Drive System Design for Lotus Elise Electric Car

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Final Year Project Thesis

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Project Summary

The number of internal combustion vehicle used in Australia has increased tremendously and released enormous amount of pollutants and carbon dioxide into the atmosphere. This raises concern for many people about global warming and climate change. The Renewable Energy Vehicle Project in UWA aims to provide solutions by promoting an alternative type of fuel for transportation through the development of performance electric vehicle Lotus Elise.

The objective of this thesis is to determine a suitable transmission for the electric car so that it can achieve an excellent acceleration and top speed of 160 Km/h. The Lotus Elise can use the original PG1 gearbox, aftermarket gearbox or just a single differential known as direct drive. A performance modelling was carried out to select the best option to drive the car and to determine the best gear ratio combinations. The final decision is to retain the original PG1 gearbox. The result showed that while using the first and third gears combination from original gearbox produces the highest acceleration and the desired top speed of 160 Km/h, the second and fourth gear combination gives more practical driving.

The conversion of sport electric car requires a new design of motor mount to fix the electric motor securely in the engine compartment. The motor mount design involves the use of Computer Aided Design and Finite Element Analysis program to model the parts and perform stress analysis. All of the motor mounts have been designed, constructed, and assembled such that it complies with Australian Design Rule 2009.

Letter of Transmittal

Frans Ho
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26th October 2009

Professor David Smith
Dean
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Dear Professor Smith,

I am pleased to submit this thesis, entitled “Drive System Design for Lotus Elise Electric Car”, to the Faculty of Engineering, Computing and Mathematics, UWA, as part of the requirement for the degree of Bachelor of Engineering.

Yours Sincerely

Frans Ho
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I would like to appreciate and thank the following people for the support, guidance, and contributions during my final year project.

To my supervisor, Associate Professor Kamy Cheng, who has been very helpful and approachable throughout the final year project, I would not have finished the project successfully without him.

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Nomenclature

v_c	Speed of car (Km/h)
C_T	Tire circumference (m)
g_f	Final gear ratio
g_T	Transmission gear ratio
g_F	Differential final drive ratio
F_d	Drag force (N)
C_d	Drag coefficient of car
A	Frontal area of car (m^2)
ρ	Air density (kg/m^3)
F_r	Rolling resistance force (N)
C_r	Rolling resistance coefficient
m	Mass of car (Kg)
g	Acceleration of gravity (m/s^2)
P	Power (W)
F	Force (N)
v	Speed of car (m/s)
P	Power (W)
RPM	Revolution per minute
F_w	Force at the wheels (N)
τ	Torque (Nm)
g_f	Final gear ratio
R_T	Tire radius (m)
F_w	Force at the wheels (N)

1. Introduction

1.1 Project Background

The emission from motor vehicle exhaust is very harmful to human health and to the environment especially in large quantities. The chemical reaction of fuel inside an engine's combustion chamber produces kinetic energy as well as small amount of incomplete combustion products. The waste products that are released from the exhaust pipes are known to cause urban air pollution, climate change and global warming.

Motor vehicles that are powered by internal combustion engine release a lot of pollutants to the environment. These include carbon monoxide, nitrogen oxide, particulate matter, hydrocarbons and volatile organic compounds (Green Vehicle Guide, 2008). The air pollutant has an adverse effect to human health and the health of other living things. It causes breathing and heart problems as well as increasing the risk of cancer (Minnesota Pollution Control Agency, 2009).

Internal combustion vehicle emit greenhouse gas in the form of carbon dioxide. The increase of greenhouse gas concentration in the atmosphere raises the global average temperature of the earth, otherwise known as the greenhouse effect. The greenhouse effect is responsible for global warming and climate change that is happening around the world.

The Department of Climate Change in Australia found that the emission of carbon dioxide from transport sector is responsible for 14.6 percent of Australia's national inventory emission in 2007. It is also one of the strongest sources of emission growth in Australia. The total carbon dioxide emission from transport sector in 2007 has increased by 26.9 percent when compared in 1990. In addition, the road transport was accounted for 87 percent of the total emission from transport sector in 2007. Moreover, the biggest transport source from all the modes of road transportation is the passenger cars (Department of Climate Change 2009). It has contributed 43 million tons of carbon dioxide and equivalent to 8% of the total emission in Australia (Green Vehicle Guide, 2008). Hence, a solution is needed to reduce the carbon dioxide emission from motor vehicle mainly in the passenger car division.

The Renewable Energy Vehicle (REV) project in University of Western Australia is re-started in 2008 to help reduce carbon dioxide and air pollutants emission. The REV project aims to promote alternative type of fuel for road transportation through the development of sustainable and environmentally friendly vehicle powered by electric. The electric car will emit zero pollution and zero carbon dioxide, which will in turn, reduces the global warming and air pollution in the atmosphere. Furthermore, the project will significantly reduce the operating cost of future road transport because the cost of electricity to power electric cars is very little compared to the cost of gasoline to power internal combustion cars. This is especially true when the oil prices around the world are currently getting more expensive and unstable.

Recently, the REV teams have successfully completed their first project to build five-seated commuting electric vehicle Hyundai Getz. The latest project is to build an electric performance vehicle Lotus Elise to demonstrate the performance of electric vehicle technologies and advance the state of art of electric cars. The racing electric car will also increase the awareness of the general public about the state of the current technology basic principles behind REV system and sustainable living. In addition, it provides undergraduate with an opportunity to develop multi-disciplinary teamwork through the organization and activities conducted in REV.

1.2 Project Objectives

The main objective of this thesis is to design the drive system mechanic of Lotus Elise car. The main mechanical parts of the drive system that will be focused in the thesis are the transmission and the motor mounts. The other component designs such as reinforcing bar for the chassis, battery housings, suspension augmentation, and motor cooling are outside the scope of the project and will be dealt with other mechanical REV members. The scopes of the project are outlined below:

- Carry out a performance modeling of the electric car when using original PG1 gearbox or a single differential known as direct drive.
- Determine the best gearing method for the electric car to achieve fast acceleration and top speed of 160 Km/h.

- Determine the gear combinations that will maximize the performance and the range of electric car.
- Model the space of the Lotus Elise engine compartment without the internal combustion engine components, using Computer Aided Design program called SolidWorks 2008.
- Design motor mounts to connect the electric motor with gearbox and to fix electric motor securely inside the engine compartment.
- Choose the best material for the motor mount to ensure sufficient strength and minimize weight.
- Perform stress analysis on all the motor mount design using Finite Element Analysis program called ANSYS Workbench. It makes sure there are strong mechanical supports for the electric motor and improves the safety and reliability of Lotus Elise electric car.
- Assess the design, construction and final assembly of motor mounts so that it complies with Third Edition Australia Design Rules and National Code of Practice for Light Vehicle Construction and Modification.

2. Literature Review

2.1 Lotus Elise

The Lotus Elise is a well known sports car with excellent handling ability and exceptional performance (Group Lotus 2008). It is a two-seat, rear-wheel drive and mid engine car that is made of extruded aluminum and bonded chassis. Due to the aluminum construction of the chassis, the unladen weight of the car for internal combustion engine is only 755 kg (Lotus Service Notes 2000).

Figure 2.1 Lotus Elise 2002 Model used in REV project (KW Historics 2003)

The REV team aims to match the performance of converted electric Lotus Elise with the internal combustion engine Lotus Elise. Lots of efforts were made to minimize the extra added weight to preserve the excellent handling characteristics as well as acceleration.

2.2 Drive System Mechanics

The drive system mechanics of electric car is similar to internal combustion vehicle except the source of energy come from batteries instead of gasoline. The transfer of power inside the drive train of electric car is drawn in Figure 2.2.

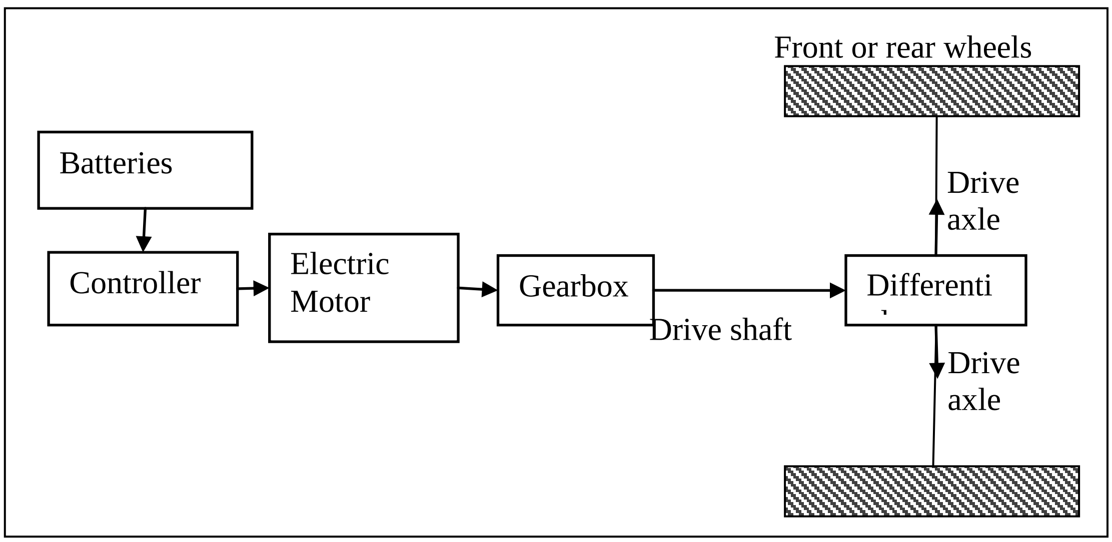


Figure 2.2 Schematic diagram of power transfer in electric car

The drive trains must be able to convert torque and speed of the engine to maintain the traction of the car (Leithman. S & Brant. B 2009). It is also required to change the directions of car, enabling forward and reverse motion. A brief detail of drive train components that are relevant to the thesis is written below.

