single user interface for finite element modeling, results evaluation and presentation; and a suite of modeling capabilities.

In a built the model in finite element analysis (FEA) the chassis design part will be analysis by using static linear stress analysis. Chassis design will select the element type, element definition and material of the chassis which is AISI 304 stainless steel. After all of it done, all part will mesh each other. Meshing that will be used is standard mesh with size 5mm; 0.25mm. The force is exerted onto the top surface of chassis design with different amount of load weight and place. At the main structure of chassis, by assuming the maximum mass of rider is around 80kg, so the force exerted around the seat section with the amount of 784.8N.

Lower front part of chassis part of chassis is exerted the force 784.8N by assuming the internal combustion engine (ICE) and controller with the mount has a mass around 80kg. At the middle and rear lower of the chassis is exerted force of 294.3N on that part. This is assuming the mass of electric motor, drive shaft, sprocket and chain, transmission, alternator, battery and others. For the failure criteria, maximum von Mises Stress Criteron will be used. The von Mises stress is used to predict yielding of materials under any loading condition from results of simple uniaxial tensile tests. The von Mises stress satisfies the property that two stress states with equal distortion energy have equal von Mises stress.

From the analysis result, the highest stress at the certain point will be determined and enhancement needed to improve the design. Some modification will be added to chassis accordingly to ensure chassis has a enough strength to support components, parts and rider.

The study of mechanics of materials is to analyze and design of load-structures. Both the analysis and design of a given structure involve the determination of stresses and deformations. When loads are applied to the chassis while being held fix, the chassis deforms both locally and throughout the body. These induce internal forces as well as reaction forces to render the body in state of equilibrium.

In general, the stress analysis software package offers four failure criteria to access the safety of design and list in Table 3.1.

Table 3.1 : Summary of failure criteria

Criterion	Material Type
Maximum von Mises stress	Ductile
Maximum shear stress	Ductile
Mohr-Coulomb stress	Brittle material with different tensile and compressive strengths
Maximum normal stress	Brittle

Source: http://help.solidworks.com (2013)

The maximum von Mises stress criterion is based on the von Mises-Hencky theory, also known as Shear-energy theory or the maximum distortion energy theory. In terms of principal stresses σ_1, σ_2 and σ_3, the von Mises stress is expressed as:

$$\sigma_{\text{von Mises}} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}} \tag{3.1}$$

The theory states that a ductile material starts to yield or at a location when the von Mises stress becomes equal to the stress limit:

$$\sigma_{\text{von Mises}} > \sigma_{\text{limit}} \tag{3.2}$$

In most cases, the yield strength is to be used as the stress limit. The factor of safety (FOS) at a location is calculated with below equation. The chassis is safe when the FOS value is more than 1.

$$\text{FOS} = \frac{\sigma_{\text{limit}}}{\sigma_{\text{von Mises}}} \tag{3.3}$$

3.3 CHASSIS FABRICATION

After the results in the simulation have proved the frame of hybrid motorcycle is in safe condition, fabrication process will be started. The beginning stage of chassis fabrication is built the jig for chassis mounting. Chassis jig will build using the hollow square 1.5 inch and L-shape 2 inch and both of them come out with the same material. The material that has been used was mild steel.

In jig fabrication process, it will start with measuring of wheelbase length as a main reference. During jig fabrication, all of a measurement must be ensured in precise and exact value. Metal Inert Gas (MIG) welding will be used in jig fabrication because it is easy to handle (Appendix B, Figure 3.3). The main chassis structure material which is AISI 304 hollow stainless steel, tools and equipment that used to fabricate the chassis will be prepared. The cutting tools that will be use are hand grinder machine and angle grinder machine (Appendix B, Figure 3.4 and Figure 3.5).

In the rolling process, the material which is hollow stainless steel cylinder will be roll by refer to the radius dimension in the design. The rolling machine (Appendix B, Figure 3.6) will be used in bending process to get the shape and curve that wanted. As knowns as the main material have a two type of dimension which is 1.5 inch and 1 inch, so the die for rolling machine should have a two different size. Rolling work must do in careful handling and slow to get the accurate radius.

For joining mechanism to joint all of stainless steel parts, tungsten inert gas (TIG) welding (Appendix B, Figure 3.7) will be used to join them. Because of handling the TIG welding machine need expert and experience in handling this machine, the energy of the person that who’s expert in handling TIG welding machine such as Instructor Engineer is needed. But the starting weld or what been called tag weld still use the MIG welding to do that. The first joining on the chassis is at the triple three holder housing. The flow of joining part is from the front part to the rear part.

