THE UNIVERSITY OF WESTERN AUSTRALIA

School of Mechanical Engineering

Design and Construction of Motor Mounts

For

Renewable Energy Vehicle

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3rd November 2008

Synopsis

In Australia, the large consumption of internal combustion engine (ICE) vehicle had produced large amount of pollutants and greenhouse gasses. In order to reduce the demands on using ICE vehicle, the UWA Renewable Energy Vehicle team has planned to demonstrate the viability of using renewable energy sources for transport by building an electric commercial car from an ICE car. The complete converted car is aimed to register as license road vehicle. This thesis describes the evaluations of parts retainability, the methodology used in the design and construction of motor mounts, as well as performance evaluation of finished product.

The early stage of motor installation requires an investigation and evaluation on the parts in the engine compartment in order to identify particular parts retainability. All of the evaluations were based on passenger's comfort, safety and vehicle performance to determine the retainability of particular parts.

In this project, a motor mounts was designed to mount the motor in the engine compartment. All the motor mount designs must conduct with the Australia Design Rules 2008 and National Code of Practice for light vehicle construction and modification. Besides, analysis such as fabrication cost and complexity, material cost, fabrication time was considered in this project. Once complete, performance evaluation was conducted to the finished product.

The complete electric car is aimed to launch at the end of 2008. Although the motor mounts had been constructed and had achieved a huge success, there is much room for improvement of the motor mounts design for the performance electric car project.

Letter of Transmittal

Dyi Zen Tan
2/26 James Street,
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Associate Professor Carolyn Oldham,
The Dean
Faculty of Engineering, Computing and Mathematics,
The University of Western Australia,
Crawley, 6009 WA.

Dear Associate Professor Oldham,

It is with great pleasure that I submit this thesis named ‘Design and Construction of Motor Mounts for Renewable Energy Vehicle’, to the Faculty of Engineering, Computing and Mathematics, UWA, as part of the requirement for the degree of my Bachelor of Engineering (Mechanical)

Your Sincerely,

Dyi Zen Tan,
10545137

Acknowledgements

I would like to appreciate to the following people for the contributions, supports and guidance throughout my final year project.

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Steve Ip and Winston Ma, my project mates of REV mechanical team, and all the UWA REV Team members for the opportunity to take part in this interesting project.

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1. Introduction

1.1 The Renewable Energy Vehicle

Most of the vehicles nowadays are completely dependent on fossil fuel, which are largely producing the greenhouse gasses by its carbon burning combustion process. The emission produced by internal combustion engine has proven to yield heat and pollution to the environment. Moreover, the increasing demands on fossil fuel and other circumstances has resulted the prise of fossil fuel increased dramatically. Hence, it is important to develop all sorts of renewable energy technologies to supersede internal combustion vehicle.

The Renewable Energy Vehicle (REV) Project is one of the major projects undertaken by UWA students to deal with the problems of vehicle pollutions and the shortage of fossil fuel in the future. This project was first started on July 2004 by the inspiration of Tamagawa University Solar Car Project in Japan on 2003. Tamagawa University were the first in the world to produce a hybrid solar and hydrogen fuel cell powered vehicle, which they successfully drove across Australia from Perth to Sydney in 2003 (Dick, 2004). With the help and inspiration of Tamagawa University, the UWA REV team was aimed to create a 2 seated with 4 wheel non pollution hybrid solar power system and hydrogen fuel cell vehicle.

In 2008, the REV project was relaunched again under the supervision of Associate Professor Thomas Bräunl and Dr Kamy Cheng by continuing the main objectives of previous project to demonstrate the viability of clean renewable energy in transportation. However, the idea of using the hydrogen source to power the vehicle has been dropped, as the plug-in electric car technology is more suitable for commercial needs.

The new REV project is aimed to a build a four-wheel, five-seater electric commuter vehicle by converting an existing internal combustion engine (ICE) car - Hyundai Getz. Although there are already many electric existed, most of these electric car are unsuitable as a commuter vehicle and are not resemble with the conventional cars. The REV goal is to produce a vehicle that gains public acceptance with its environmental friendly features, and also comparable to the conventional vehicles in terms of performance, convenience and style. With this REV project, the UWA engineering students will be able to promote greater research into REV and proof that REV is a sustainable transportation for the future.

1.2 Final Year Project Scope

In order to allocate appropriate tasks to students from particular discipline field, the REV project has been broken into smaller individual tasks. In this thesis, the author was required to design a motor mounts to mount the electric motor in the engine compartment. Therefore, the main aim of this thesis is to design and manufacture a simple but qualified motor mounts for an electric car.

In order to install a new electric motor in the engine compartment of existing internal combustion engine (ICE) vehicle, some unnecessary parts and components are required to be removed, whilst some functional parts are required to be retained. Therefore, an investigation and evaluation has to be done to identify the retainability of particular parts and components. Such evaluation has to be based on passenger's comfort, safety and vehicle performance.

When all the unnecessary parts had been removed, the electric motor is needed to be installed in the engine compartment. Since the electric motor is considered as the heart of an electric car, it is important to design a qualified motor mounts to attach the electric motor tightly in the engine compartment. The motor mounts design must include a coupling to engage the motor shaft with the transmission shaft. With the coupling, the vehicle could be propelled by the electric motor. All the designs of the motor mounts must refer to the Australia Design Rules 2008 and National Code of Practice for light vehicle construction and modification.

In addition, the author must ensure the design of motor mounts must be simple with low fabrication cost. Besides, determinations on selecting best material and selecting the most appropriate machine to build the motor mounts are another essential scope of this project.

Finally, a performance evaluation of the motor mounts is needed in order to examine the successfulness of the motor mounts design.

2. Literature Survey

2.1 Chapter Overview

This chapter discusses the overview of renewable energy vehicle and some existing electric motor mounts which available in market. Nevertheless, this chapter also discusses some existing renewable energy vehicle projects which are done by other universities or colleges.

2.2 Renewable Energy Vehicle Overview

Renewable energy vehicle (REV) is the vehicle that powered by electricity by any plug point or powered by renewable sources. In general terms, REV can be considered as an electric car. REV produces zero or low pollution compared to convectional fuel vehicle. In today technology, there are many existing renewable energy vehicle such as fuel cell vehicle, solar vehicle and battery electric vehicle.

2.2.1 Fuel Cell Vehicle

Fuel cell vehicle is an electric car powered by electricity which generated by a chemical process using hydrogen fuel and oxygen from the air. A fuel cell vehicle could be driven by 100% pure hydrogen gas or hydrogen-rich fuel. The vehicle driven by 100% pure hydrogen gas emits zero pollutant while vehicle with hydrogen-rich fuel emits small amount of pollutants.

2.2.2 Solar Vehicle

Solar vehicle is an electric car powered by electricity which generated by solar energy. The design of solar vehicle is not practically suitable for daily use due to the limited solar power input into the car. Therefore, most current solar car were built for racing purpose only.

2.2.3 Battery Electric Vehicle

The battery electric vehicle is powered by electricity which mainly from battery cells. Although electric car emits zero pollution and it is more energy efficient, it faces significant challenges:

- Driving Range - the average travel range for an electric car is 200km or below.
- Charging Time – Average charging time for electric car is 4 hour to 8 hour.
- Battery Costs – The cost of the batteries for electric car are expensive.
- Battery Size & Weight–The huge battery sets is heavy and occupy a lot of space.

Due to the shortcomings of the battery as mentioned above, electric vehicles are still unable to fully substitute internal combustion engine vehicles.

2.2.4 Plug-in Hybrid Vehicle

A hybrid vehicle cannot be considered as pure renewable energy vehicle or electric car due to it powered by both petrol fuel and electricity. Most of the hybrid vehicles operate in a charge-sustaining mode. However, a plug-in hybrid vehicle which its batteries can be charged externally to displace could be considered as pure electric car during its charge-depleting mode (Wikipedia, 2008).

2.3 Motor Mounting Kits

Figure 2.1: A sample of motor mounting kits in the electric vehicle DIY kits

There are many existing motor mounting kits available for beginners to convert an electric vehicle. These motor mounting kits are easy to install and are designed in various size and pattern to suit various model of vehicle. If there is no suitable patterns dimension of motor mounting kits, some shops would also provide the service on custom build. These custom motor mounting kits had been specially designed for particular model of vehicle and thus it only take less than an hour to mount the electric motor in the engine compartment. However, these ready-to-go motor mounting kits has an inflexible design which will limit the liberty to install other parts and components in the engine compartment.

2.3.1 Rear Support Motor Mounts.

The rear support motor mounts is to support the rear side of the motor or the side which opposite to the motor drive connection. There are two types of rear supports motor mounts available for converted electric vehicle. The first type of the motor mounts is the middle style motor mounts. This middle style motor mounts cradle the rear side of the electric motor by clamping around the motor middle. The middle type motor mounts are preferable for the in-line engine style vehicle. On the other hand, another type of rear support mounts – the plate style mounts is suitable for a transverse engine vehicle. The plate style mounts is a mounts with plate face to be bolted on the opposite end face of the motors drive shaft.

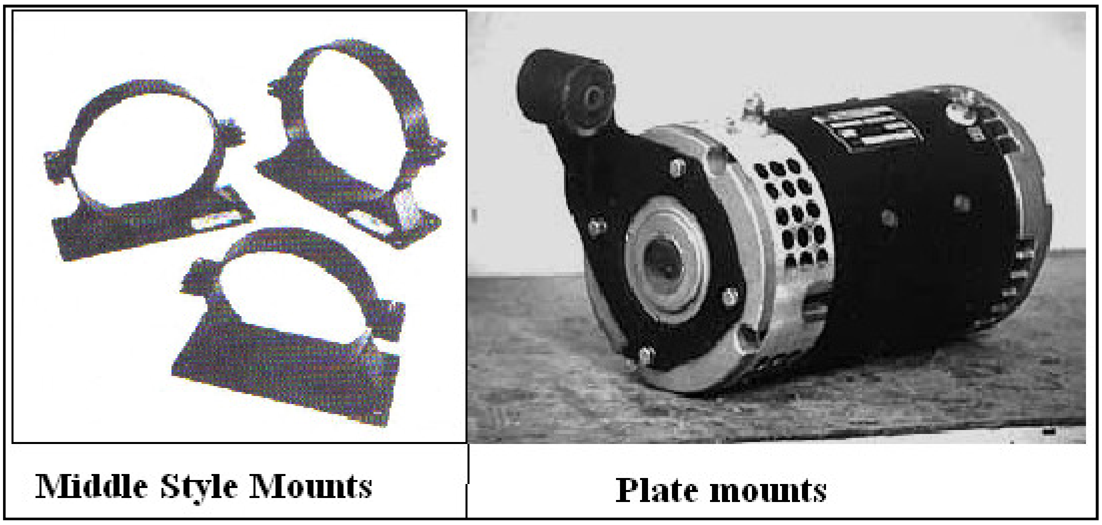


Figure 2.2: The two types of rear support mounts

2.3.2 Front Motor Support Mounts

The front motor support mounts is used to mount the electric motor to the original transmission bell housing. The most common front support mounts available in the markets is adapter plate mounts. The precision of high accuracy dimension and patterns of the adapter plate with the transmission bell is very crucial, especially the bolt holes positions for both transmission bell and motor. Most adapter plate are made of aluminium in order to have minimum weight.

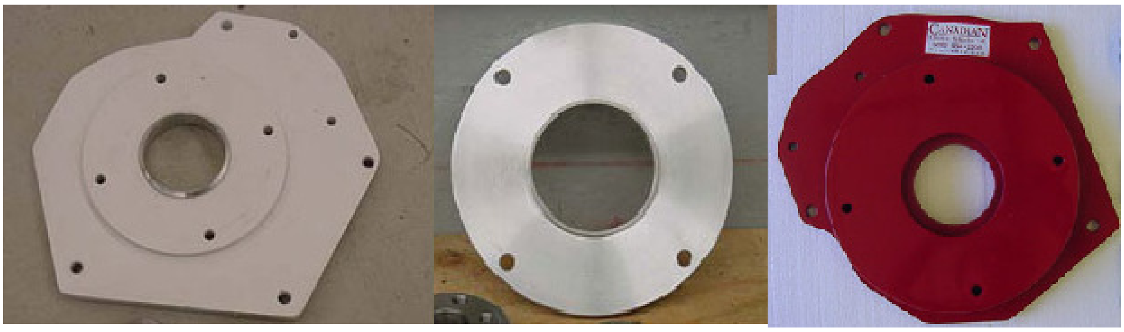


Figure 2.3: Different dimensions and patterns of adapter plate from motor mounting kits

2.3.3 Coupling

The coupling is a crucial part of motor mounts to lock the motor shaft with the transmission shaft in order to transfer motor propulsion to the wheel. Therefore, a coupling requires high mechanical strength to sustain for the high rotation per minute (rpm) and high torque application. As a result, most coupling is made of steel. There are many kinds of coupling available in the market: Set screw coupling, shrink fit coupling and taper lock hub.

2.3.3.1 Set Screw Coupling

Set screw coupling is a coupling with set screw opening. When the coupling has held the motor shaft, the set screw will be screwed in the set screw opening or thread holes to tighten the motor shaft. However, according to the Brown and Prange (1993), the set screw coupling is not safe to use as it will fail catastrophically.