Electric Motor- is a device to produce mechanical energy using electrical energy. The efficiency of electric motor can reach up to 90 to 95 percent and produce higher torque at lower rpm compared to internal combustion engine (PowerPhase 75 Traction System 2009). It also operates quieter than an internal combustion engine and produces no harmful emission (The REV Project 2009).

Gearbox- provides a speed-torque conversion to accommodate vehicle needs such as maximum torque for driving over hills and minimum rpm at cruising speed to increase fuel efficiency. It also gives mechanical reversing control and therefore eliminates the need to use a two-direction motor and controller (Leithman. S & Brant. B 2009).

Differential-transfers equal force to a pair of wheels, front or rear, and allowing each wheels to rotate at different speed when the car is cornering (HowStuffWorks 2009). This enables easy handling of the car and reduces tire damage. Most differentials also provide final gear reduction to increase the torque from the electric motor to the wheels. For some electric cars, the use of differential without a gearbox may be adequate to drive the car efficiently if it has a suitable final gear ratio.

2.3 Electric Conversion Kits

Figure 2.3 Examples of Electric Conversion Kits (Electric Vehicle Solutions 2009 & Electro Automotive 2009)

There are a few companies that offer conversion kits for people who are beginner as well as expert in the conversion of electric car. These include KTA Services Inc, Electro Automotive and Wilderness Electric Vehicles. The kits contain all the parts needed for electric conversion. There are many types of electric car conversion kits that are available in the market today. They are direct current kits, alternating current kits, universal kits, custom kits, basic kits, and deluxe kits (electric-cars-are-for-girls.com 2009). The DC kits are easier to install, simple, and is generally cheaper and readily available than AC kits (Electric Car Conversion Kit 2009). Most of the electric car conversions use the DC kits. The price of the kits is dependent on the material quality, shape complexity, manufacturing time and design time. Each company offers different design components depending on what vehicle it is specified for.

2.3.1 Front Support Motor Mounts

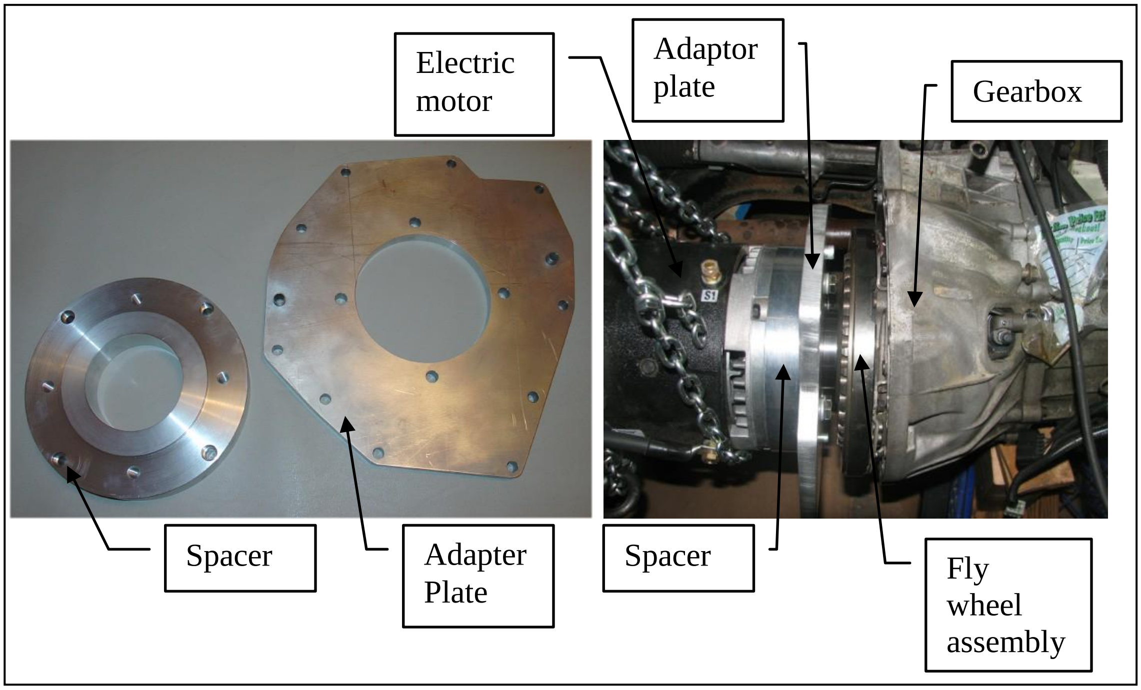


Figure 2.4 Example of front support motor mounts and a complete assembly with gearbox and electric motor (Simon Family 2008)

The purpose of having a front support motor mount is to attach and fix the front of electric motor with the gearbox's bell housing. The adapter plate prohibit electric motor from moving in all directions including rotational, sideways, forward and back. An adapter plate is commonly used by many electric conversion enthusiasts as a front support motor mounts. However, the design and manufacturing of adapter plate is difficult because the mount holes and shape of adapter plate must exactly match and align with the gearbox shape and holes pattern (Brown & Prange 1993). A spacer is often used in conjunction with adapter plate to enclose the clearance between the motor and the adapter plate. Both the adapter plate and spacer are usually made of aluminum to minimize weight.

2.3.2 Coupling

The function of a coupling is to connect and transmit power from the driving shaft to the driven shaft. In a converted electric car, the transmission shaft is coupled with the electric motor shaft through a coupling. Usually the transmission shaft is different to the motor shaft in length, size and spline profile. Hence need a coupling to accommodate the differences. A coupling also accommodates four types of misalignment between two shafts; angular, offset, combination and axial misalignment (Emerson Power Transmission, 2009).

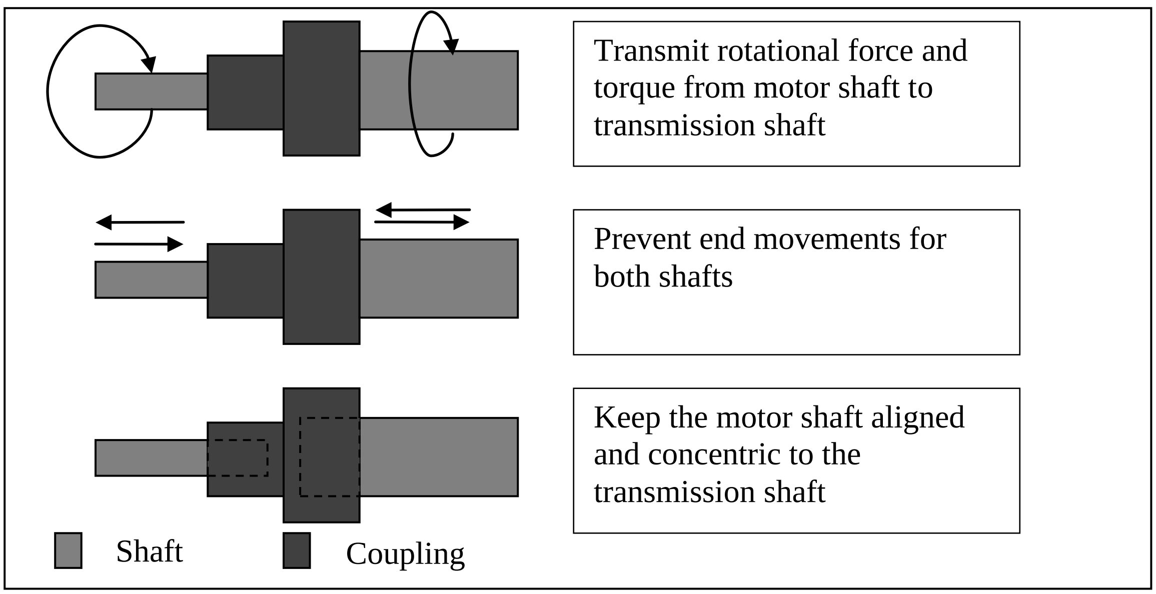


Figure 2.5 Schematic drawing of coupling and shaft assembly

For the conversion of electric car, the two shafts must be concentrically aligned at both ends using a coupling. A coupling must be made from high mechanical strength material and high fatigue rated metals because it has to endure powerful torque and rotational force (Tan 2008). Most people use mild or carbon steel for the coupling because it's relatively cheap and easy to fabricate.

2.3.2.1 Set Screw Coupler and Tapered Lock Bushing

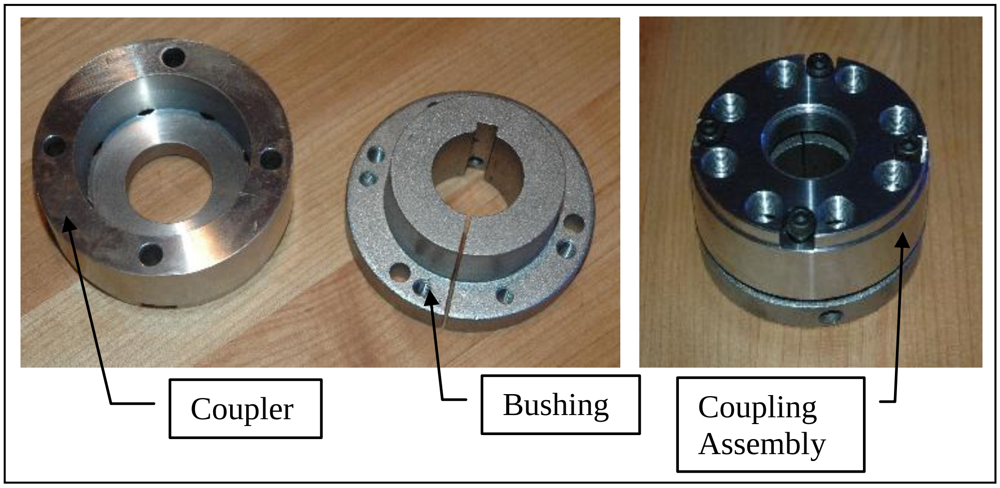


Figure 2.6 A coupling with 8 set screw coupler and tapered lock bushing (Brownout.com 2008)

This type of coupling consists of a set screw coupler and tapered lock bushing. The bushing has keyway cut to allow perfect fit with the motor shaft keyway profile. When the motor shaft is inserted inside the bushing, the screw from the coupler draws the bushing into the coupler (Brownout.com 2008). There will be a tight fit because the diameter of bushing is slightly bigger than the inner surface of the coupler. The other component, transmission shaft or flywheel assembly, can then locked with the coupler by using the 8 screws. The final assembly provides a strong locking mechanism for both of the shafts and allows easy removal for maintenance.