The most complicated in joining of the hollow round is because it need to do the perfect notching to avoid any unwanted hole is occur and does not allowed TIG welding to joint between them. So, notching of the part should be done nicely and perfectly to avoid that thing happen. Other than that, at the middle part joining, the multipurpose jig will be used to hold the chassis part while joining them. The purpose of using the multipurpose jig because it ease to assemble and diassemble and does not need a lot of time to fix it. After all part of joining have been tag weld using MIG welding, seam weld works will be on going. The chassis prototype will be dismantle from the jig after seam weld have been done.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 CHASSIS DESIGN

Initial sketches of the proposed design were drawn. Upon thorough discussion and comtemplation one of the designs were chosen to be worked on further. The futuristic notion is added by the curved frames used in the chassis design. By means of SolidWork software, the chassis is designed. In Solidworks, there are 3 type of option file which are part file, assembly file and 2D drawing file. The chassis design was started drawn in sketches in a part file with the complete radius and placing of the origin. Then, each of the sketches was copied and pasted into another part file. In this part file, the Sweep Boss feature was used in design. After completed that part of chassis design, it was opened in assembly file to join all of them. To get the perfect joint between part, the same method was used to cut the interference between part. Figure 4.1, Figure 4.2 and Figure 4.3 illustrates the chassis design 3D modeling.