Figure 2.4: A coupling with six set screw opening.

2.3.3.2 Shrink Fit Coupling

Shrink fit coupling has a diameter smaller than the shaft. In order to fit the shaft into the coupling, either heat the coupling or freeze the shaft to allow heat expansion phenomena to fit the coupling to the shaft. However, this technique is nearly impossible to remove apart once it in place.

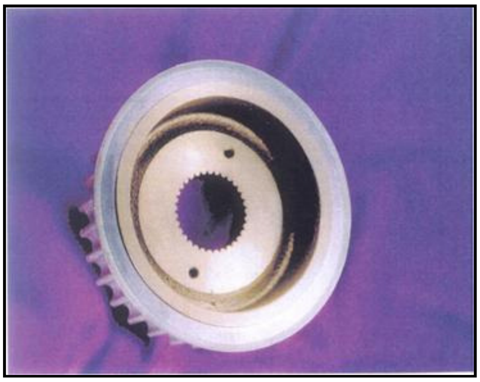


Figure 2.5: Shrink fit coupling for transmission shaft

2.3.3.3 Tapper Lock Hub

The taper lock hub includes a hub and a bushing. The hub inner surface is tapered, which slides over a matching to the tapered bushing. The bushing has a split with an outer diameter of slightly larger than the inner surface of the hub. When the bushing had put in the motor shaft, bolts were used to draw the bushing into the hub. Since the outer diameter of the bushing is larger than the hub, when the bushing was drawn into the hub, the split of the bushing will be squeezed to close and the bushing will lock to the motor shaft tightly. This technique is very secure and could be remove easily for maintenance.

Figure 2.6: A taper lock hub with a bushing.

2.4 Existing University REV Project

2.4.1 Two-seater Renewable Energy Vehicle by The University of South Australia

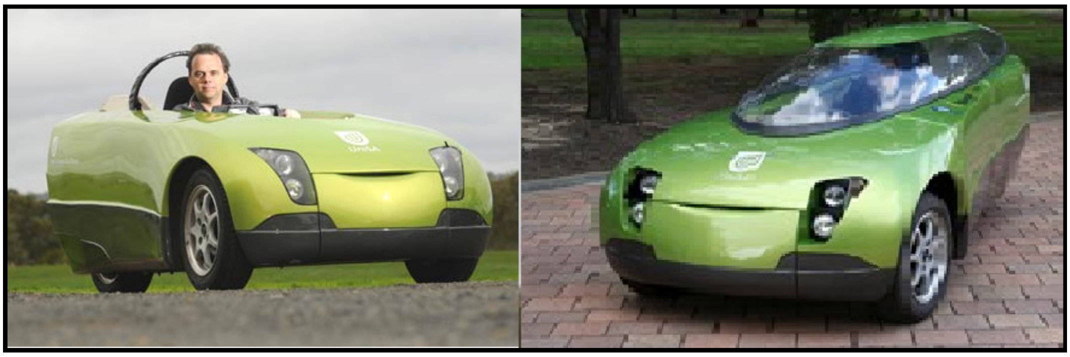


Figure 2.7: The TREV

The 300kg Two-seater Renewable Energy Vehicle (TREV) is a clean, quiet and efficient electric drive system which was constructed by The University of South Australia. The TREV is powered by a total of 45kg lithium ion polymer battery which provides 150-kilometre of driving range. It has a ultra-light body with a tandem seating layout which enable a lower aerodynamic drag and better balance. The energy consumption of TREV is about 6.2 kWh/100km, which in turns means the cost of recharging TREV is around 1.1 cents per kilometer. Unfortunately, TREV cannot be sold in Australia because it cannot be registered for road use due to not meeting the safety regulations.

2.4.2 Indian First Plug-in Hybrid Car - Chimera Project

Figure 2.8: The Chimera Hybrid Car

The Chimera is the first plug in hybrid car in Indian which was constructed by 11 engineering students from RV College of Engineering in Bangalore. The car uses both electric energy and bio-diesel, thereby maintaining an eco-friendly tag (CIOL, 2008). The car is fitted with a 440cc diesel engine, and features an onboard charging.

2.4.3 Centaurus-The University of Minnesota Solar Vehicle Project (UMNSVP)

Figure 2.9: The 8th Generation solar vehicle – Centaurus

The 190kg Centaurus is the 8th generation of solar vehicle which is designed and constructed by The University of Minnesota. This solar vehicle uses total of 30kg Lithium Polymer batteries to propel the Custom, Brushless DC Motor. The chassis of the car was constructed out of fiberglass composite panel and double A-arm suspension was used up front, while a single swing-arm was utilized in the rear (UMNSVP, 2008). The top speed of the car can reaches up to 80mph and all of the electrical components on the car are designed and manufactured in-house by The University of Minnesota Solar Vehicle Project (UMNSVP).

2.4.4 Electric Blue by Brigham Young University

Figure 2.10: Electric Blue – The electric formula racing car.

The Electric Blue is a electric formula racing car was constructed by Brigham Young University (BYO). The unique of this car is its power source-88 piece of 36-volt batteries formerly used to power cordless drills. The power source is different from the common electric car but still an environmentally friendly alternative fuel source.

3. Retainability of Original Parts and Components for Hyundai Getz

3.1 Chapter Overview

This chapter covers the substitution of electric motor instead of internal combustion engine in the Hyundai Getz. Evaluation of unwanted original parts and components from Hyundai Getz is required to determine which components were needed to be removed and which components were needed to retain. A motor mount has to be designed and constructed to attach the electric motor into the car to move the car.

3.2 Methodology

In order to convert an existing internal combustion engine vehicle to an electric car, some original parts and components from the car must be removed. There are two reasons why these unwanted or unused parts and components have to be removed. The first reason is to provide more space for the installation of new electrical parts and components for an electric car. Another reason for unwanted parts removal is to lower the overall weight of the vehicle in order to meet higher efficiency.

The original parts and components in the Hyundai Getz can be grouped into three categories, A, B and C category. The parts and components which belong to category A are highly unwanted as most of these parts and components are only necessary for internal combustion engine vehicle but not electric car. Category B belongs to parts and components which remove or retain these components are to be decided. The parts and components that belong to Category C are highly recommended to be retained in the car.

3.2.1 Category A

In order to minimize the weight of the converted vehicle and supply enough space for electric motor installation, some unessential items from Hyundai Getz had to be removed. These parts include the internal combustion engine, engine mounts, exhaust system, fuel system, ignition system and starter system. All of these parts and components were removed and weighted for calculation of front to rear vehicle weight distribution.

Category A
• Internal combustion Engine • Fuel System • Exhaust system • Emission control system • Ignition system • Starter system

Table 3.1: Showing the unessential items which required to be removed in the car

3.2.2 Category B

Deeper analysis and evaluation is needed for parts and component in Category B to determine whether these items should be retained or removed from Hyundai Getz. These parts and components could be completely removed from the car but they have certain functions which could ease the controlling or handling of an electric car or expand more comfort to the car passengers. These items include clutch system, air conditioner system and the 12volt battery.

Category B
• Clutch system • Air conditioner system • 12 volt battery • Power Steering System

Table 3.2: Showing the items which required deeper evaluation to determine either those items to be retained or be removed.

3.2.3 Category C

The parts and components that belong to Category C are the items that are highly recommended to be retained in the car. The items in Category C include transmission and engine mount rubber. Without these parts, the converted Hyundai Getz would not be able to run properly or unable to run.

Category C
• Transmission • Engine Mount Rubber

Table 3.3: Showing the items which are necessary to retain in the engine compartment.

3.3 Result and Discussion

3.3.1 Category A

The internal combustion engine, engine mounts, exhausts system, fuel systems, ignition system and starter system were categorized in Category A because these parts are unnecessary for an electric car. An electric car is run on electricity instead of fuel and an electric car does not emit any pollution. Therefore, the exhausts system and fuel system could be removed from the electric car without any dispute. In addition, an electric car is started by switching on the circuit. As a result, the ignition system and starter system of the original car could be removed from the car.

3.3.2 Category B

3.3.2.1 Clutch System

Whether a clutch system is chosen to be leave in an electric car or not is depended on subjective view. Both methods, with clutch or clutchless in an electric car have the advantages and disadvantages.

An electric car with clutch system is easier and pleasant to be driven. Without a clutch, a driver requires very high practical driving skill to drive an electric car from rest position to freeway speed without a sudden jerk. In addition, the rotation per minute limits of an electric motor is very similar to the original internal combustion engine, which results an electric car requires the clutch with transmission to achieve a full range of performance. In other words, an electric car with clutch system is more efficient than a clutchless electric car. Besides, in safety aspect, an electric car with clutch system is better as the driver can disengage the motor rotation from the wheels when an emergency incident such as under power was occurred. Another advantage of retaining clutch system in an electric car is to minimize the possibility of the gears inside the transmission been worn out.

On the other hand, about twelve kilograms of weight could be saved from the electric car if the clutch system is removed. The lost of weight from the removal of the clutch system could be substituted by installing more batteries into the electric car. By installing more batteries into the electric car, the travel range of the car could be extended when the car is fully charge.

Retain Clutch System	
Advantages	Disadvantages
• Easier handing on the car • High efficiency • Minimize gears wear in the transmission • Safety feature –disengage motor from wheel when incident happens	• Increase the weight of the vehicle

Table 3.4: Advantages and Disadvantages of an electric car which retaining the clutch system

Remove Clutch System	
Advantages	Disadvantages
• Save more weight from the vehicle • More batteries could be installed in the vehicle due to weight loss of the clutch system • The travel range of a fully charged electric car could be extended.	• Low efficiency • Gears wear in the transmission is more likely to happen

Table 3.5: Advantages and Disadvantages of an electric car without the clutch system

In this renewable energy vehicle project, the converted electric Hyundai Getz is aimed to build appropriate for the personal transport needs of the Australian public. Therefore, the safety feature of the Hyundai Getz must be advanced and the handling and controlling of the electric car must be simple. As the result, the clutch system had judged to be retained.

3.3.2.2 Air Conditioner System

Vehicle air conditioning is an important part of an integrated system which provides cooling, heating, defrosting, demisting, air filtering and humidity control for both passenger comfort and vehicle safety (Andersen et al. 1997). The maximum temperature during the summer time in Australia could be reached more than 40 degree Celsius. Therefore, the installation of air conditioner systems in a vehicle could allow the passengers and the drivers feel more comfortable during hot climate. Besides, another function for the installation of air conditioner systems in a vehicle is to increase the safety for passengers and driver. Air conditioner systems with the function of comfort cooling and dehumidifying could maximize the visibility of drivers when window demisting is necessary. Moreover, a vehicle with air conditioner systems driving in freeway speed would have lower energy consumption, if compared to an open window driving vehicle. This is because an open window driving vehicle would have higher aerodynamics drag and thus need more energy to move the vehicle.

However, the operation of air conditioner systems in an electric car could produce some greenhouse gasses emission. In additions, the used of air conditioner systems in an electric car could lower the travel range of the car and thus diminish the efficiency of the car. Moreover, the retainment of air conditioner systems in the electric car requires redesigning and reconstructing new mounts to attach the air conditioner systems in the engine compartment.

Retain Air Conditioner Systems	
Advantages	Disadvantages
• Increase comfort to passenger • Increase vehicle safety, due to higher visibility when stem has fogged the windows • Lower energy consumption in freeway speed	• Need to reserve space in the engine compartment for air conditioner systems • Need to redesign a mount to attach air conditioner systems in the engine compartment • Produce greenhouse gasses • More energy consumption if air conditioner systems is used improperly

Table 3.6: Advantages and Disadvantages of an electric car which retaining the air conditioner system

Remove Air Conditioner Systems	
Advantages	Disadvantages
• Zero pollution • More space in engine compartment • Higher efficiency and the travel range of the vehicle is higher	• Driver and passengers are less comfortable • Low safety due to low visibility when window has fogged • Use more energy when the vehicle is driving on freeway speed due to increase of aerodynamic drag

Table 3.7: Advantages and Disadvantages of an electric car without the air conditioner systems

Although both methods; retain the air conditioner systems in an electric car and remove air conditioner systems from the electric car have its own advantages and disadvantages, the converted Hyundai Getz was selected to retain the air conditioner systems. In spite of retaining air conditioner systems in Hyundai Getz requires more time and effort to redesign mounts in the engine compartment, it is worthy as this method could increase the vehicle safety and expand passengers comfort.

3.3.2.3 12 Volt Battery

The original function of the 12 volt battery from the Hyundai Getz is to generate electricity to the ignition systems and order electrical parts such as head lights and air conditioner systems. However, the converted Hyundai Getz had aimed to install forty five blocks of lithium-ion battery to run the electric motor. The operating voltage for each block of lithium-ion battery is 3.2volt, where total operating voltage of 144volts are generated from 45 blocks of lithium-ion battery. These high voltage generated from lithium-ion batteries are high enough to substitute the original 12 volt battery.