2.3.3 Rear Support Motor Mount

The main function of rear support motor mount is to securely fix the electric motor in the engine compartment by supporting it from car chassis or mount rubber. It must support both the weight of electric motor and the reaction force produced from the generated torque. Furthermore, a good motor mount must isolate the car chassis from any vibration created from electric motor. A strong rear support motor mount is very critical for drive system of electric car and special attention on the stress analysis should be focused when designing it.

Middle style motor mount | Rear style motor mount

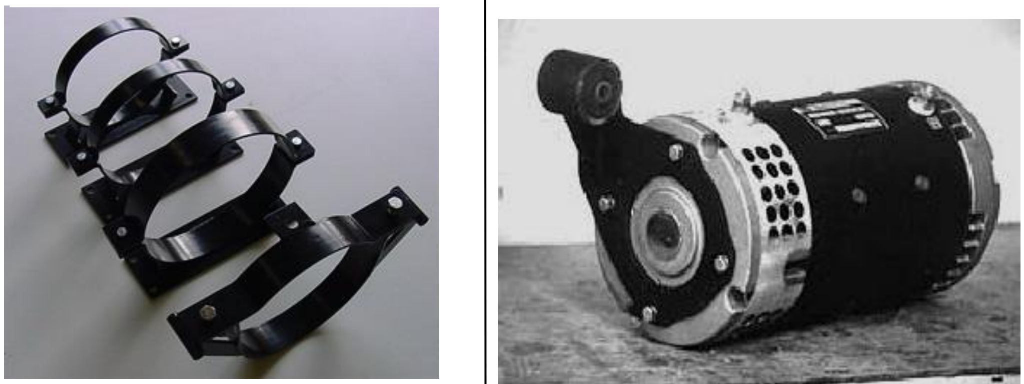


Figure 2.7 Example of two different types of rear support motor mounts (Canadian Electric Vehicles 2001 & Dyi Zen Tan 2008)

There are two kinds of rear support motor mount available in the market today. The first type supports the electric motor from the middle length called middle style motor mounts. It is more preferable for an in-line engine style vehicle. The middle style motor mount has a collar bracket approximately the same diameter as the electric motor. It is mounted on the middle of the electric motor and attached to the car chassis by bolts. The mount rubber is usually sandwiched between the chassis and motor mount to damp vibration. The second type is the rear style motor mount. It supports the loading of electric motor from the rear side. Usually it has a flat mounting plate to join with the rear side of electric motor and it is fixed by bolts. The mount rubber connects on the opposite end of motor mount and joins to the car chassis by bolts.

2.4 Australian Design Rule 2009

The Lotus Elise electric car needs to comply with the Third Edition Australian Design Rule in order to be qualified for Australian road use (Third Edition Australian Design Rule 2006). The most relevant requirement from ADR for this thesis is to ensure the noise level from motor vehicle is not excessive (ADR 28). The maximum sound level for passenger car is 84 dB and the sound level is tested according to the procedure given in the ADR. This can be achieved by stopping or dampening the vibration source inside engine compartment. Using mount rubbers on vibrating components can be a very effective solution. The ADR 42 also requires that general design and construction must ensure safe operation of the vehicle. Hence, for this thesis, all the motor mount designs and assemblies must be able to resist loading and torque reaction without failing. Also the electric motor must be properly fixed so that no significant movement can be observed when operating.

Another rule that has to be abided is the 2006 National Code of Practice for Light Vehicle Construction and Modification (NCOP). The technical and safety requirement, Clause 2.8, enforces that all components under loading must acquire adequate strength and high fatigue resistance. The strength of motor mount design can be assessed and checked by Finite Element Analysis program. However, fatigue resistance analysis can only be conducted once the Lotus Elise is fully completed and running because the amount of vibration is unknown at this stage.

3. The Transmission Selection for Lotus Elise Electric Car

3.1 Selection Criteria for Lotus Elise Transmission

These are the selection criteria for choosing the transmission of Lotus Elise electric car:

- It has to maximize the performance of electric car, including the acceleration and top speed.
- It maximizes the available space in engine compartment.
- It minimizes the weight of the car.
- It minimizes the cost and time spending on the conversion of electric car.

3.1.1 Maximizing the Performance

The ultimate goal of having a speed-torque conversion device in a car such as a gearbox is to maximize the acceleration and the top speed of a car. By having a gear reduction mechanism in a car, the car is able to make effective use of the power created by electric motor. Gear ratio is a number, usually expressed by decimals, representing how many turns of the input shaft cause one revolution of the output shaft. Having a gear reduction is very useful for going uphill or accelerating fast in a short period. On the other hand, overdrive is favorable when the car is going at the cruising speed in order to maximize the fuel efficiency. An ideal gearing alternative for Lotus Elise would have one or two gear speed gearbox. The 1st gear that has the highest gear ratio will be used to accelerate the car as fast as possible. The other gear that has the lowest gear ratio will be used to reach the top speed of 160 Km/h and provide good fuel efficiency when driving at cruising speed of 100 Km/h.

3.1.2 Maximizing the Available Space in Engine Compartment

The engine compartment of Lotus Elise is small. The removal of internal combustion engine and original PG1 gearbox helps to accommodate the other drive train components which are necessary for electric conversion. However, all the mechanical components must be strategically placed so that it can fit nicely inside the engine compartments. One of the approaches to achieve this is to select a gearing method that has a small dimension and a different arrangement. Having a small size gearbox can provide extra clearance and space between other components. The different arrangement of gearbox in engine compartment can also create more space for batteries.

3.1.3 Minimizing the Weight of the Car

The weight of the electric car has a big impact on the performance especially the acceleration. Newton's Second Law states that force (F) is equal to mass (m) times acceleration (a).

$$F = ma \tag{3.1}$$

This can be applied to the electric car whereby F is equal to the force required to move the car in Newton, M is the total mass of the car in kg, and a is the acceleration of the car in m/s^2. The force required to move the car, F, is reduced when the total mass of the car, m, is reduced. Reducing the total weight of the car can be achieved by using a light-weight gearbox.

The weight of the electric car also affects the range or the distance of travel of the car. The heavier the car the more power required to drive at the same speed. Since there is only a certain amount of power stored in a battery, having a lighter gearbox in the car will increase the range of the car.

3.1.4 Minimizing the Cost and Labor time

Purchasing a new gearbox or differential for Lotus Elise can be very expensive and time-consuming if it's not readily available in the market. The waiting time for shipping and handling can take weeks especially if it is shipped from overseas. Hence, in order to avoid unnecessary spending, a thorough research of the price and benefits associated with different gearing designs should be done. Another way to minimize cost and labor time is to have a matching shaft profile and holes patterns as the electric motor. This way the fabrication for motor mounts can be minimal and will ultimately reduce labor cost.

3.2 Constraints

The converted Lotus Elise is aimed to produce the same or better performance than the 2005 ICE Lotus Elise. The electric Lotus Elise should aim to achieve the following performance:

Cruising speed: 100 Km/h	
Top speed: 160 – 200 Km/h	
Acceleration (2005 ICE Lotus Elise):	0 to 60 Km/h: 2.1 seconds
	0 to 100 Km/h: 5.1seconds
	0 to 160 Km/h: 13 seconds

The gearing method for Lotus Elise electric car must:

- Be compatible with the independent suspension arrangement
- Fit into engine compartment without major modifications
- Have a torque capacity that exceeds the maximum torque of electric motor

3.3 Gearing Method Selection Process for Lotus Elise car

The gearing method for the Lotus Elise can be selected from four options:

1. The original PG1 gearbox from Lotus Elise
2. Aftermarket gearbox
3. Custom made gearbox
4. A single differential that has one fixed final gear ratio

Each of the option has its own advantages and disadvantages in terms of the performance, utilization of available space, weight distribution, and cost. Each of the alternatives of gearing method is described below in relation to the aim and constraints of the project.

3.3.1 Retaining the Original PG1 Gearbox

The easiest way to gear the electric motor would be to use the original gearbox from Lotus Elise. The parts are already in place and guaranteed to fit with all the other components of car's drive system. Retaining the original gearbox would also save a substantial amount of money because there is no need to purchase another gearing device. The money saved could be used to further improve the performance of the electric car. The original gearbox also has multiple gears that can offer the driver the ability to suit different driving conditions, for example racing or daily commuting. This solution was previously used for the Hyundai Getz so the technique to mount the electric motor can be reapplied to Lotus Elise electric car. This makes the fabrication and design of motor mounts much easier. Moreover, the gearbox castings are full aluminum constructions which make it very light-weight. The major disadvantage of using original gearbox is the space it takes up in the engine compartment. It would take half of the engine compartment space and leave small space for batteries and controllers.