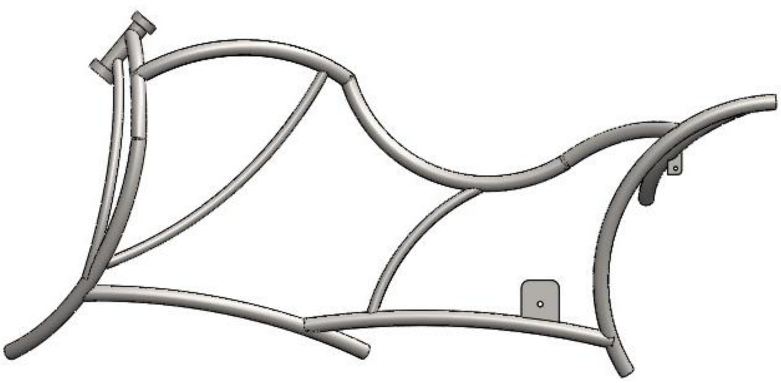


Figure 4.1: Side view of chassis 3D design

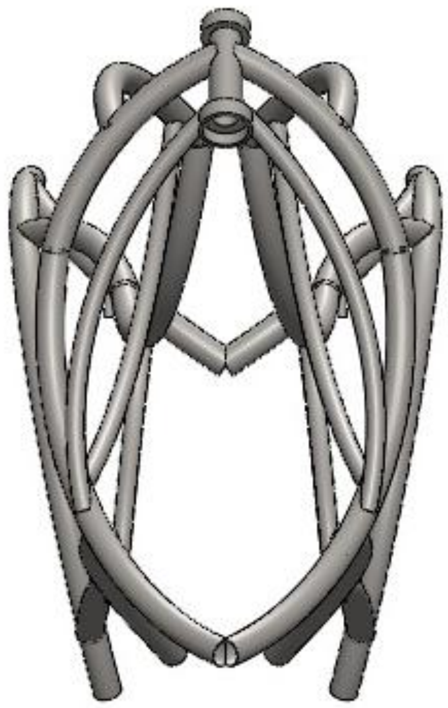


Figure 4.2: Front view of chassis 3D design

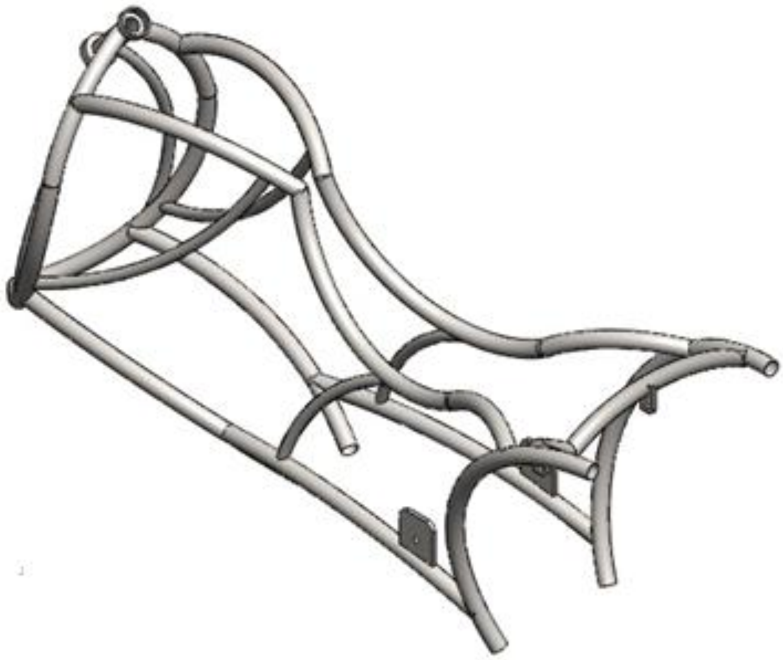


Figure 4.3: Isometric view of chassis 3D design

4.2 SIMULATION RESULT

Stress-strain simulation feature is available in SolidWorks 2012. In linear static load, triple tree and bracket absorber rear were set as fixed geometry, forces are applied on the chassis as the load from the components and the weight of the rider. Force F_1 is the weight from the petrol tank. While forces F_2 and F_3 is the weight of the rider and the weight contributed by the engine as well as the control box, respectively. Force F_4 is caused by weight from drive-train mechanism, batteries and electric motor.

Finite Element Analysis (FEA) provides a reliable numerical technique for analyzing the chassis design. The FEA software mesh the model with a number of small pieces of standard shape or element, connected at common points or nodes. Figure 4.4 illustrates chassis 3D model with fixtures, loads and meshing. Figure 4.4 shows the chassis 3D model with fixture and load and Figure 4.5 shows the chassis 3D model meshing. Table 4.1 shows the simulation force and meshing value.

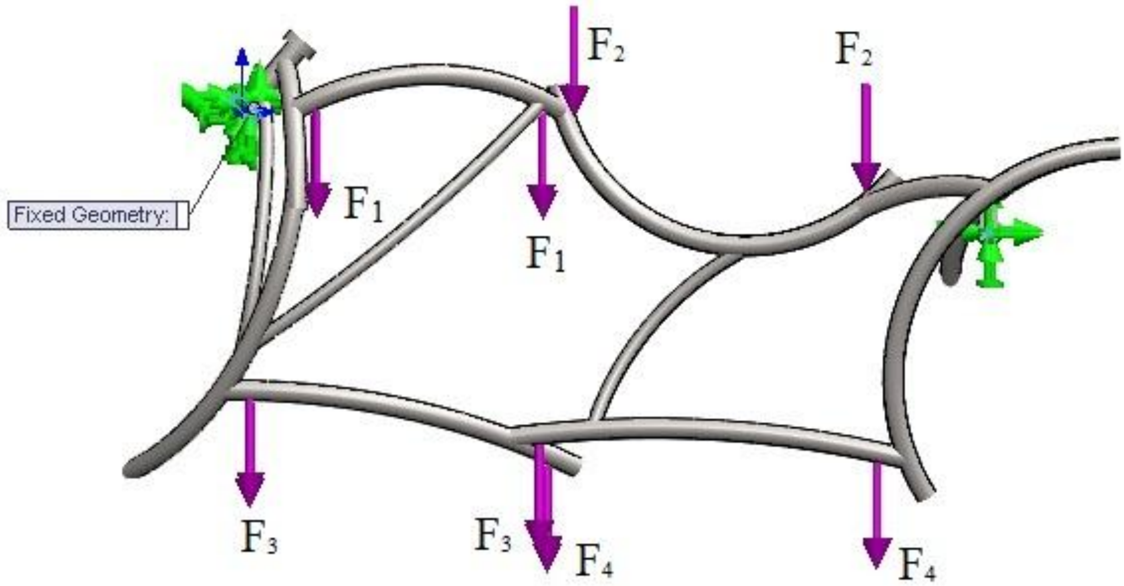


Figure 4.4 : Chassis 3D model with fixtures and loads.