However, the 12 volt battery had been chosen to be retained in the converted Hyundai Getz, inasmuch as the retainment of 12 volt battery could expand the travel range of the electric car due to all the lithium-ion batteries could concentrate on generating electricity to electric motor while the 12 volt battery generate electricity to order electrical components.

3.3.2.4 Power Steering Systems

Power steering is a system that to reduce the input force required to turn or to steer the road wheels by using external power source. An electric car could be driven without power steering systems but it would be difficult for the driver to maneuver the vehicle wheels at low speeds. Since the converted Hyundai Getz is build appropriate for the personal transport needs of the Australian public, the power steering systems was decided be retained in the converted car to enable the car is easy and pleasant to be driven.

3.3.3 Category C

3.3.3.1 Transmission

Transmission or commonly known as gearbox is used to provide a speed-torque conversion for a vehicle. With the installation of transmission, a slower but more forceful output could be done from a high rotation motor. When a car is traveling slowly or moving from standstill speed, a greater torque is required. Therefore, transmission is necessary for a vehicle to transforms a low speeds rotation motor into a high torque rotation. In additions, transmission is needed in a car to ensure the electric motor is operating within its limits when the vehicle is running in a freeway speed.

3.3.3.2 Engine Mount Rubber

Engine mount rubber is an important vehicle component which is used to isolate the vehicle structure from vibration of the engine or electric motor. Without the engine mount rubber, the passengers and the driver of the vehicle might be uncomfortable due to the vibration from high rotation motor. Since the converted Hyundai Getz is a brand new car, it is not necessary to replace a new pair of engine mount rubber. Although an electric motor is generally lighter and less vibration than an internal combustion engine, the engine mount rubbers are still necessary to retain in the engine compartment in order to isolate vehicle structure from the vibration of motor.

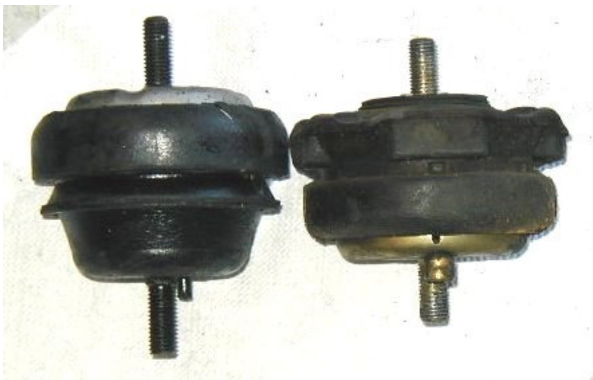


Figure 3.1: Sample picture of engine mount rubbers.

4. Design of Motor Mounts for an Electric Motor

4.1 Chapter Overview

This chapter covers the design and modeling of the motor mounts for attaching the electric motor in the engine compartment. Since the converted Hyundai Getz is proposed to register as a licensed road car, the entire design of motor mounts for the car must conform under the restraint of certain regulations and rules.

4.2 Aims of the REV Project

The constraints imposed by the aims of the project are shown as follow:

- Design must be fully compliant with the National Regulations
- Design must be as simple as possible with low fabrication cost

4.3 Constraints

The converted electric car in this project is aimed to register as a licensed road vehicle. Therefore, the design of the motor mounts for Hyundai Getz must be strictly conform to design rules and regulations which are nationally accepted in Australia. There are few nationally accepted guidelines which have been introduced by The Australian Motor Vehicle Certification Board Working for the installation of electric drives in Australia. These guidelines include National Code of Practice for Light Vehicle Construction and Modification, Australian Vehicle Standards Rules 1999 (AVSR) and with Australian Design Rules (ADR).

However, neither Australia Design Rules nor other standards have relevant regulations or rules that restraint the design and construction of motor mounts. In order to design a qualified motor mounts for Hyundai Getz, a clearer and deeper understanding on original engine mounts should be existed.

4.3.1 The Main Functions of Engine Mounts

There are two main functions of an engine mount in a vehicle. Along with securing the engine in place, the engine mounts have another equally important function, which is to isolate the whole vehicle from engine vibration or shaking. Engine mounts allow the rotation between engine shaft and transmission shaft, but still assist to keep the engine and transmission in the proper alignment. One of the critical parts of the engine mounts is engine mount rubber. The main function of the engine mounts rubber is to perform as a damper to damp the vibration and noise created by engine.

4.3.2 Requirements of Qualified Motor Mounts Based on the Original Engine Mounts

As there do not have the relevant codes or regulations that restraint the design of motor mounts for an electric car, some assumption had to be made in order to design a qualified motor mounts. Firstly, the motor mounts must be tough enough to secure the electric motor with the transmission in the engine compartment. Secondly, the engine mounts have to be designed to isolate the motor vibration from being transfer to the vehicle structure.

The first requirement of building a qualified motor mounts is to ensure the motor mounts must attach the electric motor tightly in the engine compartment with the transmission. However, the motor mounts are not designed to sustain a high frontal impact. The original engine and transmission of Hyundai Getz were designed to drop out of the bottom of the engine compartment when a frontal impact occurred. This design is used to prevent the intrusion of the engine and transmission into the passenger compartment and thus lower the risk of the driver and passengers when accident is occurred. The design of very high strength motor mounts to sustain for frontal impact was considered as undesirable. A motor mounts which are tough enough to secure the motor firmly with the transmission in the engine compartment could be considered as a qualified motor mounts.

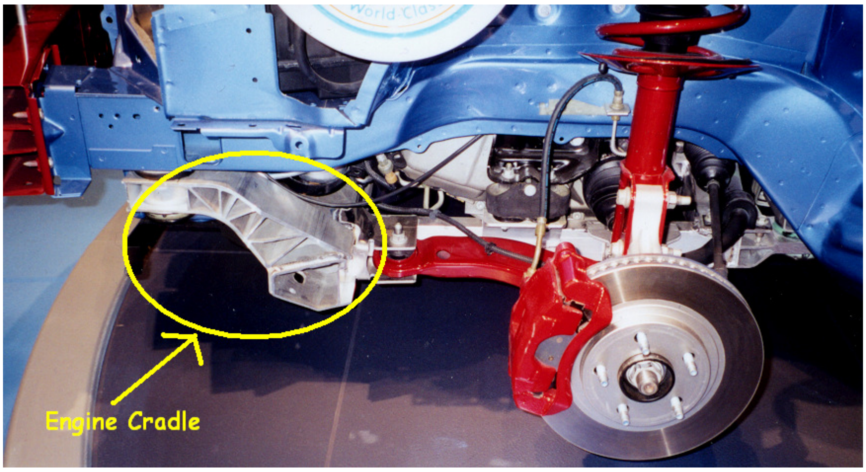


Figure 4.1: The Engine Cradle is designed to drop the engine and transmission out of the bottom of engine compartment (Cincurak 2008).

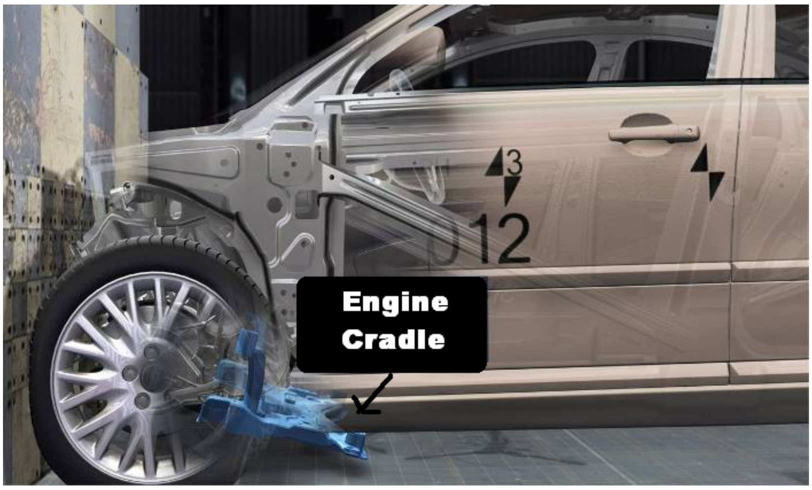


Figure 4.2: During the frontal impact, the front end of the vehicle continues to collapse and absorb energy as the engine cradle continues to move back and down,(Cincurak 2008).

The second requirement of building a qualified motor mounts is to ensure the motor mounts are able to isolate or lessen the vibration of motor to the vehicle structure. One of the advantages of an electric motor is the electric motor is much silent and less vibration during operations if compared with an internal combustion engine. Therefore, the original engine mount rubbers in Hyundai Getz are well enough to perform as dampers to damp the vibration of the electric motor. The original engine mount rubbers were chosen to be retained in the converted Hyundai Getz as explained at section 3.3.3.2. As a result, the second requirement of the design of motor mounts for this project is to ensure the motor mounts are able to transfer the motor vibration to the engine mount rubbers to be damped

4.4 Design and construction of Motor Mounts

Motor mounts are used to secure the electric motor firmly with the transmission in the engine compartment. In regard to the motor attachment, the motor shaft have to be aligned with the transmission shaft all the time while the motor mounts are able to transfer the motor vibration to the engine mount rubber to be damped. There design of motor mounts had been split up to four parts :

- Front support- motor to transmission adapter plate
- Rear support for electric motor
- Mounting bar for extra support of motor mounts
- Motor Shaft with Transmission shaft connection via coupling

A complete motor mounts design must be covered by four elements above and deeper evaluation on these four elements is needed. The design and construction of each part of the elements above will be discussed below in sequence.

4.4.1 Design and Construction of Frontal Support

The main function of the front support of the electric motor (adapter plate) is to fix the motor and the transmission tightly together to allow motor shaft turns the transmission shaft smoothly. The adapter plate has to be bolted on both the front of the motor and the front face of the transmission bell housing.

4.4.1.1 Methodology of Front Support Design

There were four steps to be taken to analyse in order to design and construct an adapter plate:

1. A critical distance between the motor shaft and transmission shaft had to be calculated.
2. The frontal shape of the transmission bell housing had to be recorded.
3. The location of the bolts holes and screw holes of the frontal of the transmission bell housing and the electric motor has to be determined

4. The centre point for the adapter plate had to be determined.

4.4.1.1.1 Critical Distance

The critical distance is the distance between the frontal area of transmission bell housing and the frontal area of the electric motor. The distance was needed to determine the thickness of the adapter plate. From Appendix A, the length of a Advanced DC #FB1-4001A motor shaft is 50.8 mm. By measurements, the distance between the front face of the transmission bell housing and the transmission shaft is 35.8mm, which is shown in Figure 4.3.

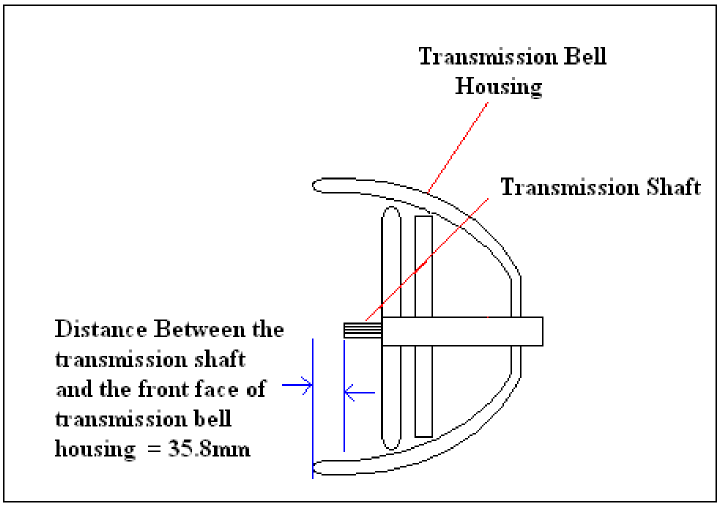


Figure4.3

From the formula shown below, the critical distance was calculated as 15mm.

Critical Distance = Motor shaft length – Distance between front face transmission and transmission shaft Critical Distance = 50.8mm – 35.8mm

However in practical, a gap between the motor shaft and the transmission shaft should be reserved for a blocker which was aimed to build in the centre of the motor coupling. When the motor shaft rotates with the coupling, there might be a possibility that the coupling might slides in and out from the motor shaft. With the design of locating a blocker in the centre of the coupling, the possibility of coupling slides could be prevented.

Therefore, a gap of 5mm was reserved for the coupling design requirement in order to prevent coupling sliding in and out from the motor shaft. The confirmed critical distance of the motor and transmission is 20mm, which indicate the thickness of the adapter plate is 20mm.

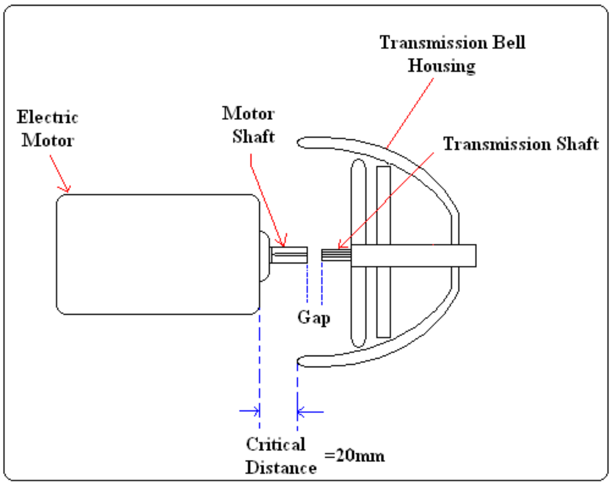


Figure 4.4: The gap distance and critical distance between motor and transmission.