However, the clutch in the gearbox must be upgraded or removed so that the gearbox will be compatible with electric motor. This is because the torque of electric motor is too high at low rpm and would wear out the clutch very fast. The cost of high performance clutch and flywheel is very expensive. Furthermore, the use of clutch in gearbox would require a customized housing to mount with the electric motor. Hence, further increases the cost of the project and delays the progress of the car.

3.3.2 Purchasing a New Gearbox

Purchasing an aftermarket gearbox or a custom-made gearbox would provide bigger space for the batteries while retaining the flexibility of multiple gears. The size of gearbox may be smaller and may be positioned differently in the engine compartment to maximize engine compartment space. Buying another gearbox also helps to increase the performance of electric car because the gear ratios can be chosen such that it optimizes the acceleration and top speed. However, the availability of a new gearbox that could sustain the powerful torque of electric motor is very low. Most of them are not designed for high torque output. Buying a new gearbox would also require a new differential and other important components such as a matching spline half-shaft. Hence, further increases the spending of the project. The price for a used 5-speed gearbox varies greatly depending on the quality. It is expensive and costs approximately $1000 to $2000 for a non-performance gearbox (eBay 2009). The weight of new gearbox may not be much different to the original gearbox because the Lotus gearbox casting is already light-weight.

3.3.3 Using a Single Differential

A differential has a single final drive ratio and it is permanent. It usually has a high torque capacity that can easily withstand the maximum torque of electric motor (240Nm). It is lighter than a gearbox because it doesn't have many gears inside. There is less mechanical losses in differential because it doesn't have many moving parts. However, a differential is usually bigger than a gearbox and has a different attachment configuration compared to original gearbox with the electric motor. The original gearbox attaches to electric motor horizontally where as the differential attaches to the electric motor vertically. Hence the electric motor is pushed far backward to the rear of the car and may come in contact with the rear bumper of the car. Mounting the electric motor will also be more difficult because it will be pushed too far backwards and limit the location of mounting. Furthermore, it is difficult to find a differential with the desired final drive ratio unless it is common to all cars. If the Lotus Elise electric car requires a final drive ratio that is not found in most common cars, then a custom-made differential is necessary. This can be a very expensive approach and takes a long time to find the right ring and pinion gears to make up the desired final gear ratio.

3.4 Modeling the Performance of Lotus Elise Electric Car

The car performance when using different gearing method must be modeled to help determine the best gearing method for Lotus Elise car. The information about tires and gearbox can be found in Appendix A **.**There are many assumptions and constraints that must be considered before modeling a performance curve of electric vehicle.

- Mechanical friction including brake pads contact and drive train loss is not taken into account
- Motor is performing at 95% efficiency
- The vehicle is on flat ground
- Vehicle is always moving at non-zero speed
- Gear change takes 2 seconds

Drag Coefficient: 0.36	Rolling Resistance Coefficient: 0.01
Frontal Area: 1.65 m^2	Mass of car (driver & luggage): 1000 Kg
Tire Circumference: 1.992 m	Air Density: 1.2 kg/m^3

In order to model the performance of the electric vehicle, there are a number of steps that has to be followed. Acceleration curve for each gear is generated at 10 Km/h increment. The sequence of calculations is shown in Figure 3.1.

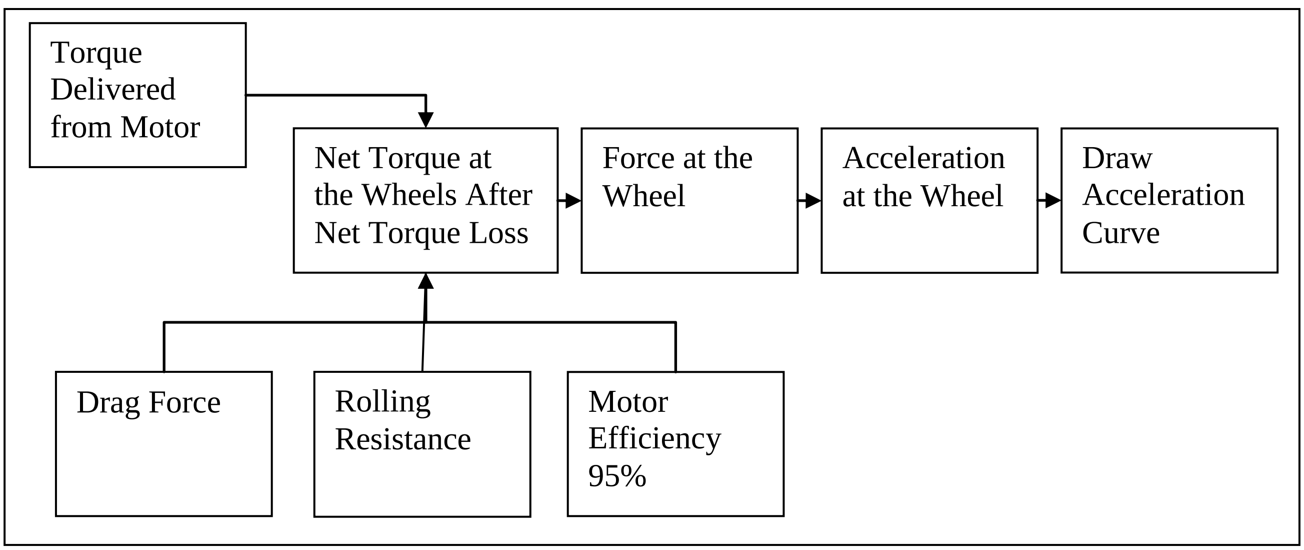


Figure 3.1 Computational method to model acceleration curve for electric vehicle

3.4.1 Computational Method for Performance Modeling

To find out the torque delivered from motor, the rpm of motor shaft when travelling at a particular speed must be known.

$$RPM = \frac{v_c * g_f}{C_T} * \frac{1000}{60} \frac{m}{min} \tag{3.2}$$

$$g_f = g_T + g_F \tag{3.3}$$

The torque output from motor can then be found from the motor torque curve graph given in the Appendix B. For the same speed of the car, the amount of power needed to overcome the aerodynamic drag force and rolling resistance of tires must be found. This is considered as a power loss because it reduces the available power from motor. It can be seen in the Appendix D. The equation to calculate the drag force and rolling resistance are as follow.

$$F_d = C_d * A * \rho * \frac{v^2}{2} \quad (3.4) \qquad F_r = C_r * m * g \quad (3.5)$$

The two forces are added up and converted into power using the equation below.

$$P = Fv \quad (3.6)$$

The power loss is converted again to become a torque loss.

$$\tau = \frac{P}{RPM} * \frac{60}{2\pi} \frac{min}{rad} \quad (3.7)$$

The torque output from motor is subtracted by the torque loss resulted from the drag force and rolling resistance. This is the net torque at the wheel after net torque loss. The net torque at the wheel is then converted into force at the wheel.

$$F_w = \frac{\tau * g_f}{R_T} \quad (3.8)$$

Lastly, the acceleration of the car can be calculated by using the following equation.

$$a = \frac{F_w}{m} \quad (3.9)$$

This calculation process is then repeated for various speeds in incremental of 10 Km/h. The acceleration curve can be drawn for any gear combinations. It can then be used to calculate the top speed and benchmark acceleration times of 0 to 60 Km/h and 0 to 100 Km/h.

Furthermore, in order to maximize the power of the electric motor, a number of possible gear combinations and gear ratios must be assessed. The gear combination that produces the best acceleration and desired top speed will be chosen to power the electric vehicle.

The various gear combinations are listed below.

Option	Gear Combinations
1	First and Third
2	Second and Fourth
3	Third
4	Differential: Gear Ratio of 5.5:1
5	Differential: Gear Ratio of 6:1
6	Differential: Gear Ratio of 6.5:1

Table 3.1 Possible gear combinations

3.5 Results and Discussion for Lotus Elise Transmission Selection

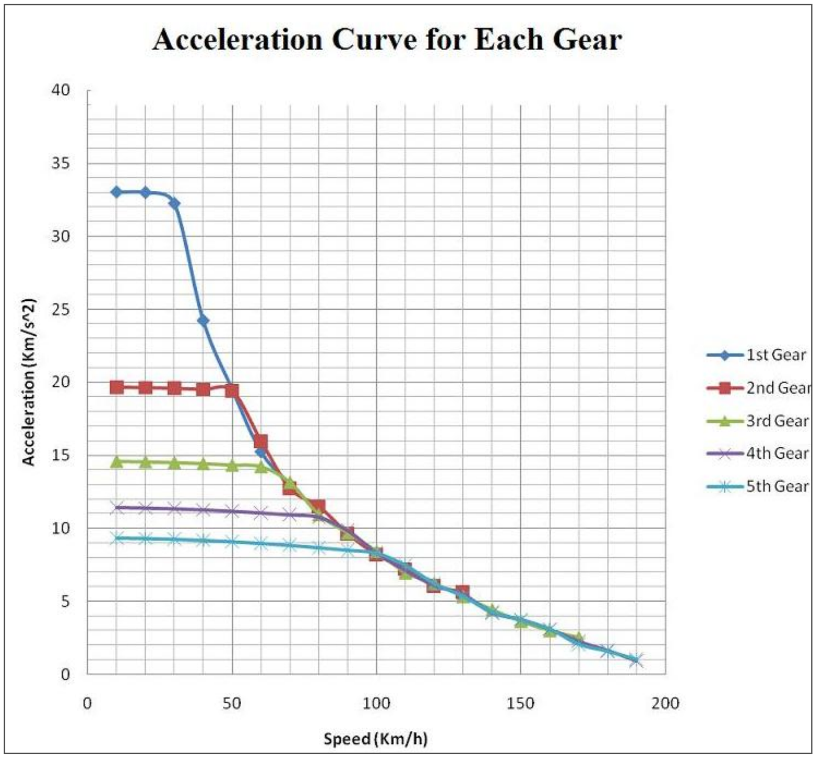


Figure 3.2 The acceleration versus speed graph for each gear of PG1 gearbox

The Figure 3.2 shows how much acceleration the electric motor can provide at different speed of the car. For example, when the speed of the car is 20Km/h, the maximum power of the electric motor at first gear can give an acceleration of up to 33 km/s^2. If the driver is using the second gear instead, the maximum acceleration that the electric motor can provide will be 20 Km/s^2. The car has reached the top speed when the acceleration is at zero.