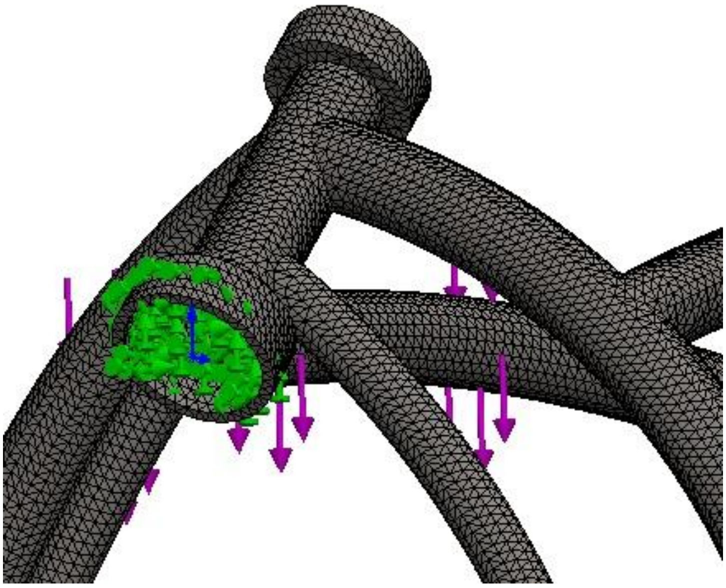


Figure 4.5 : Chassis 3D model meshing.

For the mesh type, the standards mesh was used with the mesh size is 5 mm and 0.25 ratio. Table 4.1 shows the static load stress-strain analysis parameters

Table 4.1: Static load stress-strain analysis parameters

Element	Label	Force (N)
Weight of the petrol tank	F_1	147.15
Weight of the rider	F_2	784.80
Weight of engine, control box and drive-train mechanism	F_3	784.80
Weight of drive-train mechanism, batteries and electric motor	F_4	294.3

From the stress simulation result (Figure 4.6), the maximum of the stress of von Mises Stress is equal to 206.8MPa. From the study, yield strength of the material stainless steel 304 is equal to 215MPa. In von Mises Hecky theory, if the maximum of von Mises stress is higher than yield strength of the material, so that deisgn could be failed. But from this result, the yield strength of material is more larger than the von Mises stress. This essentially means, that this particulat chassis design is safe.

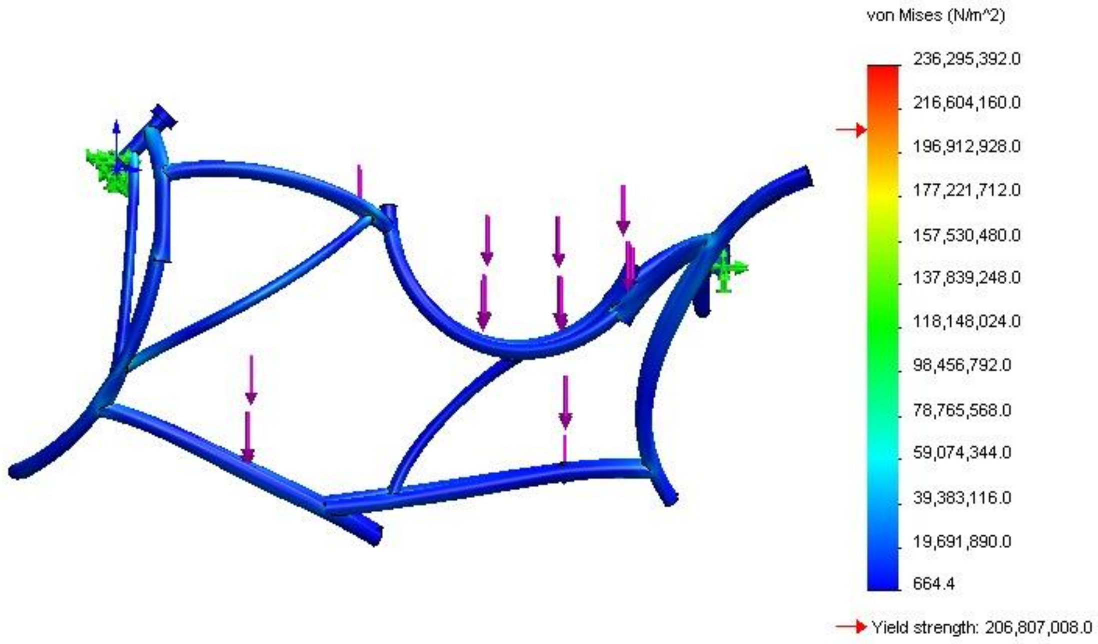


Figure 4.6 : Stress simulation result (von Mises Stress).