4.4.1.1.2 Determination of the Shape of Adapter Plate and the Transmission Bolts Hole Location

The shape of the adapter plate had to be determined to ensure the adapter plate is large enough to cover all frontal area of the transmission bell housing and the frontal area of the electric motor. However, the method on how to determine the shape of the adapter plate was complicated as the shape pattern of the front face of the transmission is irregular as shown in Figure 4.5. A primitive method (stencil and mimeograph) had been chosen to record the front pattern or template of the transmission due to its easiness, high accuracy and rapidty.

Firstly, a large cardboard and some watercolour were prepared. Secondly, the front face of the transmission was painted by watercolour to act as a stencil. When the front face of the transmission was fully painted, the large cardboard was attached firmly and calmly to front face of the transmission. While the watercolour on the front face of the transmission was still wet, the pattern or template of the front face of transmission could be mimeographed on the large cardboard in true scale. All of the bolts holes from the transmission bell housing would also be recorded on the large cardboard. The front face pattern was then scanned into the computer as shown in Figure 4.5.

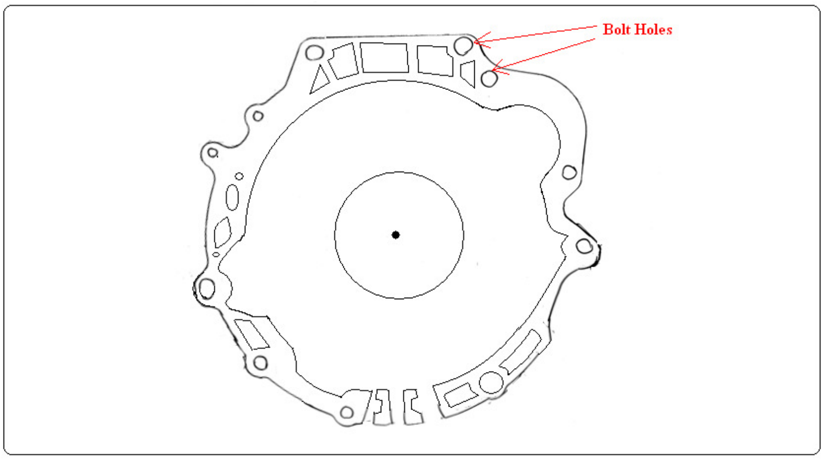


Figure 4.5: The exact front face pattern of the transmission which was mimeographed from the original transmission.

With the mimeograph pattern of the transmission bell housing front, a general pattern or shape of the adapter plate could be trimmed with a computer software named Malz++Kassner CAD 4.7 Workstation. In order to ensure the adapter plate could be completely cover the bell housing front, the whole pattern of the adapter plate (except the top side) was trimmed for 25mm or less overhang all around the transmission pattern mimeograph. The top side of the adapter plate was trimmed 40mm higher than the original transmission pattern in order to accomplish the attachment between the adapter plate and the mounting bar. Further discussion about the connection between adapter plate and mounting bar will be written in the following chapter. Nevertheless, the bolts holes location from the mimeograph were all been marked on the general pattern of the adapter plate by the Malz++Kassner CAD 4.7 Workstation.

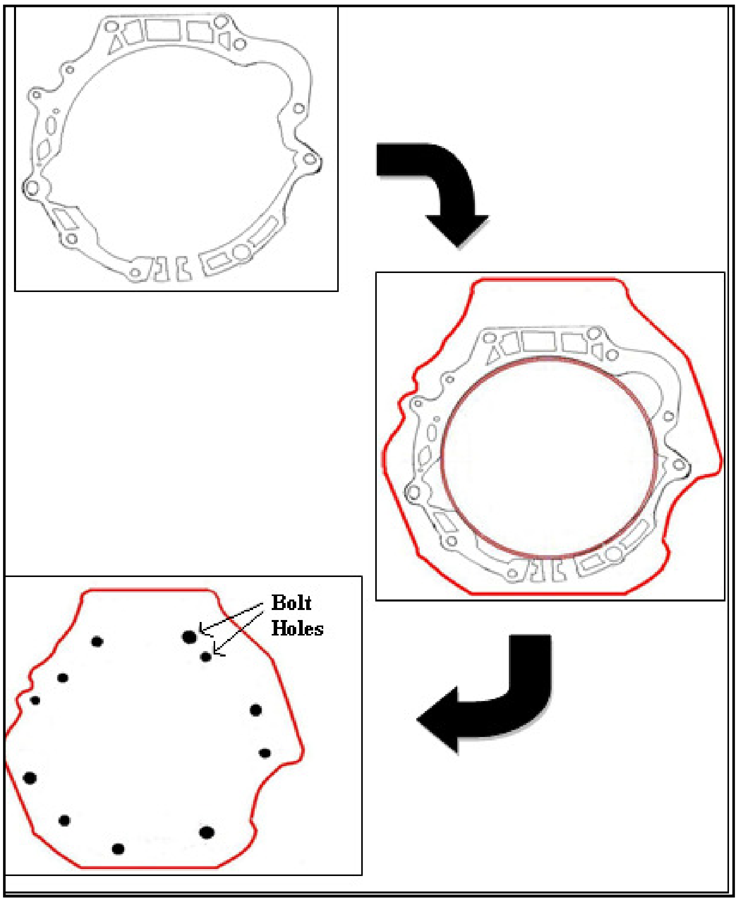


Figure 4.6: The flow diagram showing how was the template of adapter plate and the bolt hole location been determined based on the transmission pattern mimeograph.

4.4.1.1.3 Determination of the Adapter Plate Centre Point

A centre hole of the adapter plate had to be cut out in order to ensure the motor shaft could pass through the adapter plate to connect with the transmission shaft. Therefore, a centre point of the adapter plate had to be determined. Since the pattern of the front face of the transmission bell housing is irregular, the centre point of the transmission shaft might not be the centre area of the transmission template. A method had been chosen to determine the centre point of the adapter plate. Firstly, a distance between any two bolts hole of the transmission bell housing and the distance of these bolt holes with the centre of the transmission shaft were measured. These dimensions were taken later to determine the exact centre point of the adapter plate as shown in Figure 4.7. These steps were repeated again with different bolt holes in order to obtain higher accuracy.

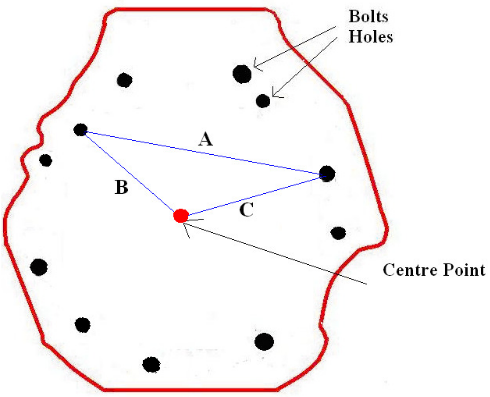


Figure 4.7: With the dimension A, B and C, the location of the centre point could be determined.

After the centre point of the adapter plate had been determined, the bolt holes pattern of the electric motor could be transfer easily to the adapter plate by using the adapter plate centre point as a reference. Nevertheless, a centre hole on the adapter plate is needed to be cut for motor shaft to past through. The diameter of the centre hole could be in any size within the bolt holes pattern, as long as the motor shaft with coupling could past through it. A diameter of 150mm had been chosen for the centre hole in this project, as the adapter plate could have minimum weight without affectedness on the bolt holes pattern.

4.4.1.1.4 Conceptual Design of Adapter Plate

In this phase, all of the rough idea of the design was been recorded and developed. Feasibility study of the conceptual design was discussed with other mechanical students, technicians and supervisor in order to ensure the advantages and disadvantages of each design.

4.4.1.1.5 Modelling of Adapter Plate

When the feasibility of the conceptual designs was feasible, a greater refinement and better dimensions of these designs would be developed. A better dimensions determination and quality 3D drawing of these designs would be aided by some computer softwares such as Malz++Kassner CAD 4.7 Workstation and Solidwork.

4.4.1.1.6 Material Selection and Fabrication of Adapter Plate

The finalized adapter plate design drawing was submitted to the Electrical Engineering Workshop for fabrication. A discussion and analysis had done with technician Ken in order to determine the available material and machines used to fabricate the finalized design. King Rich vertical milling machine with the aid of rotary table were used to fabricate adapter plate.

4.4.1.2 Result and Discussion for Adapter Plate

4.4.1.2.1 Initial Design of Adapter Plate

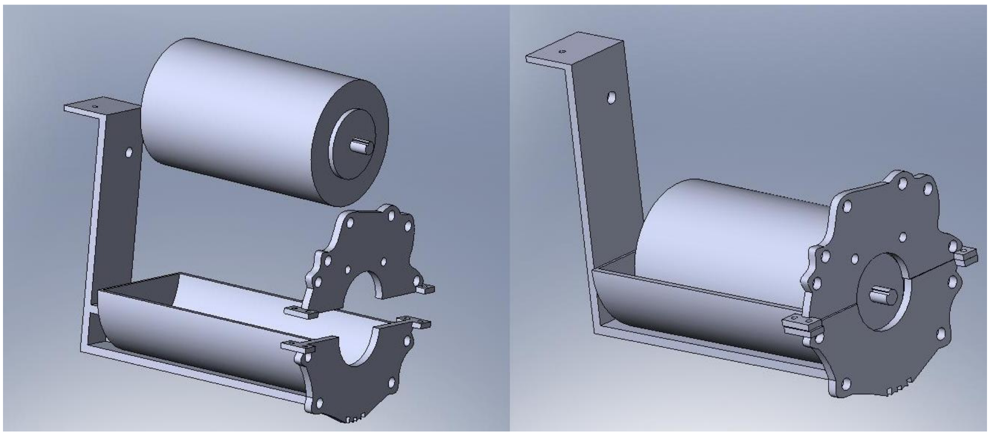


Figure 4.8: Electric motor assemble with initial design of adapter plate

Figure 4.8 shows the initial design for the adapter plate. The initial design of the adapter plate was split into two pieces and both half pieces of the adapter plate could be bolted with the ear on the side of the adapter plate. The bottom piece of the adapter plate was welded with a half barrel shape container to hold the electric motor and the half barrel shape container was supported by a metal frame to be mounted on the engine mount rubber. When the electric motor was held by the half barrel container, the top piece of the adapter plate was bolted on the electric motor and the bottom piece of the adapter plate.

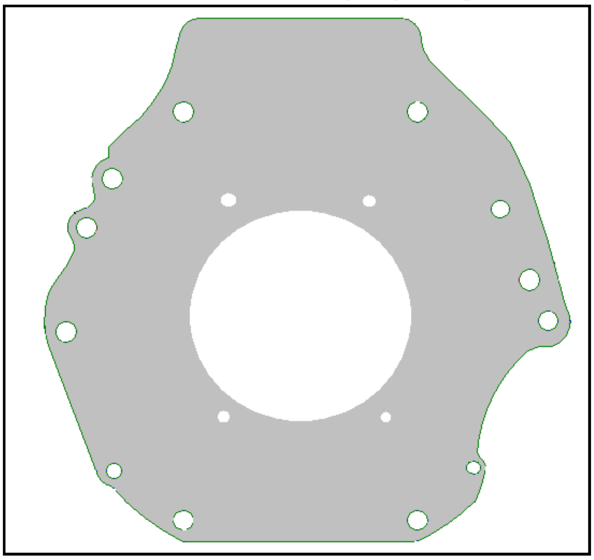
Instead of only supporting the frontal part of the electric motor, this initial design was built to support the whole body of the motor. As a result, the rear support mounts of the motor were not needed.

However, this initial design had been rejected due to the possibility that the water might be stored on the half barrel container during rainy day. The catchment of water on the barrel container would be resulted on short circuit of the electric motor. In addition, the fabrication with this design was complex as there were many little parts which need to be jointed in this design. Moreover, the material cost of this design might be very high due to this design required large amount of material to be built, which will also increase the weight of the mounts. Due to the safety reason and high fabrication cost, this design had been rejected.

Initial Design	
Advantages	Disadvantages
• High strength • Support whole part of Motor	• Safety problem – could stored water • High fabrication cost • Overall weight is heavy

Table 4.1: The advantages and disadvantages of the initial design.

4.4.1.2.2 Final Design of Adapter Plate



Final Dimension of the Adapter Plate	
Thickness	20mm
Maximum Width	360mm
Maximum Height	390mm
Centre Hole Diameter	150mm
Transmission Bolt Holes	Four M12 Bolts and 8 M10 Bolts
Motor Bolt Holes	Four M8 Screw

Table 4.2

The final design of the adapter plate is much smaller, lighter and simpler than the earlier idea. This simple design was only require a piece of square aluminium alloy plate to be fabricated. The design is simple but well enough to hold the motor with the transmission tightly. The design is lighter if compared with initial design and less fabrication cost and techniques to be constructed.