As expected, the gear that will provide the highest acceleration is the first gear, followed by the second gear and so forth. The maximum acceleration that can be achieved by the PG1 gearbox is 33 Km/s^2. Furthermore, there is a big difference of acceleration when using 1^{st} gear compared to using 2^{nd} gear. It is also interesting to see that the acceleration curves are quite similar for all gears and follow the same downward trend. This indicates that multiple gears are not necessary for electric cars and it is best to use only two gears. The reason is that the torque generated from electric motor is sufficient to power the car until top speed by using only two gears. The purpose of having a 2-gear combination is that the first gear is for fast acceleration and the second gear is for reaching the desired top speed.

Referring to Figure 3.3, the 1^{st} and 3^{rd} gear combination provides the fastest acceleration with top speed of approximately 170 Km/h. The 2^{nd} and 4^{th} gear combination provides a slightly lower acceleration but with higher top speed of 200 Km/h. It is interesting to see how the car will perform if using only a single differential instead of a gearbox. A differential has one final drive ratio and it is not adjustable. In the result, it is represented by its final gear ratio.

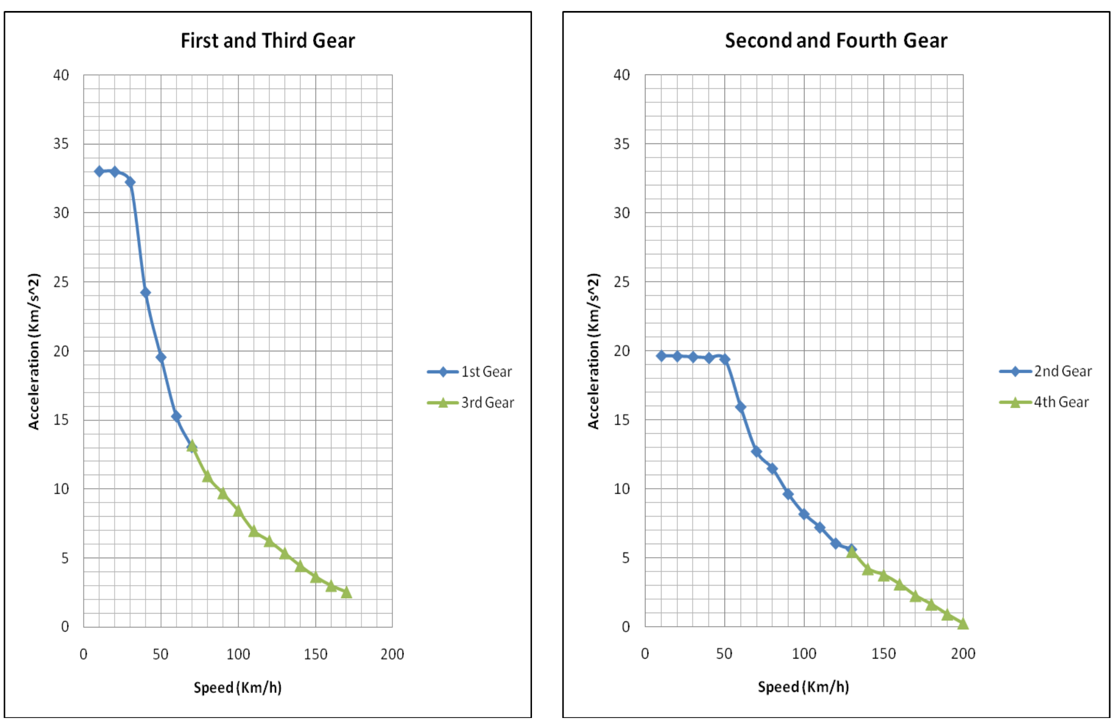


Figure 3.3 The acceleration curve when using two gear combinations

	Time (s)						
Performance	**ICE 2005 Lotus Elise**	**PG1 Gearbox**			**Differential**		
		1st and 3rd Gear	**2nd and 4th Gear**	**3rd Gear Only**	**5.5:1**	**6:1**	**6.5:1**
0 - 60 Km/h	2.1	2.2963	3.4882	4.1407	4.140719	3.784809	3.5048957
0 - 100 Km/h	5.1	7.9001	7.0817	8.2676	7.767697	7.124848	7.13713524
0-160 Km/h	13	19.9295	21.0790	20.297	19.79708	17.56408	18.198489
Top Speed (Km/h)	240	170	200	170	170	160	145
Shifting time (s)	0.5	2	2	2	N/A	N/A	N/A

Table 3.2 Performance analysis for all gear combinations

It can be seen from the Table 3.2 that the best performance can be achieved by using the original PG1 gearbox. A more detailed result can be seen in the Appendix E**.** The differential will give a performance that is worse than using PG1 gearbox. The gear combination that has the fastest acceleration with a top speed within the aim of the project is the 1st and 3rd gear combination. It will also produce the fastest time in 0-60 km/h time attack. However, the 2nd and 4th gear will be the fastest from 0 to 100 Km/h because it doesn't need to shift gear from second gear till after 130 Km/h. Unlike the 1st and 3rd gear combination there is a shift gear at 78 Km/h. Therefore, it is best to use the 2nd and 4th gear combination for daily use because it is more practical. The 2nd and 4th gear combination also has a higher top speed than 1st and 3rd gear combination, a top speed of 200 km/h.

Cruising speed = 100 Km/h	
	Motor RPM
1st and 3rd Gear	4602 (at 3rd Gear)
2nd and 4th Gear	3618 (at 4th Gear)

Table 3.3 Motor rpm at cruising speed

As shown in Table 3.3, the motor shaft is rotating slower when using the 2nd and 4th gear combination compared to using 1st and 3rd gear combination at cruising speed. Therefore, the motor will use less power when using 2nd and 4th gear combination and will give a longer range for the car.

Thus, the best solution to drive the Lotus Elise electric car is by retaining the original PG1 gearbox and using the 2nd and 4th gear combination to achieve maximum range and good overall performance. However, the electric car will be slightly slower in acceleration than the ICE Lotus Elise model. This is because the electric motor has a smaller power rating (75 kW) than the ICE model (88 kW). However, the difference of performance does not differ by much. For example, the electric car can accelerate from 0-100 Km/h in 7 seconds compared to 5.1 seconds for the ICE Lotus Elise car.

Furthermore, the maximum torque capacity of PG1 gearbox is rated the same as the motor's maximum torque (240 Nm). The gearbox may fail if the maximum torque of electric motor is applied for a long time. However, according to the motor torque curve, the likelihood of constantly using 240 Nm maximum torque is low because at cruising speed of 100 Km/h, the maximum torque output of motor is about 190 Nm. Thus it will be safe to retain the original PG1 gearbox.

4. Motor Mount Design Process for Lotus Elise Electric Car

4.1 Constraints

The constraints associated with the design of motor mounts are as follow:

- Design must fully comply with the Third Edition Australian Design Rule and National Code of Practice for Light Vehicle Construction and Modification.
- Design must be as simple as possible to achieve low fabrication cost and minimal weights
- Design must be reliable

The motor mount design must meet the following conditions in order to be considered for fabrication.

- The ability to support the proposed loadings without failure
- Strong and stable mounting to the car chassis with the addition of rubber mounts
- Suitable mounting location without disrupting other components

4.2 Computer Aided Design Program

The most important factor when designing the motor mounts is whether it will fit into an allocated space. The program used to model the space of Lotus Elise engine compartment and motor mounts is SolidWorks 2008. The SolidWorks is a 3D mechanical Computer Aided Design program that allows user to model their design virtually. This program is also able to produce a detailed final drawing so that it can be manufactured without difficulty.

4.3 Finite Element Analysis Program

When the design has finished, the motor mount will then undergo a stress analysis using Finite Element Analysis software called ANSYS Workbench. Firstly, the motor mount model from SolidWorks is directly imported to ANSYS Workbench for stress analysis. The material for the motor mount is then selected from the available material data sheet. Next, the motor mount model is given a meshing either automatically from meshing tool or by setting it manually. The loadings and boundary conditions are then added to the geometry model. Each motor mount has different constraints and loadings depending on the location and condition present. Lastly, the safety factor and equivalent stress analysis is performed.

Having an acceptable mesh density is very important. The meshing size of a model can affect the accuracy of the analysis result. Therefore it is important to carry out a mesh convergence to ensure the results of analysis are not affected by changing the size of the mesh. There are many ways to perform a convergence test. The formal method of establishing mesh convergence is to perform an initial analysis that has a particular size of meshing and compare the result with a more refiner meshing of the model. The meshing is said to be converged if one or more refined meshing has a similar analysis result to the initial analysis result. The mesh is converged if the difference is within 5%.