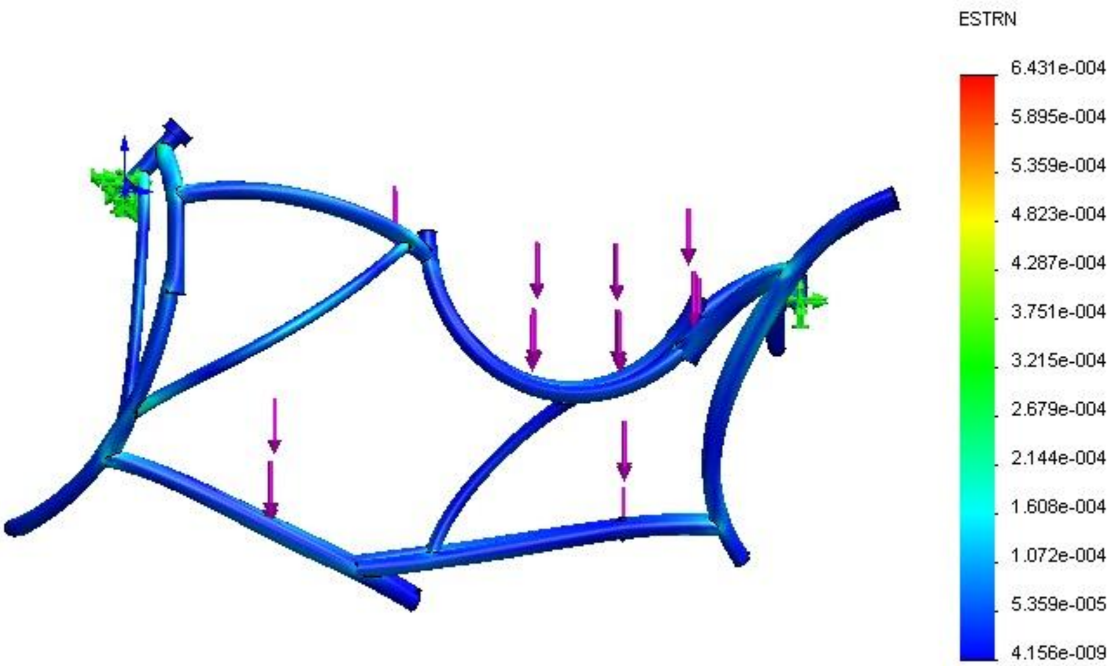


Figure 4.7 : Strain simulation result.

In the strain simulation result (Figure 4.7), the maximum of strain value computed is 6.431×10^{-4}. Highest strain occurs at the joining point between the frames. The maximum strain that has be allowed is 0.2% from the yield strength value. By using the modulus of elasticity formula, the maximum allowable strain was obtain. The value of maimum allowable strain is 1.075×10^{-3}. From the result it shown the maximum strain is less than the maximum allowable strain, which in turn suggests that this chassis is safe.

Figure 4.8 depicts the displacement simulation results. It shows that the maximum value of displacement is 1.232mm. The simulation result for displacement show highest displacement is at the frame where the rider sits and the frame supporting the weight of engine, electric motor, controller, batteries and drive-train mechanism. The maximum of displacement is less than the elongation limit, thus providing insignificant undesirable effect neither the chassis nor the rider.