A total of four M12 Bolts and eight M10 Bolts and Nuts were used to secure the adapter plate with the transmission bell housing. These bolts were original used to secure the internal combustion engine with the transmission bell. The electric motor used in this project is only half the weight of the original engine and an electric motor is generally less vibration than an internal combustion engine. Therefore, the original bolts which used to secure the engine and transmission were confirmed strong enough to hold the adapter plate tightly with the transmission bell.

The front face of the electric motor was originally equipped with four 8mm screw holes which were designed to be held by four M8 screw. As a result, four high tensile stainless steel (M8) socket head cap screws were used to secure the adapter plate with the electric motor.

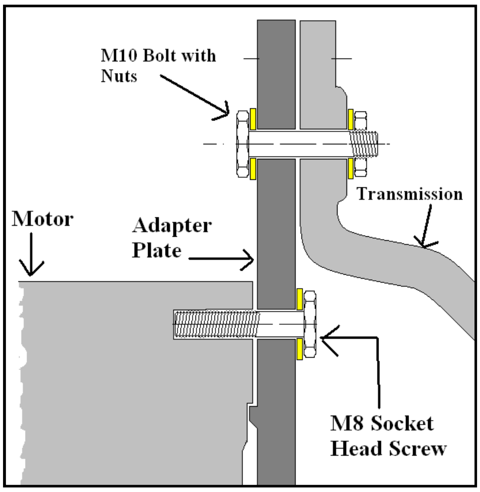


Figure 4.9: Figure showing how the bolts secure the adapter plate with the motor and transmission.

Although the motor shaft with coupling could past through a minimum diameter of 80mm for the centre hole, the diameter of the adapter plate centre hole was determined to 150mm. This decision was made to reduce extra weight of the adapter plate and thus increases the efficiency of the electric car.

4.4.1.2.3 Material Selection and Fabrication of Adapter Plate

The final design of the adapter plate was fabricated with a 400mm x 400mm x 20mm aluminium alloy 5083 square plate. These 5000 series aluminium alloy are alloyed with magnesium. By solution hardening, the level of strength for 5000 series aluminium alloy are comparable to steel but its weight to volume ratio (density) is much lower than steel. As a result, aluminium alloy 5083 had been chosen as then material to build adapter plate in stead of steel

The complexity shape of the adapter plate contains numbers of arcs with some tangent surfaces had increased the level of difficulties to be machining. In this project, King Rich vertical milling machine with the aid of rotary table had been chosen to machine the adapter plate. There were two options of milling machine which are suitable to machine the adapter plate:

- A manual milling machine with the aid of a rotary table attachment on a standard knee mill.
- A computer numerical control (CNC) milling machine

The CNC milling machine is a machine tool which driven by computer. It is more accurate and faster than a manual milling machine. However, a manual milling machine had been chosen in this project because:

- Only one piece of adapter plate is needed to be fabricated. In order to use a CNC milling machine, it requires some time spending and effort to insert computer data for controlling the CNC machine. If there are many same product required to be fabricated, CNC machine is faster. However, the fabrication time is much shorter for a manual milling machine to fabricate only one adapter plate.
- Limited facility in the electrical building workshop. All the fabrication works of the REV project were set to be done in the electrical building workshop. However, there is no CNC machine in the electrical workshop.

As a result, the adapter plate was constructed by the King Rich vertical milling machine with the aid of rotary table. All the bolt holes of the adapter plate were matched with the bolt holes of the transmission bell and the electric motor.

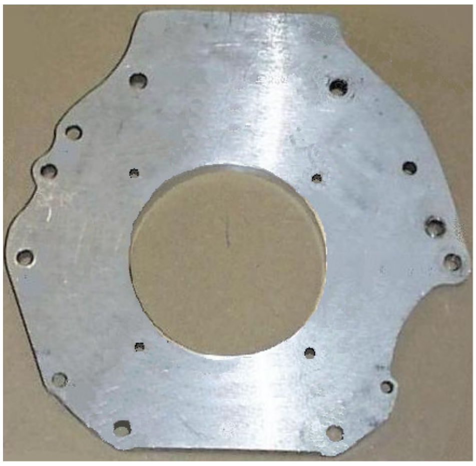


Figure 4.10: The adapter plate had been fabricated by the vertical milling machine

In summary, the tasks of the adapter plate are to support the front of the motor in place with the transmission bell and withstand the opposing torsion force created by motor shaft. These two tasks are satisfied with the manufacture of one component and thus the overall weight and complexity of the design of the adapter plate is kept to a minimum.

4.4.2 Design and Construction of Rear Support

The main function of the rear support of the electric motor is to support the rear side of the motor. The rear support of the motor was aimed to connect with the engine mount rubber which located on the side in the engine compartment. Therefore, the rear support of the motor can also be functioned as transmission medium of motor vibration to the engine mount rubber.

4.4.2.1 Methodology of Rear Support Design

In order to design the rear support for the electric motor, the vertical distance and horizontal distance between the electric motor and the location of engine mount rubber had to be determined. Figure 4.11 shows how was the electric motor secure with the transmission bell by the front adapter plate and how was the transmission mounted by the engine mount rubber.

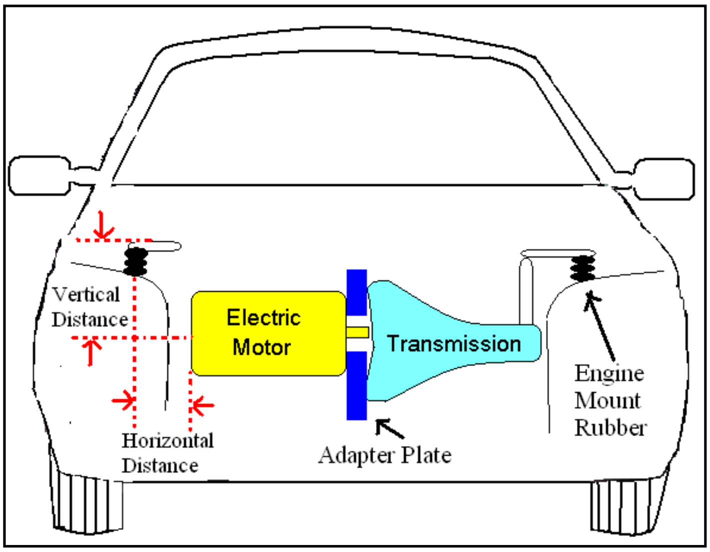


Figure 4.11

4.4.2.1.1 Measurement of Vertical Distance and Horizontal Distance

The vertical distance is the distance from the centre of the motor to the top of the engine mount rubber; while the horizontal distance is the distance from the end of the motor to the centre of the engine mount rubber. There were some difficulties on measuring both vertical distance and horizontal distance due to:

- The electric motor was not securing in the engine compartment. In the early stage of the design, the front adapter plate was still in fabrication stage. The motor could not support in the exact position without the support of the front adapter plate and the transmission bell.
- The limited space and the complexity structure of the engine compartment. Although the engine compartment was cleared from internal combustion engine and other components, the chassis structure in the engine compartment had increased the difficulties to measure the exact vertical distance.

In order to get the high accuracy measurement, it is necessary to wait for the completion of finalized front support plate. When the front adapter plate was finish constructed, the end of the transmission bell was taken to mount on the engine mount rubber with the motor. The frontal part of the electric motor was bolted to the adapter plate with the front face transmission bell and the end of the transmission bell was supported by engine mount rubber. Meanwhile, the end of the motor was hung by a mobile crank. A spirit level was used to confirm the electric motor was in the level position when hung by mobile crank.

When all of steps mentioned above were set up, the vertical distance and the horizontal distance could be measured with the aid of ninety degree ruler, cord and measuring tape. A few people were needed to measure the vertical distance and horizontal distance in this situation. The final measurement of the vertical and horizontal distance was listed in Table 4.3.

Vertical Distance	276mm
Horizontal Distance	132mm

Table 4.3

4.4.2.1.2 Conceptual Design, Modelling and Fabrication of Motor Rear Support

Firstly, all the rough idea about the design of rear support were recorded and sketched in this stage. Next, formal meeting and discussion were held with other mechanical students and project supervisor to analyse the feasibility of the design. The eligible conceptual designs were drawn with the aid of Solidworks 2007. A stress analysis would also be done with ANSYS Work Bench in order to ensure the strength of the design. Next, the 3D CAD drawings were again discussed with supervisor and workshop technician for further feasibility study and machining analysis. Machining analysis in this stage includes material selection, fabrication cost analysis and analysis on level of fabrication simplicity. There were only one design sample would be chosen as the final design to be fabricated.

4.4.2.2 Result and Discussion for Motor Rear Support

4.4.2.2.1 Initial Design

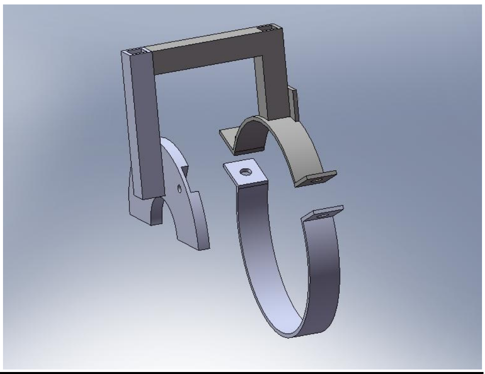


Figure 4.12: Initial Design

Figure 4.12 shows the CAD drawing of the initial design. This initial design of the rear support has a two ways supporting point to support the rear side of the motor. The front part of this initial design is used to support the motor around its middle by clamping down the motor. While the design of the end part of this initial design is very similar to the adapter plate- it bolts on the motor end face through the moulting holes. The little linkage bar which connected the end part and front part was designed to be bolted on a long mounting bar.

One of the advantages of this design is it has a very strong supporting ability to hold the rear side of the motor. As it has been mentioned on the paragraph above, this design has a two way supporting point to support both the end face of the motor and the middle of the motor. Beside, this design enables an easy fabrication. Several parts of this design could be machined separately and these parts could be connected with appropriate welding technique.

However, this design had been rejected due the excessively parts of the design. A total of three square bar, half adapter plate and a circular strip had to be welded together in order to form one piece of completed rear support mount. This is not qualified in the matter of economic benefits. Moreover, too much welding point would decrease the overall strength of the mounts. Therefore, a better design is needed.

4.4.2.2.2 *Improved Design of Rear Support Mount*

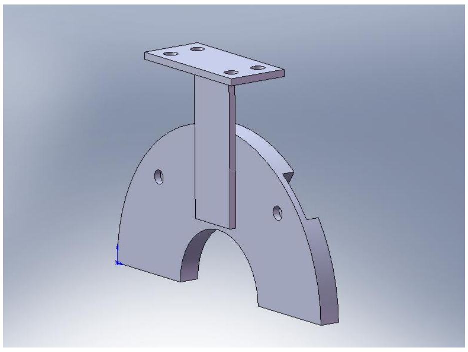
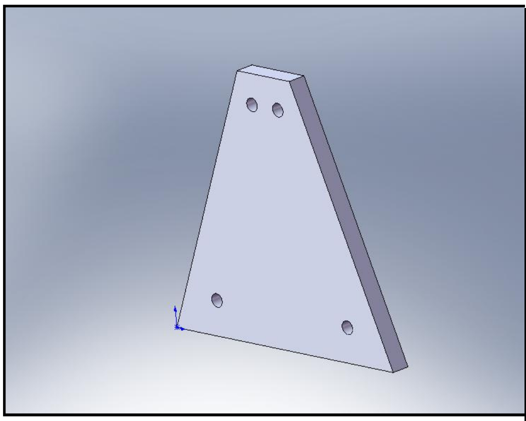


Figure 4.13 : Improved Design of Rear Support Mount

The subsequent design had some of the unnecessary material removed in order to reduce the parts to be welded and save weight. In this design, the middle support clamp was removed and only the rear plate been reserved. The rear plate is welded by a T-shape mount. This T-shape mount was intended to be bolted on the bottom of a mounting bar, which attempted to support the entire later half weight of the motor. However, with the aid of ANSYS stress analysis, the welding joint of the T-shape mount might not be able to sustain the weight of the motor very well. As a result, further improvement of the design is needed.

4.4.2.2.3 *Final Design of the Rear Support Mount*



Height	230mm
Top Side Width	70mm
Bottom Side Width	180mm
Thickness	10mm
Bolt Holes	4 x M8 Socket Head Cap Screw
Material	Aluminium Alloy 5083 Series

Table 4.4

Again, the final design of the rear support mount is as simple as the design of the front adapter plate. It is much smaller, lighter and simpler than the earlier idea. This simple design was only require a piece of square aluminium alloy plate to be fabricated.

The final design of the rear support mount had been successfully reduced all parts into one piece. This simplicity design of this rear support mount does not affect its performance in supporting the rear part of the motor.