4.4 Flow Chart for Motor Mount Design

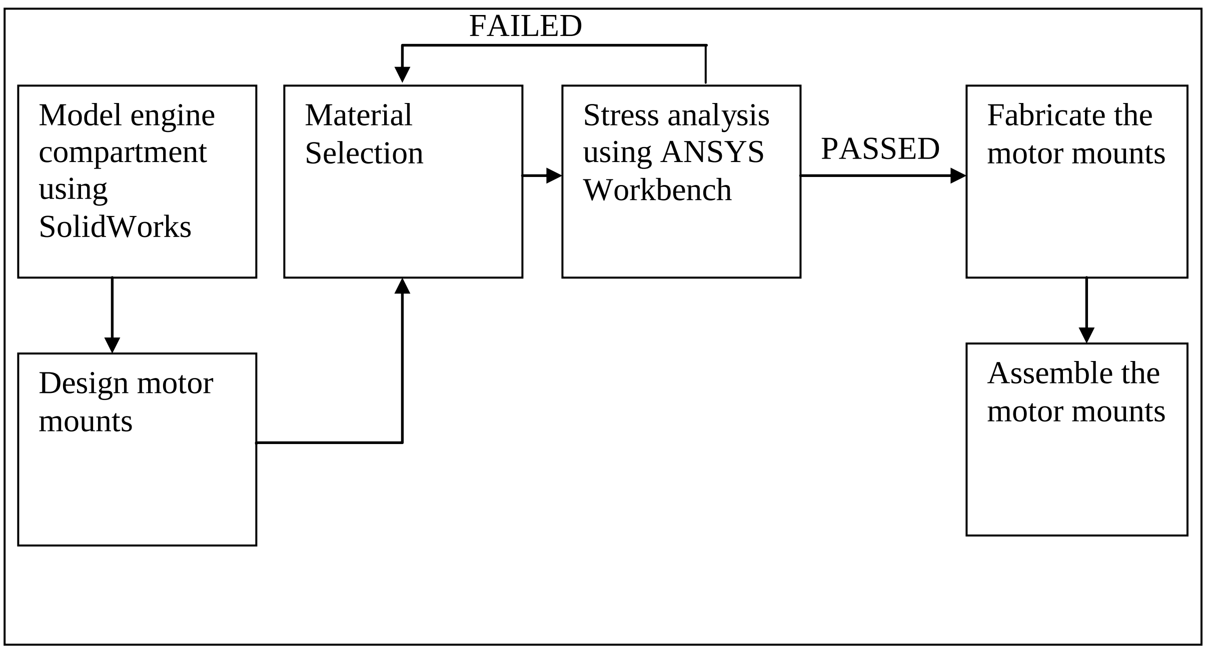


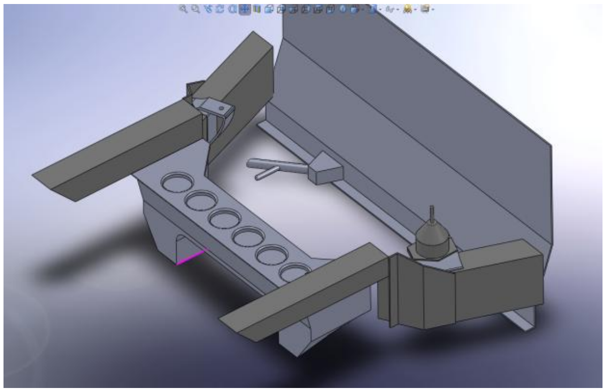
Figure 4.1 Flow chart for design and construction of motor mounts

Each component in the engine compartments are drawn accurately including the electric motor and the gearbox. The available space for motor mount can then be determined and motor mount can be designed based on that selected space. When the design has finished, the motor mount will then undergo a stress analysis using Finite Element Analysis software called ANSYS Workbench. After passing the stress analysis on the design, the next step is to fabricate and assemble the motor mounts in the engine compartment.

4.5 Spatial Modeling

It is necessary to produce an accurate spatial modeling of the engine compartment. It helps other group members in REV team to visualize how much space is available for their individual design. This is very critical for the battery cage design where most of the space will be occupied by batteries. Consequently, it will help them to oversee the compatibility of their design, whether it is suitable for a chosen location. Only the basic and important components are included in the modeling such as the rear section of the chassis, the mount rubbers, reinforcing bar, fire walls and drive axles. The final modeling of the Lotus Elise engine compartment can be seen in Figure 4.2.

2002 Lotus Elise Engine Compartment Photograph



Spatial Modelling in SolidWorks 2008

Figure 4.2 Spatial modeling of Lotus Elise engine compartment

4.6 Design and Construction of Motor Mounts

The conversion of an electric vehicle requires a new design of motor mounts. The complete motor mounts consist of four components.

- Frontal support
- Motor-Transmission shaft coupling
- Primary rear support
- Secondary rear support

Each component contributes greatly to the success of the project and therefore not one component can be excluded. Furthermore, there are various constraints imposed on the design of each component. This is mainly due to the limited space in the engine compartment. The design and construction for each component of motor mount will be discussed sequentially.

4.6.1 Design and Construction of Frontal Support

The purpose of using frontal support is to support and fix the front of electric motor in the engine compartment. The frontal support consists of two parts; the adapter plate and spacer. The adapter plate is usually mounted to the gearbox's housing, where the previous internal combustion engine was originally mounted. Hence, it generally has an outer profile similar to gearbox's bell housing so that it can fully attach to the gearbox. A spacer is used to enclose the clearance between the adapter plate and electric motor.

These are the necessary steps to design the frontal support of Lotus Elise car:

1. Measure the critical distance between the motor shaft and transmission shaft.
2. Record the transmission bell housing profile.
3. Record the location of bolt holes for transmission and electric motor.
4. Determine the centre point of adapter plate to indicate the centre of axis for alignment between motor shaft and transmission shaft.

4.6.1.1 Critical Distance

When the electric motor shaft is placed head to head with the gearbox shaft, the critical distance is the distance from the front face of gearbox to the front face of electric motor. The measurement for the critical distance is shown in Figure 4.3.

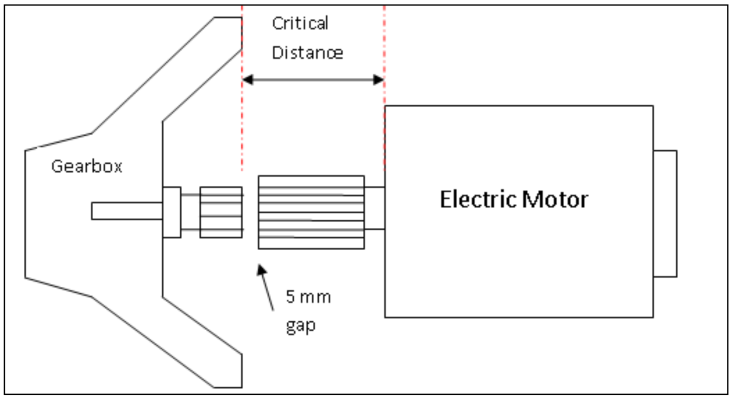


Figure 4.3 The critical distance between gearbox and electric motor

There is a 5 mm gap between the two shafts to prevent physical contact from the two moving parts. The critical distance for Lotus Elise is 70 mm; hence the frontal support will have a thickness of 70 mm.

4.6.1.2 Shape of Adapter Plate and Holes Locations

The size of adapter plate has to be sufficiently large in order to cover the front face of gearbox and electric motor. The adapter plate shape has to closely follow the shape of the face that is the largest out of the two components. For the Lotus Elise design, the PG1 original gearbox has a larger front face than the electric motor. Hence the adapter plate will follow the shape of gearbox's bell housing.

The easy method to record the frontal shape of gearbox is to trace the shape on to a paper with a pencil. The shape of the adapter plate will have the necessary area for mounting. The area around the drive axle from differential is cut out to provide clearance.

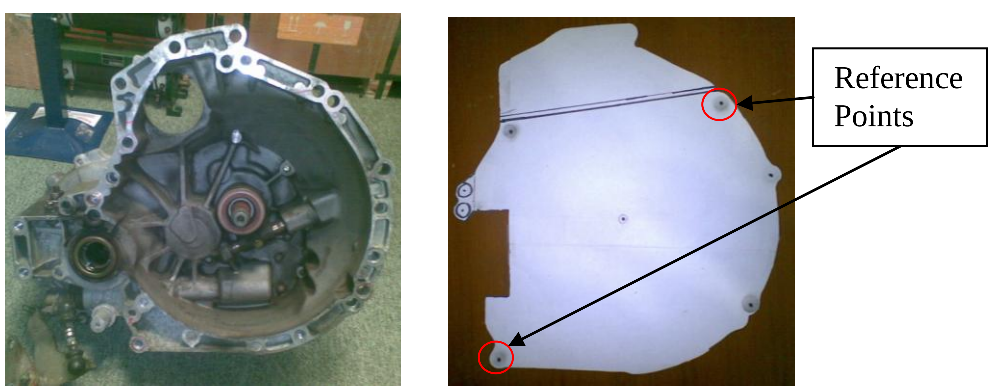


Figure 4.4 Tracing the shape of gearbox bell housing

One REV group member proposed to slice the top of gearbox to provide more space for the batteries, and to reduce a bit of weight. A line was drawn at the top of the traced paper to indicate where the slice occurs. The bolt holes for electric motor and gearbox are determined from 2 critical points. The critical points are circled in Figure 4.4. The rest of the holes are calculated in reference to those critical points.

4.6.1.3 Adapter Plate Centre Point

The gearbox shaft can be used as a reference location for the centre point of adapter plate. The determination of centre point is very critical in the design because it ensures that the gearbox shaft and electric motor shaft are aligned perfectly. The centre point is then used as a reference for drawing the hollow centre of adapter plate. The hollow centre creates a space for coupling. The spacer will also have the same hollow section diameter as the adapter plate.