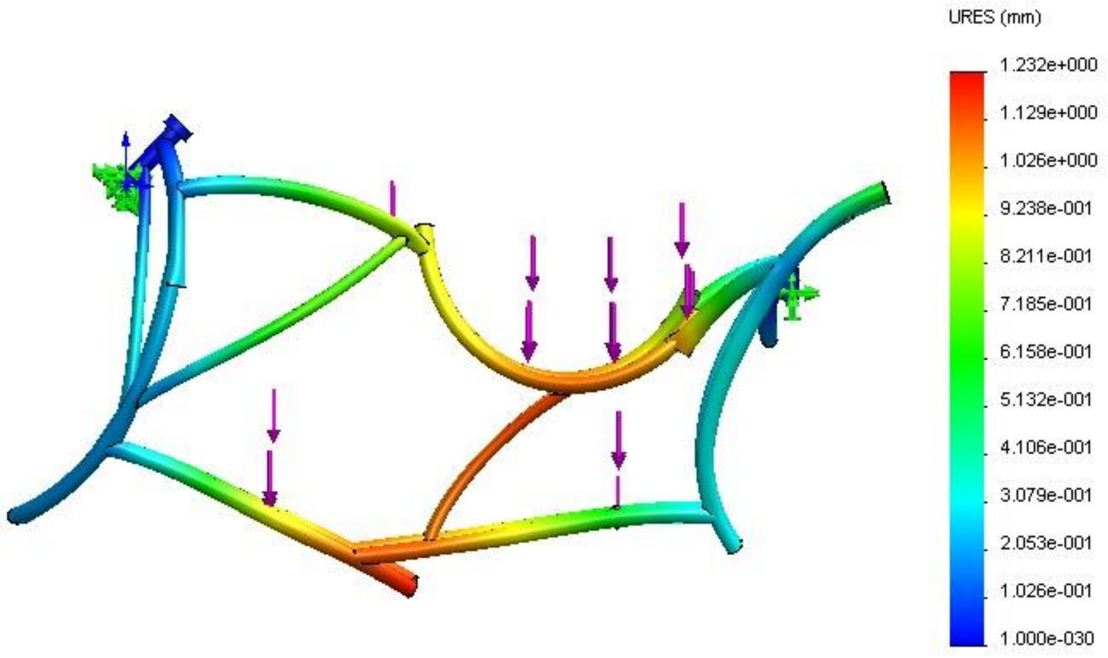


Figure 4.8: Displacement simulation result.

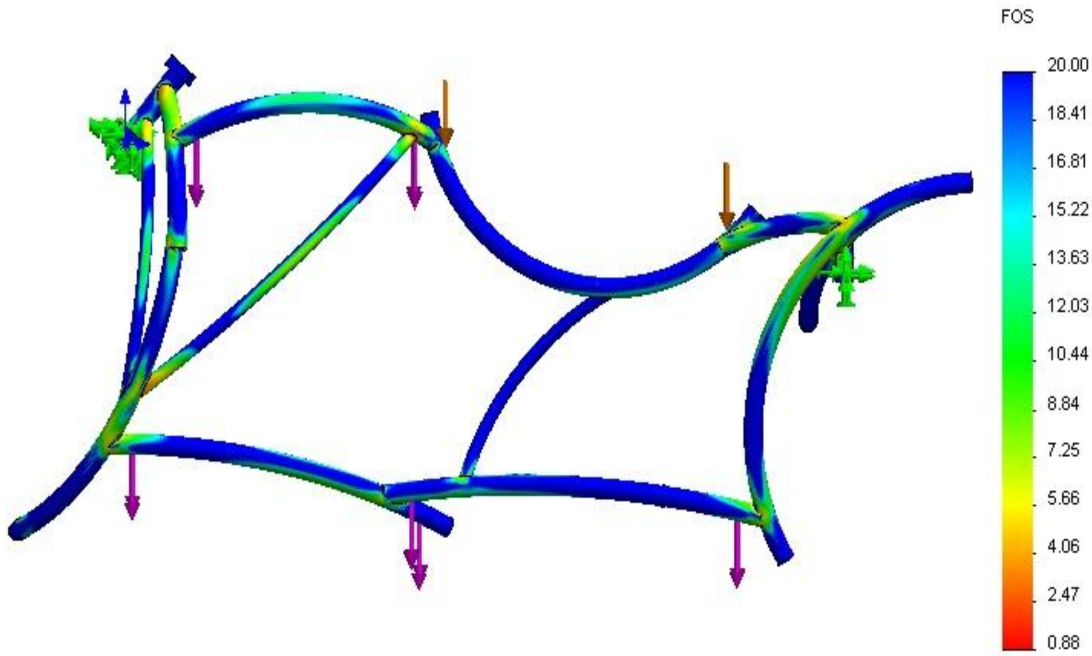


Figure 4.9: Factor of safety simulation result.

Figure 4.9 shows the factor of safety (FOS) simulation results. It is apparent that from the simulation results, the FOS ranges from 0.88 up to 20. The overall of the result shows the chassis is structurally sound and safe to use as a hybrid electric motorcycle chassis.

4.3 CHASSIS FABRICATION

The fabrication of the related parts to assemble the chassis were done in the university by utilizing the facilities available at the faculty's labararoties. The jig frame was built first as a reference place of chassis joining. Jig frame was completed with the angle bar for front triple three holder place. Figure 4.10 shows the complete jig with assembling of front and rear wheel.