The final design had two simple M8 holes, located at the top side of the plate, which was aimed to bolt on the cap of engine mount rubber. Also, the bottom side of the plate had another two M8 holes which is used to bolt on the motor end face through mounting holes. The trapezoid shape of the plate with a narrow top and wide bottom involved a 20% reduction in mass than the previous design. The thickness of the rear support plate was determined to 10mm instead of having the same thickness of the front adapter plate because there was less force needed to be supported on the rear side of the motor. The front adapter plate was required to hold the weight of both motor and transmission. Nevertheless, the front adapter plate required to withstand the opposing force which generated by the rotating motor shaft. As a result, only half the thickness of the front adapter plate was required for the rear support plate.

4.4.2.2.4 Material Selection and Fabrication for Rear Support Mount

The material selection process and fabrication process of the rear support mount are exactly the same with the front adapter plate. Same material of aluminium alloy 5083 series was used to build the rear support plate and a manual King Rich vertical milling machine with the aid of rotary table was used to fabricate the rear support mount. The reason of choosing aluminium alloy 5083 series as the raw material and using a manual vertical milling machine was described in Section 4.4.1.2.3.

Figure 4.14 : The motor and transmission are supported by the front adapter plate and the rear support plate.

In summary, the task of the rear support plate is to mount the rear side of the motor in place, ensure the motor in level and help to transfer the vibration to the mount rubbers. These three task are satisfied the manufacture of one component, so the overall weight and complexity of the rear support mount is kept to a minimum.

4.4.3 Design and Construction of Mounting Bar

A mounting bar was aimed to built and mounted on the top of the motor and the transmission bell housing. Although both the end side of the motor and transmission bell were supported by the engine mount rubber tightly, the mounting bar was purposed to strengthen the hold of motor and transmission. Both end side of the mounting bar were secured on the mount rubber and the middle of the mounting bar would be bolted on the top of the front adapter plate. Therefore, the mounting bar can also help to transfer the vibration of motor and transmission to the engine mount rubber. Nevertheless, the mounting bar was aimed to be built to provide more mounting base for other electrical parts such as controller box, throttle potentiometer and air conditioner motor.

4.4.3.1 Methodology of Mounting Bar Design

In order to design the mounting bar for the electric motor, the vertical and horizontal distance between two engine mount rubbers had to be measure. The measurement of the vertical and horizontal distance between two mount rubbers is straight forward as both engine mount rubbers were attached steadily in the engine compartment. Table XX is listed the vertical and horizontal distance between two mount rubbers.

Horizontal Distance	945mm
Vertical Distance	105mm

Table 4.5

4.4.3.1.1 Conceptual Design and Modelling of Mounting Bar Design

The conceptual design stage and modelling stage of the mounting bar were same as the front support and rear support mount design. Rough sketches had been drawn and were analysed with other mechanical students and supervisor. Once the rough design of the mounting bar was feasible, 3D modelling sketch would be done by Solidworks 2007.

4.4.3.1.2 Material Selection and Fabrication of Mounting Bar

Material analysis was done in this stage with the electrical workshop technician in order to choose the appropriate material to build the mounting bar. When the appropriate material had been chosen, the machining analysis which includes cost of fabrication analysis and simplicity of fabrication was completed with technician.

4.4.3.2 Result and Discussion of Mounting Bar Design

4.4.3.2.1 Final Design

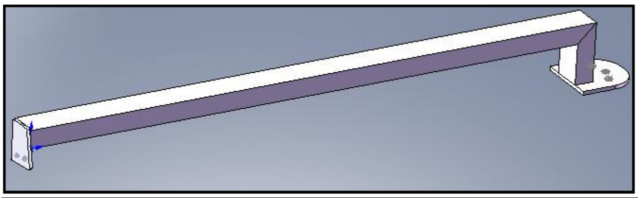


Figure 4.15

Bar Size	25 x 50 x 2mm
Length	937mm
Height	105mm
Material	Mild Steel
Bolt holes	Five M8 holes, two on the left and three on the right side. Another two M8 holes are designed to be bolted on the top of the front adapter plate.

Table 4.6

Base from the previous design experience on the front adapter plate and the rear support mount, the initial design of the mounting bar is simple and thus the initial design was well enough to be the final design. A rectangular mild steel bar of 25mm height x 50mm width with 2mm thickness was chosen to be the main body of the mounting bar. Since the main functions of the mounting bar are to provide a mounting base for other electrical parts and to transfer vibration from the motor to the mount rubber, the requirement strength of the bar is low. Therefore, mild steel bar was chosen as its price is relatively low compared to higher carbon steel.

The left hand side of the mounting bar was welded with a square 6mm thick plate to be bolted on the mount rubber cap; while the right hand side of the bar was welded with another 105mm long mild steel bar to be bolted on the top of the mount rubber cap. MIG welding was chosen to weld this joint due to its high versatility and lower welding time.

In summary, the tasks of the mounting bar are to act as a mounting base for other electrical parts, strengthen the motor mounts and increase the efficiency to transfer the vibration of the motor to the mount rubbers. These three tasks are satisfied with just a simple design of rectangular bar with legs to be bolted on the mount rubber caps.

4.4.4 Design and Construction of Coupling

Coupling design is one of the critical parts for motor mounts design. A coupling is used to connect the motor shaft to the transmission shaft which enables the motor to turn the transmission shaft and thus moves the vehicle. Since the dimension and shaft pattern of the motor shaft is different with the transmission shaft, two different patterns of couplings were needed to be design respectively:

- Motor Shaft Coupling
- Transmission Shaft Coupling

4.4.4.1 Methodology of Coupling Design

In order to design the appropriate coupling for both motor shaft and transmission shaft, the dimension and patterns of the motor shaft and transmission shaft had to be measured.

4.4.4.1.1 Motor Shaft Structure

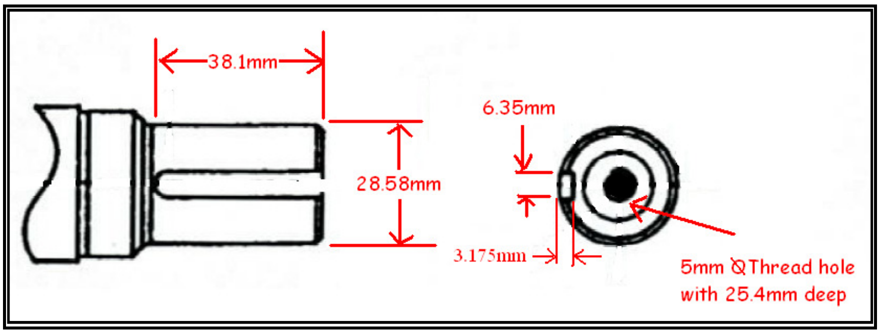


Figure 4.16: Dimension of the motor Shaft

The Advanced DC FB1-4001A motor shaft is formed with a circular tube which contain a contains a keyway (square notch in the central shaft opening) which requires a 6.35mm x 6.35mm square key to turn the coupling. Therefore the motor shaft coupling was required to be designed with a keyway as well.

4.4.4.1.2 Transmission Shaft Structure

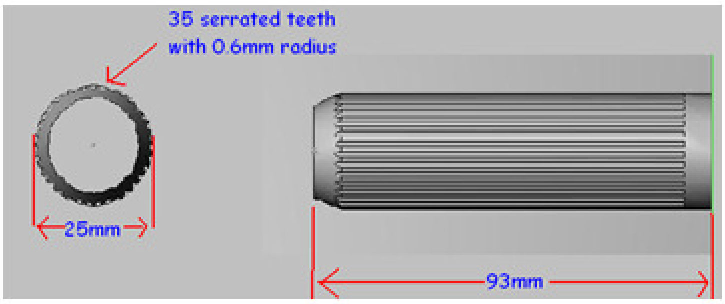


Figure 4.17: Dimension of the transmission shaft

The transmission shaft of the Hyundai Getz is a 25mm circular tube with 35 serrated teeth around the shaft. Therefore, the hub that was designed to hold the transmission shaft had to be in serrated pattern which could press fit into the transmission shaft.

4.4.4.1.3 Conceptual Design, Modelling and Fabrication of Coupling

In the conceptual design stage, the rough idea was developed and was noted down with rough sketch and notes. Feasibility studies of the conceptual design would be done and the feasible design would be drawn in 3D sketches by Solidworks 2007. On the following stage, all of the 3D sketches would be taken to discuss with workshop technician to determine the feasibility of fabrication. The designs which could not be fabricated by the workshop would be redesigned.

4.4.4.2 Result and Discussion of Coupling Design

4.4.4.2.1 Initial Design for Motor Coupling

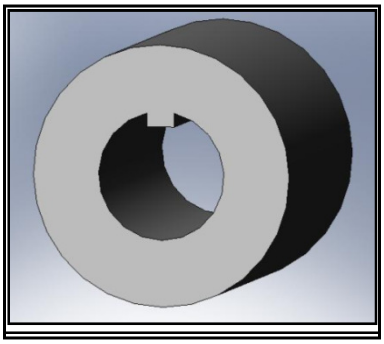


Figure 4.18

The initial design of the motor coupling was attempted to build with only one component. The hollow tube was designed with a rectangular salient on the inner surface to act as a key to turn the motor shaft keyway. However, this design required complicated manufacture because of its rectangular salient on its inner surface. According to the workshop technician Fodgen Ken, the university workshop was unable to fabricate this initial design coupling due to the limited appropriate machine in the workshop. Moreover, this initial design should supplement a feature to prevent coupling sliding way from the motor shaft. Therefore, another appropriate design was required.

4.4.4.2.2 Final Design of Motor Coupling

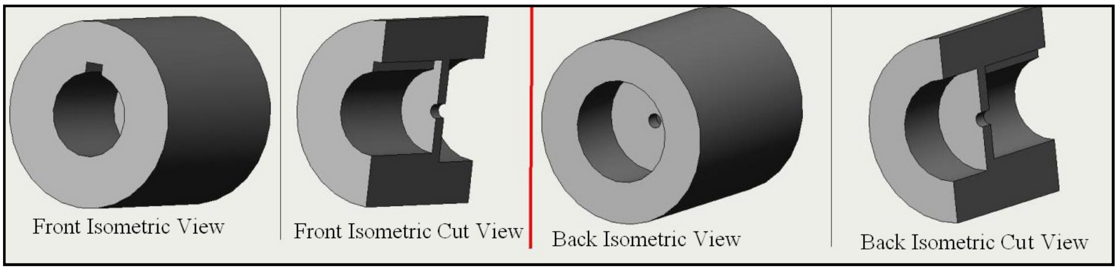


Figure 4.19

The final design of the motor coupling had a large improvement compared to the initial design. The front part of the tube was broached with a keyway. Since the university workshop was unable to fabricate a coupling with a rectangular salient, a replaceable idea had been chosen to redeem the defect. A 6.35mm x 6.35mm super hard steel square key with length of 35mm had been bought to operate with motor coupling to fit onto the motor shaft. This super hard steel key was specially designed for the uses of Advanced DC #FB1-4001A motor shaft and was available in most machine specialist shop.

At the other end of the motor coupling was a 35mm diameter hole. This circular hole was aimed to be connected with the transmission coupling Details of the connection between the motor coupling and transmission coupling will be discussed in latter section.

There is one special feature of this final design where there is a 5mm thick wall at the middle of the motor coupling. This wall was aimed to be the blocker for the motor shaft. A blocker is used to prevent the motor coupling sliding during the rotation of the motor. The middle 5mm diameter hole of the wall was designed to allow a M5 stainless steel socket head cap screw to secure the coupling with the centre of the motor shaft.

The tube which used to build the motor coupling is made of ultra high strength steel. The electric motor could reach a maximum torque of 155m/kg where ultra high strength steel was needed to sustain the torque of the motor. In the fabrication stage, the machines involve in the fabrication of the motor coupling include a lathe machine and a broaching machine. The lathe machine was chosen to drill all the holes in the tube while the broaching machine was used to cut a key way for the coupling.

4.4.4.2.3 Final Design of Transmission Coupling

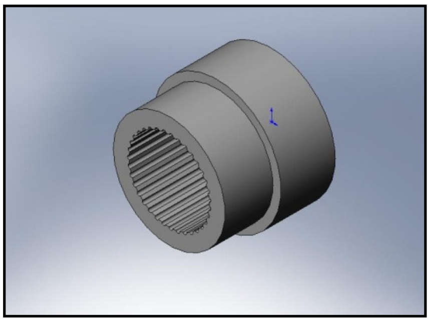


Figure 4.20

For strictly description, the final product of the transmission coupling is a modification rather than a design. A similar pattern of design with the final product which shown in Figure 4.20 had been done earlier and was intended to be fabricated. However, according to the workshop technician Fogden Ken, the only machine available in university which can manufacture the inner serrated pattern coupling is wire cutting machine. Unfortunately, the wire cutting machine is located in physics workshop and booking of using the machine is required.

In addition, a very high precision on the dimension of the transmission shaft and the pattern of the serrated teeth is required in order to machine a perfect fit coupling. The possibility of failure or unfitness of the fabricated transmission coupling is high. Therefore, Mr Fogden Ken had recommended modifying the original flywheel into the transmission coupling. The original flywheel was used to be a part to hold the transmission shaft and thus it has the similar serrated pattern which perfectly fit with the transmission shaft. By cutting the centre piece of the flywheel and having appropriate level of grind on the outer surface of the centre piece, the transmission coupling had done.