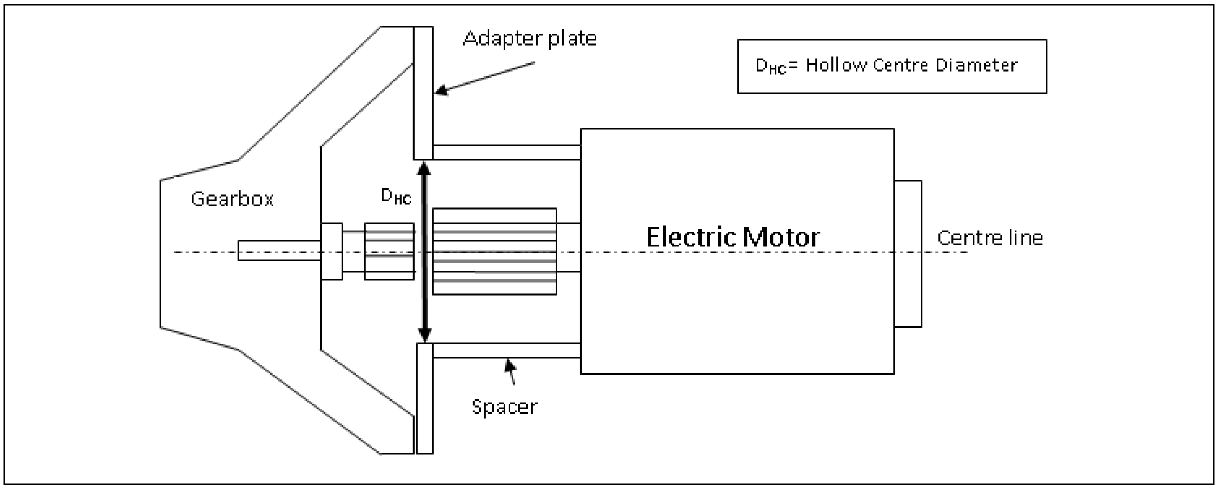


Figure 4.5 The schematic diagram of adapter plate and spacer assembly

4.6.1.4 Results and Discussion of Frontal Support Design

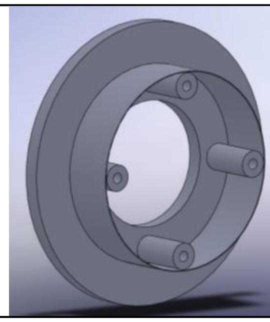
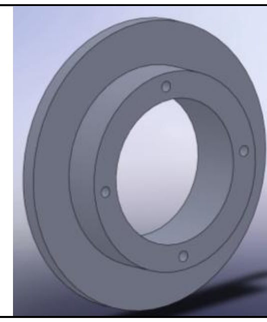
	
Adapter plate with pillar spacer	Adapter plate with collar spacer

Figure 4.6 Initial design of frontal support modeled in SolidWorks 2008

There are two initial designs for the frontal support. The first one is by using a pillar spacer and closed around by a thin plate of aluminum. This design is lacking the strength around the pillar section. When the electric motor is bolted to the end of the pillar, the area of contact between pillar and electric motor is small. Hence it is more likely to experience high localized stress on the pillar and may fail. One way to solve this problem is to replace the pillar spacer with a collar spacer. This helps to distribute the loading evenly because there is more contact surface area between electric motor and spacer. However this design can be further modified to achieve a lighter weight.

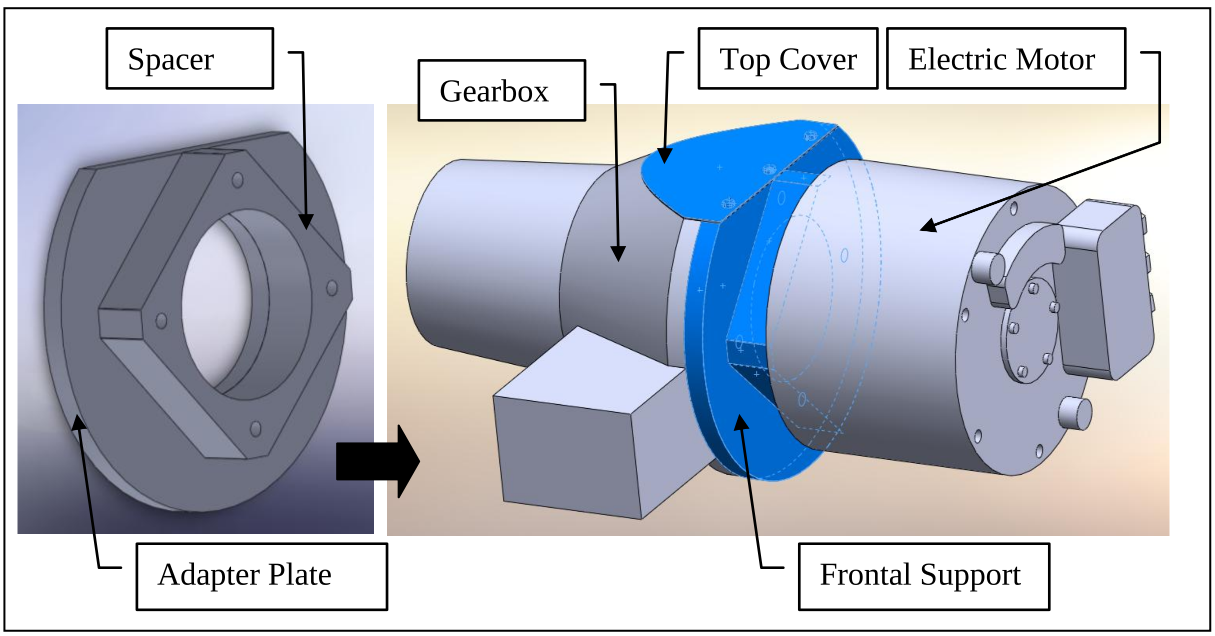


Figure 4.7 Final design of frontal support with gearbox and electric motor

The final design of frontal support is lighter because the spacer is trimmed in such a way that it does not compromise the strength of the design. The spacer is trimmed to become a square shape instead of a circular shape. The final design is simple and aligns the electric motor with gearbox perfectly. A top cover is also fabricated to enclose the sliced section of gearbox and it is bolted at the top of adapter plate. The detailed drawing of frontal support can be seen in Appendix G.

The front of electric motor is secured to the adapter plate by using four M8 nuts. The adapter plate is then bolted to the gearbox using nuts and bolts. The representation of how the adapter plate is mounted is drawn below.

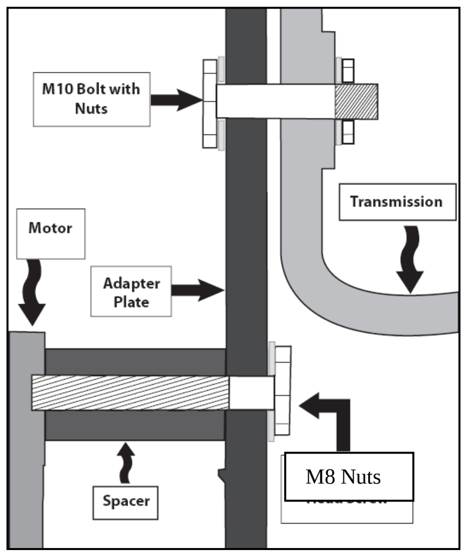


Figure 4.8 The mounting configuration of adapter plate

4.6.1.5 Material Selection and Fabrication for Frontal Support

The material used for the frontal support does not have to be very strong because it does not have to resist the weight of electric motor. Fabricating it from aluminum instead of mild steel will make the frontal support lighter. Hence, the adapter plate is made out of 400mm x 400mm x 20mm thick aluminum 6061 alloy and the spacer is made 50 mm thick aluminum 6061 alloy.

There were two options to machine the shape of adapter plates. The first method was to use a Computer Numerical Control milling machine and the second method was to use a manual milling machine available in workshop. The method that was chosen for fabricating the frontal support is by using the King Rich vertical milling machine and operated manually by workshop staff. The CNC milling machine is very accurate for cutting shapes but very costly and time consuming if fabricating only for one item. In addition, the shape of adapter plate is not critical and not too difficult for the manual milling machine to cut out.

4.6.2 Design and Construction of Motor-Transmission Shaft Coupling

The motor shaft and the gearbox shaft need a coupling as a tool to connect and align the two shafts together. The coupling also transmits the rotational force produced from the electric motor shaft to the gearbox shaft.

Since the two shafts have a different spline dimension to each other, the coupling have to be split into two components:

- Transmission-side Coupling
- Motor-side Coupling

Each component must have a matching spline dimension with its assigned shaft in order to fully transmit the rotational force. Thus, a good understanding of splines is necessary in order to produce the exact spline profile on to the coupling. Furthermore, the coupling must be restricted from moving side by side along the shafts. Thus, the coupling design requires a method to fix the coupling on a shaft.

4.6.2.1 Transmission-side Coupling

The spline dimension for PG1 gearbox shaft is not publicized anywhere in the Lotus Elise Car Manual or the PG1 gearbox specification data. Measuring the spline profile requires a special tool and a good background understanding of splines. Hence, one way to avoid the mismatching of spline dimension is to use the hub of the original flywheel as the transmission-side coupling. The hub of flywheel has a matching spline profile to the transmission shaft.

4.6.2.2 Motor-side Coupling

The shaft for the electric motor has a unique spline dimension and can be obtained from the electric motor data measurements. The spline measurement data for the electric motor shaft can be seen below and it is measured in inches.