Figure 4.10: Jig frame with assembling front and rear wheel

The rolling machine was used to bend the hollow round stainless steel tube. There are two types of die that have been use in rolling process. There are 1 inch and 1.5 inch of a die size according to the hollow round size. Figure 4.11 showns the main material which is hollow round stainless steel 304 had been rolled.

Figure 4.11: Hollow stainless steel that had been rolled.

After assembled the front wheel and rear wheel to the jig frame, the first joining process was done at the frontal area that called frontal part joining. For this part of joining, the part of top, front and bottom are joint together using the MIG welding as a tag weld. Figure 4.12 shows the frontal part joining.

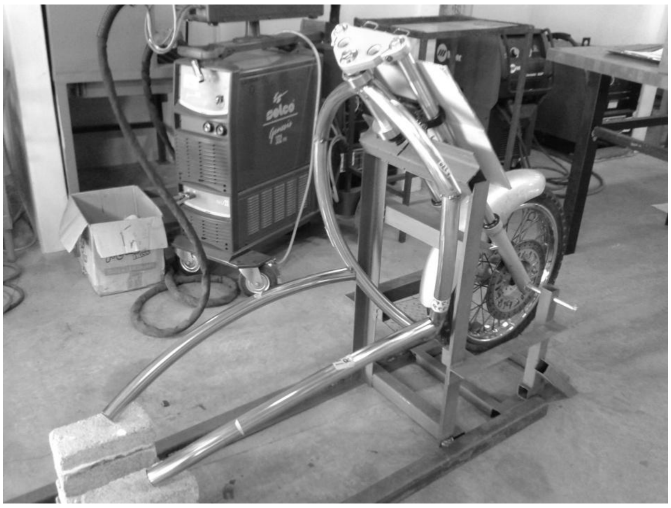


Figure 4.12: Frontal part joining

The ensuing fabrication process was the middle part joining process. The multipurpose jig was used as a holder jig to joint the middle part with frontal part. Figure 4.13 shows the middle part joining with multipurpose jig.

Figure 4.13 : Middle part joining with multipurpose jig

In the assembly of the rear part, an additional multipurpose jig was required to hold the rear part of the chassis. This is due to the fragile tag welds on the joining sections, hence the extra jig will help to support all the joining part before it was seam welded together. Figure 4.14 and Figure 4.15 shows the rear part of joining with extra multiporpuse jig.

Figure 4.14: Rear part joining side view

Figure 4.15: Rear part joining isometric view

Finally, after all part have been joint together using MIG welding, all of joining part was been seam weld using TIG welding. After done seam weld, the jigs were dismantled. Figure 4.16 shows the complete chassis design without support.

Figure 4.16: Complete chassis design without support

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The development of two wheel space-frame plug-in hybrid electric chassis has been established. The design fulfilled the requirement specified for this project in terms of spece and structural integrity. Computational stress and strain analysis were conducted to study the strenght of the chassis.

From the simulation results, it was apparent that the von Mises Stress is lower than the yield strength of the material stainless steel type 304 which essentially means the chassis structurally sound according to von Mises Hecky theory. The computed Factor of Safety (FOS) ranged from 5 to 12. This in turn means, that the chassis was a strong enough to withstand all the loading. The fabrication process ensued upon the completion of the stess analysis.

As a concluding remark, the objectives of this project has been successfully accomplished. The simulation results shows desirable results whilst the chassis has been fabricated.

5.2 RECOMMENDATION

During the development of two-wheel space-frame hybrid electric chassis, there are a lot of thing that can be improved in order to increase the quality of the product that has been produced.

a. The equipment and facilities that used in fabrication process must be complete set.
b. The jig frame to be done completely in order to get the accurate dimension and right position.
c. The curving design of the chassis need a expertise in notching work in order to get the perfect notching on the chassis part.
d. A welder man that handling in welding process should be expert to get the nice surface of welding join.

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APPENDIX A

Gantt Chart

	SCOPES	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
FYP 1	Literature review															
	Benchmarking of motorcycle chassis															
	Conceptual design															
	Computational stress/strain analysis															
	FYP1 report preparation															
FYP 2	Standard parts & material preparation															
	Prototype fabrication															
	System integration															
	Final report preparation															

APPENDIX B

Tools and equipments

Figure 3.3: MIG welding machine

Figure 3.4: Hand grinder machine

Figure 3.6: Rolling machine

Figure 3.5: Angle grinder machine

Figure 3.7: Tungsten Inert Gas (TIG) welding