4.4.4.2.4 Connection of Motor Coupling and Transmission Coupling

The motor coupling and transmission coupling are required to connect together in order to function as a coupling to move the vehicle. There were two recommend welding techniques which is appropriate in the connection of motor coupling and transmission coupling:

- Vacuum Brazing

Vacuum brazing is a materials joining technique that offers significant advantages: extremely clean, superior, flux-free braze joints of high integrity and strength (Wikipedia, 2008). This joining method is preferable as it provides a higher strength of joint compared with the normal welding techniques. With vacuum brazing, all the contact area of between the motor coupling and transmission coupling will be welded, as shown in Figure 4.21. Therefore, both couplings were taken to physic workshop to be vacuum brazed. Unfortunately, the vacuum brazing technique had failed to connect the connection of those couplings. After an evaluation of the failure with Mr Fogden Ken, the connection failure of vacuum brazing might be caused by the different material of motor coupling and transmission coupling. The motor coupling is made of ultra strength steel but the transmission coupling might be made of some kind of alloy. The different melting temperature of two different materials might results a connection failure with vacuum brazing technique.

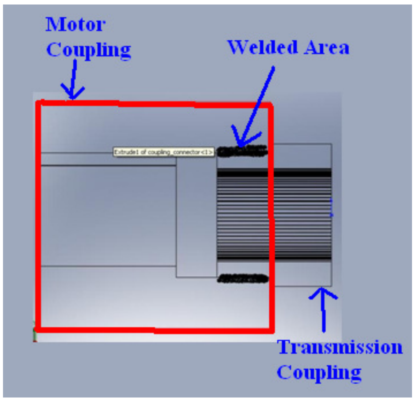


Figure 4.21 : Welded Area of Vacuum Brazing

- MIG welding

MIG welding is a less preferable technique due to its lower strength of joint compared to vacuum brazing. MIG welding technique would only weld on the contact edge of the connection between motor coupling and transmission coupling, which is shown in Figure 4.22. Although the MIG welding technique has a lower strength of joint, the welding joint is capable to sustain the maximum torque of the motor, which had been proven by the stress analysis which done by ANSYS Workbench. As a result, MIG welding technique had been chosen to connect both couplings together.

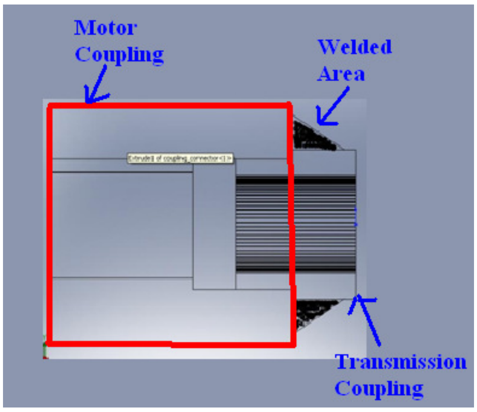


Figure 4.22: Welded Area of MIG Welding

In summary, the main task of the coupling is to connect the motor shaft and transmission shaft together, which enables the motor engage with the transmission and thus move the vehicle. This task had been satisfied with the connection between the motor coupling and transmission coupling.

4.5 Assembly of Motor Mounts

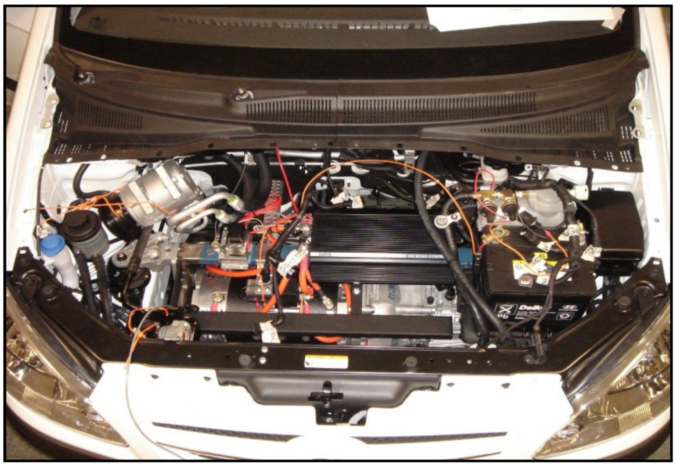


Figure 4.23: Later Stage of the engine compartment

The final assembly of the motor mounts was simple because all the dimensions of each separated complication part were taken care before constructed in order to be assembled perfectly. The mounting bar that was discussed in early section is bolted on the top of the motor and transmission to provide a mounting base for other electrical parts. Figure 4.23 shows the electrical parts such as controller, power steering motor and air conditioning motor were mounted on the mounting bar.

The overall appearance in the engine compartment of the electric car can be considered as a little bit messy due to limited space of the engine compartment. In this project, in order to upgrade the performance of the car and increase comfort to the passengers and driver, there were a lot of new parts and systems installed in the engine compartment. This parts and systems include vacuum brake system, 12V rail system for auxiliary components, digital instrumentation and sensor connection and computer control system that utilizing the Eyebot Mk6 to display car information and statistics to user. Most of these parts were required to squeeze in the small engine compartment which result an ordinary appearance in the engine compartment. However, since there is a need for versatility, the ordinary appearance is acceptable.

5. Performance Evaluation

The main tasks of the motor mounts design was to provide a support to attach the electric motor with the transmission in the engine compartment, transfer all the motor vibration to the engine mount rubbers and provide a mounting base for other electrical parts. In order to ensure these tasks were fully satisfied by the motor mounts design, some tests had been done.

The first test was done when the electric car was 90% constructed. Although the electric car was not fully completed, most of the important parts and system which are required to run the vehicle had been installed. Parts and components which had not been installed at that stage include dashboard, air conditioner systems and other parts which will not affect the performance of the car. The main objective of this first test is to ensure the motor were attached securely with the transmission.

Firstly, the motor was first run in different speed in the condition when the front wheel of the car was lifted up by jack. This test was done to ensure all the motor mounts parts and couplings are tough enough to run in low load condition. As what had been expected, the front wheels of the car rotate smoothly in all speed and in different gear shifts conditions, include the reverse gear mode. Besides, an observation of the vibration from the motor and transmission had been done throughout the test. By observation, the electric motor and transmission seemed to operate without any vibration. However, a second road test had to be done to observe the vibration condition of the motor running on road and to ensure the motor mounts and couplings are tough enough to sustain the rotation of the motor.

The second test was a practical road test which was done within the university area. Since the car had not been registered as a licensed road vehicle, the practical road test could only be done in a moderate speed driving within the university area. The test was started with only a driver driving along particular route within university area. A passenger will be added each time when the car was finish tested, until a total of four passengers and a driver were sat in the electric car. In the stage where the electric car was full of passenger, the driving condition of the car was still smoothly. According to all the passengers and drivers of the electric car, the car was powerful but still very quite. The only problem of the electric car is too quite until the pedestrians did not notice a car was coming towards them, which leads to a safety problem.

Since the electric car had not been licensed as a qualified road vehicle, the car could not be tested on public highway with freeway speed. However, more different tests were purposed to be done when the electric car had registered as a licensed road vehicle.

6. Conclusion

Overall the design and construction of the motor mounts was a success. Some simple tests had proved that the design was satisfied to engage the electric motor with the transmission and isolate the vehicle structure from motor vibration. However, there is still much room for improvement and adjustment of the motor mounts design and construction. The completed electric car is planned to register as a licensed road vehicle and it is aimed to launch at the end of 2008. Following the electric Getz project, the REV team has planned to build a performance electric car by converting a Lotus Elise into a performance electric car. All of the experience gained from Getz project can be used as a valuable experience and guide for building the performance electric car later.

7. Recommendations of Future Project

The successful completion of this project had provided a reliable and steady foundation for the development of UWA Renewable Energy Vehicle. Although the Hyundai Getz Project had achieved a huge success, there is much room for improvement of the motor mounts design for the performance electric car project.

Firstly, the connection between the motor coupling and the transmission coupling could be strengthened by adding keys or screws for further securement.

Secondly, a longer size of transmission coupling should be designed to lock the transmission shaft. The more contact area of transmission coupling lock to the transmission shaft, the less abrasion of the serrated teeth of transmission shaft and thus increase the coupling and shaft life.

Finally, a professional vibration analysis of the motor and transmission should be performed to understand how well the motor mounts transfer the vibration to the mount rubber and how efficient the vibration been interfered.

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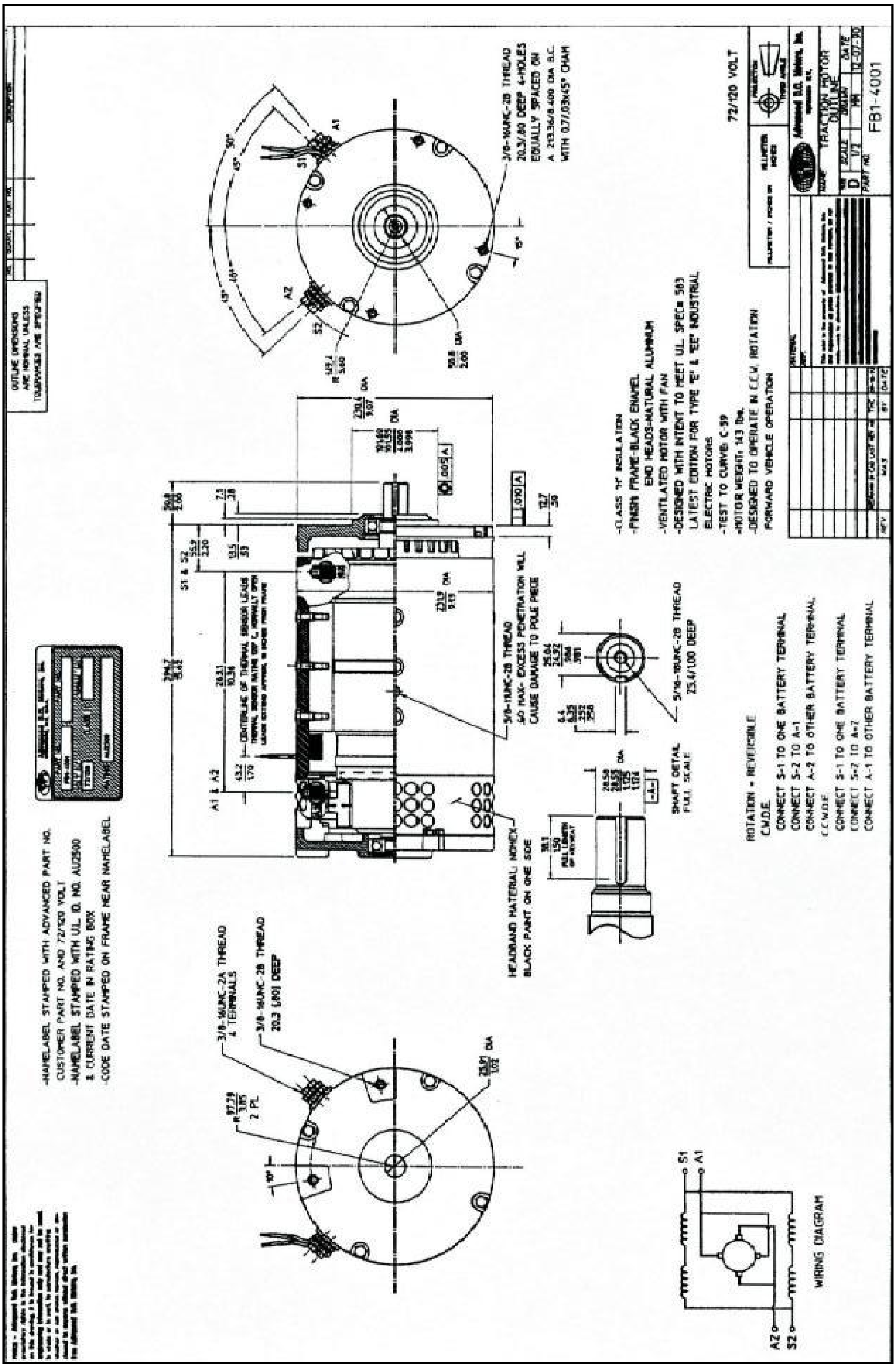
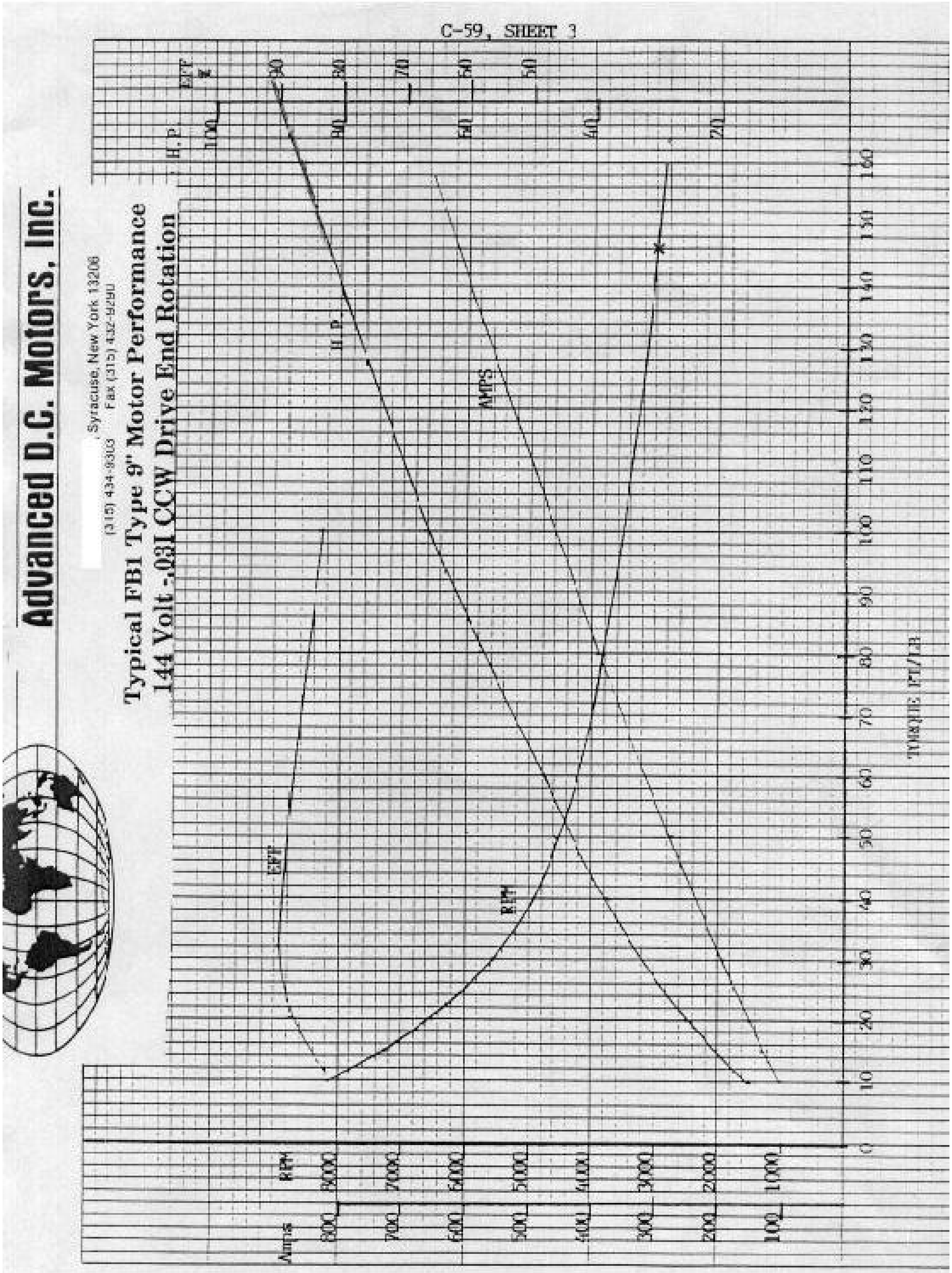
9. Appendix

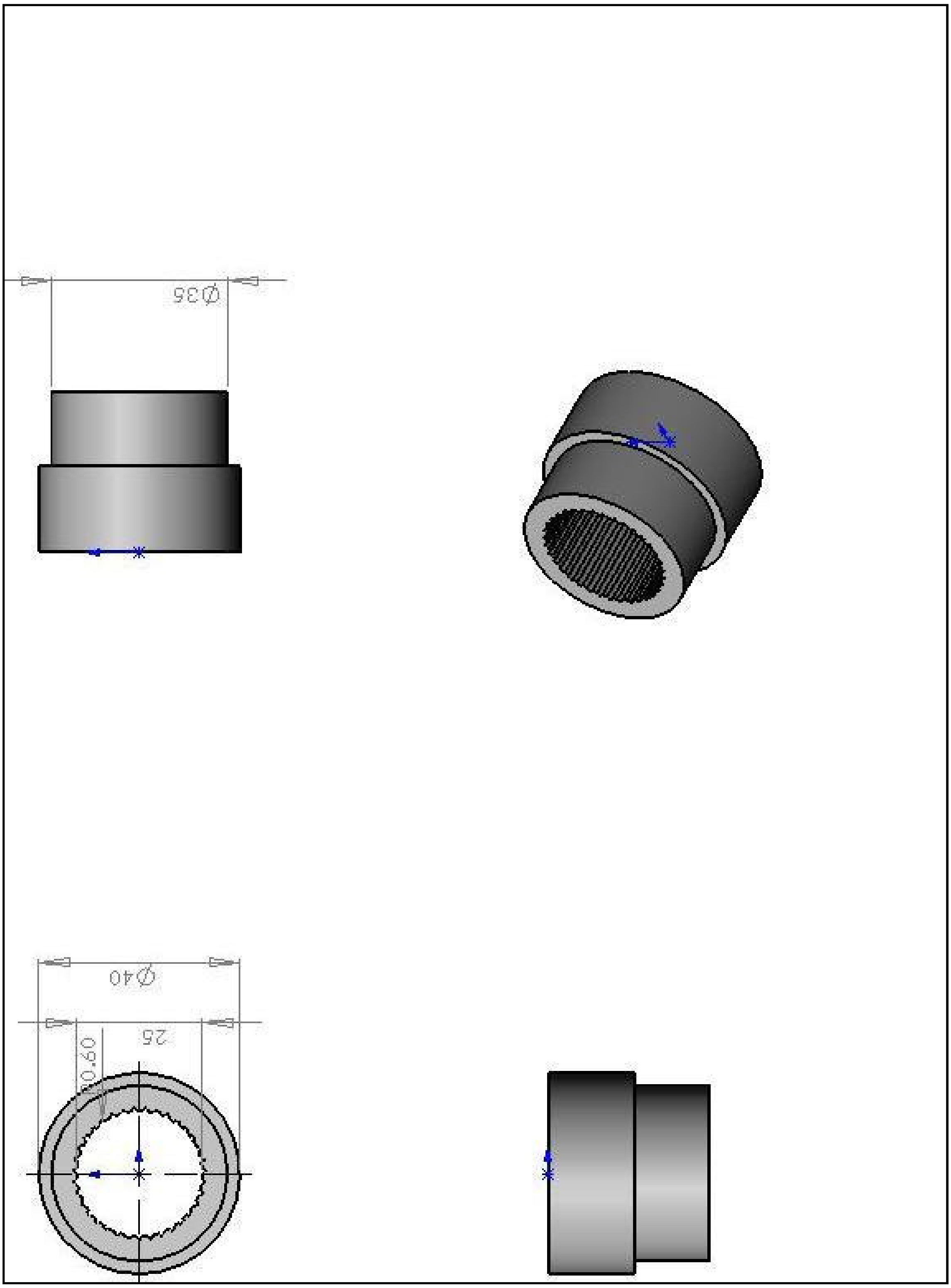
9.1 Appendix A: Dimension of Advanced DC #FB1-4001, 9.1", single shaft



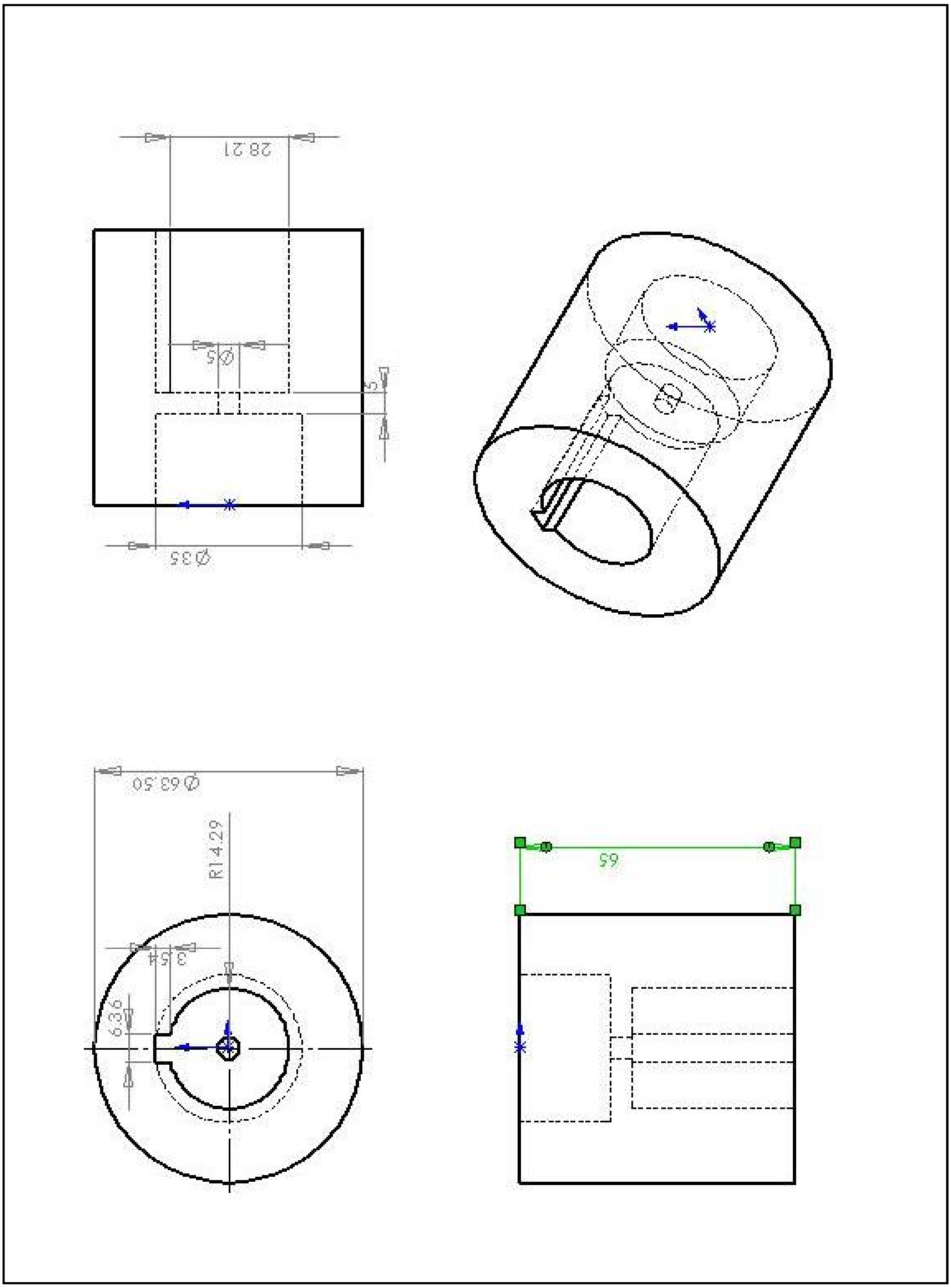
9.2 Appendix B : Torque Curve of Advanced DC #FB1-4001, 9.1", single shaft



9.3 Appendix C: Dimension of Transmission Coupling



9.4 Appendix D: Dimension of Motor Coupling



9.5 Appendix E: Material Properties of Aluminium Alloy 5083 Series

Physical Properties	Metric	Comments
Density	2.66 g/cc	AA; Typical

Mechanical Properties	Metric	Comments
Hardness, Brinell	81.0	500 kg load with 10 mm ball. Calculated value.
Hardness, Knoop	104	Converted from Brinell Hardness Value
Hardness, Rockwell B	50.0	Converted from Brinell Hardness Value
Hardness, Vickers	91.0	Converted from Brinell Hardness Value
Tensile Strength, Ultimate	300 MPa	
Tensile Strength, Yield	190 MPa	
Elongation at Break	16.0 %	In 5 cm; Sample 1.6 mm thick
Modulus of Elasticity	70.3 GPa	In Tension
Compressive Modulus	71.7 GPa	
Poissons Ratio	0.330	Estimated from trends in similar Al alloys.
Shear Modulus	26.4 GPa	
Shear Strength	180 MPa	Calculated value.

Electrical Properties	Metric	Comments
Electrical Resistivity	0.00000590 ohm-cm	

Thermal Properties	Metric	Comments
CTE, linear	23.8 µm/m-° C @Temperature 20.0 - 100 ° C	AA; Typical; average over range
	26.0 µm/m-° C @Temperature 20.0 - 300 ° C	average
Specific Heat Capacity	0.900 J/g-° C	
Thermal Conductivity	117 W/m-K	
Melting Point	590.6 - 638 ° C	AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater
Solidus	590.6 ° C	AA; Typical
Liquidus	638 ° C	AA; Typical

Processing Properties	Metric	Comments
Annealing Temperature	413 ° C	holding at temperature not required
Hot-Working Temperature	316 - 482 ° C	

Material Components Properties	Metric	Comments
Aluminum, Al	92.4 - 95.6 %	As remainder
Chromium, Cr	0.0500 - 0.250 %	
Copper, Cu	<= 0.100 %	
Iron, Fe	<= 0.400 %	
Magnesium, Mg	4.00 - 4.90 %	
Manganese, Mn	0.400 - 1.00 %	
Other, each	<= 0.0500 %	
Other, total	<= 0.150 %	
Silicon, Si	<= 0.400 %	
Titanium, Ti	<= 0.150 %	
Zinc, Zn	<= 0.250 %	