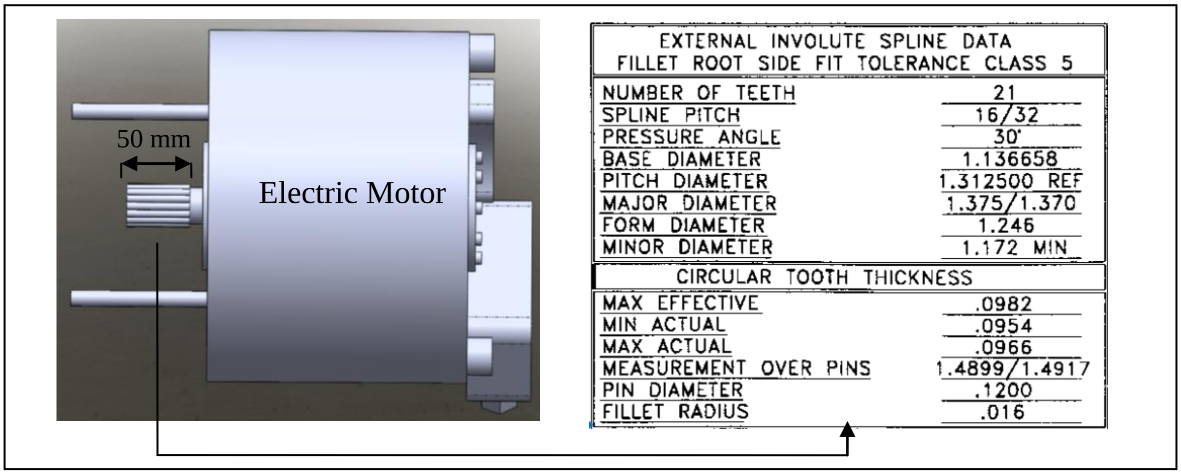


Figure 4.9 PowerPhase 75 Traction System Electric Motor

The motor side coupling must be as long as the electric motor shaft to ensure proper grip. Hence the motor-side coupling must be more or equal to 50mm long.

4.6.2.3 Result and Discussion of Coupling Design

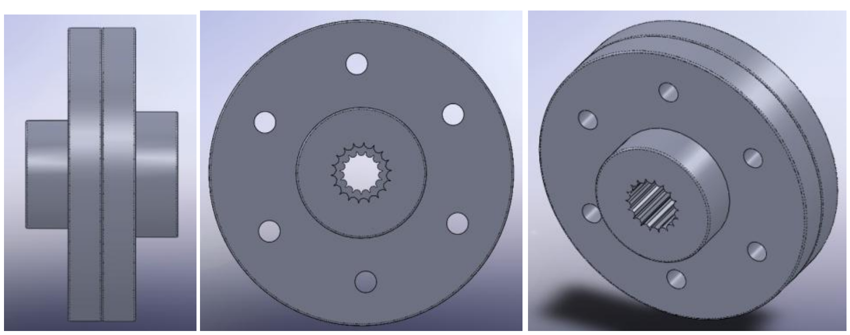


Figure 4.10 The first coupling design

The set screw coupling was the initial coupling design for Lotus Elise. This design uses six set screws to fix the two couplings together. However, according to the Brown and Prange (1993), using a set screw coupling can be very dangerous because it can fail catastrophically. This design is also very difficult to carry out because the transmission-side coupling requires a matching spline profile as the transmission shaft. However, the spline data for transmission shaft is not publicized anywhere and has to be measured carefully to ensure perfect fitting. Thus, this design is not cost efficient and not safe for Lotus Elise.

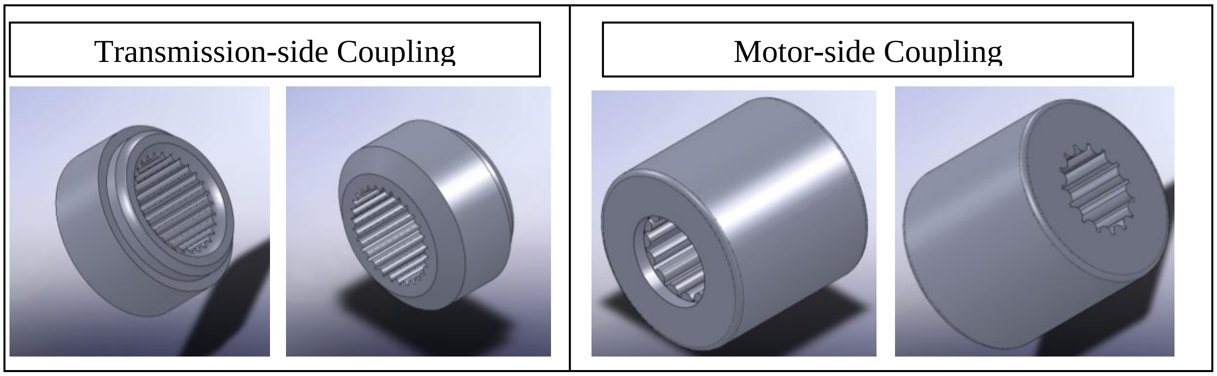


Figure 4.11 The final coupling design

For the final coupling design, the original flywheel hub from Lotus Elise is cut out to be used as the transmission-side coupling. This avoids having to cut involutes splines on transmission-side coupling because the flywheel hub fits perfectly to the transmission shaft. The detailed drawing is included in Appendix G. The motor-side coupling is intentionally designed bigger than transmission-side coupling for joining purpose. Moreover, there is a circular extrusion cut at the front of motor-side coupling so that the transmission-side coupling can be inserted and secured together. The two couplings will then be joined together by welding. The welding location on the coupling can be seen in Figure 4.12.

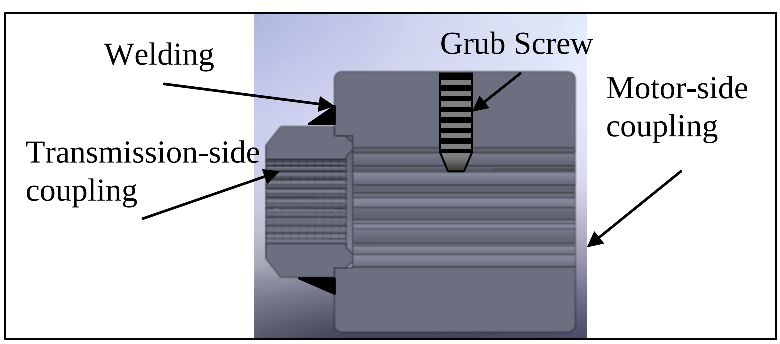


Figure 4.12 Joining method for transmission-side coupling and motor-side coupling

A grub screw is also used to fix the coupling in place on a shaft and prevents it from moving sideways. For this design, the grub screw is situated on the motor-side coupling because the transmission-side coupling has limited space.

4.6.2.4 Material Selection and Fabrication for Coupling

A coupling must be made from high mechanical strength material and high fatigue rated metals because it is constantly exposed to rotational force and shear stress. Carbon steel 1040 was the best material for the two coupling because it has a good machinability, high strength and weldable by all of the welding methods.

Property	Carbon Steel 1040
Young's Modulus (E)	200 GPa (eFunda 2009)
Tensile Yield Strength	353.4 MPa(eFunda 2009)
Ultimate Strength	520 MPa (Bernard, Steven & Bo 2004)
Poisson Ratio	0.3
Density	7850 kg/m^3 (Bernard, Steven & Bo 2004)

Table 4.1 Carbon Steel 1040 Properties

The motor-side coupling was fabricated using a wire cutting machine in the physics workshop. The wire cutting machine was able to fabricate the matching spline dimension on the coupling using the spline tool program. The grub screw holes and welding was done in the electrical building workshop. The welding procedure was made sure to be completed properly with high quality welding to prevent cracking and premature failure.

4.6.2.5 Finite Element Analysis Result of Coupling Design

The loading condition for the coupling is 240 Nm torque reaction produced from the electric motor. In order to make sure there is no calculation error associated with a particular size of meshing, three different refinements of meshing was performed. If the stress obtained from ANSYS Workbench does not differ greatly, it shows that the stress value is accurate and not affected by any error. The grub screw loading and hole is not taken into account in the stress analysis. The grub screw is considered as one body part with the motor-side coupling. The loading conditions of coupling are shown in Figure 4.13.

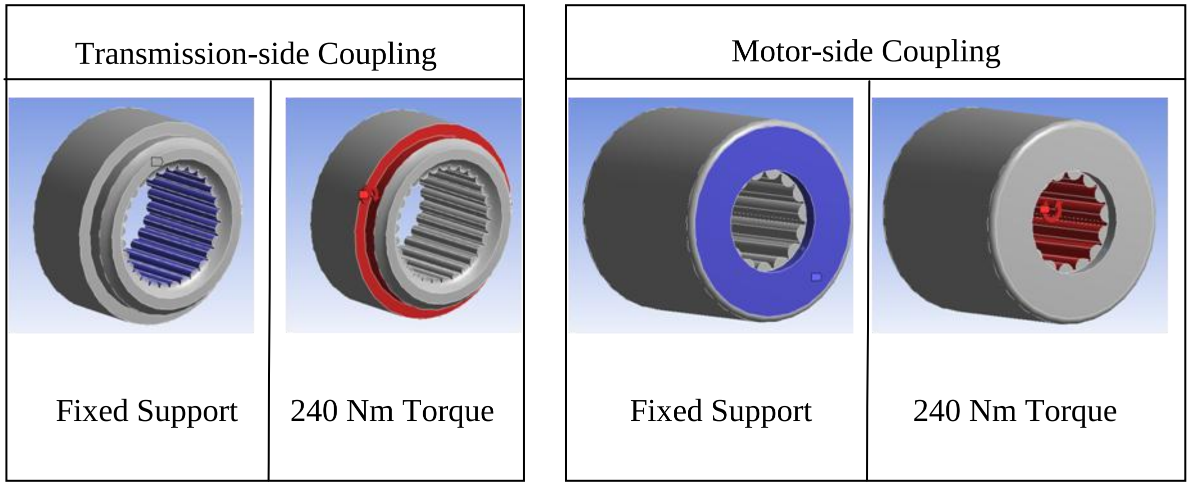


Figure 4.13 Loading condition for coupling in ANSYS Workbench

The spline curves for each coupling are drawn as close as possible to the real one. It has the same number of teeth, base diameter and major diameter.

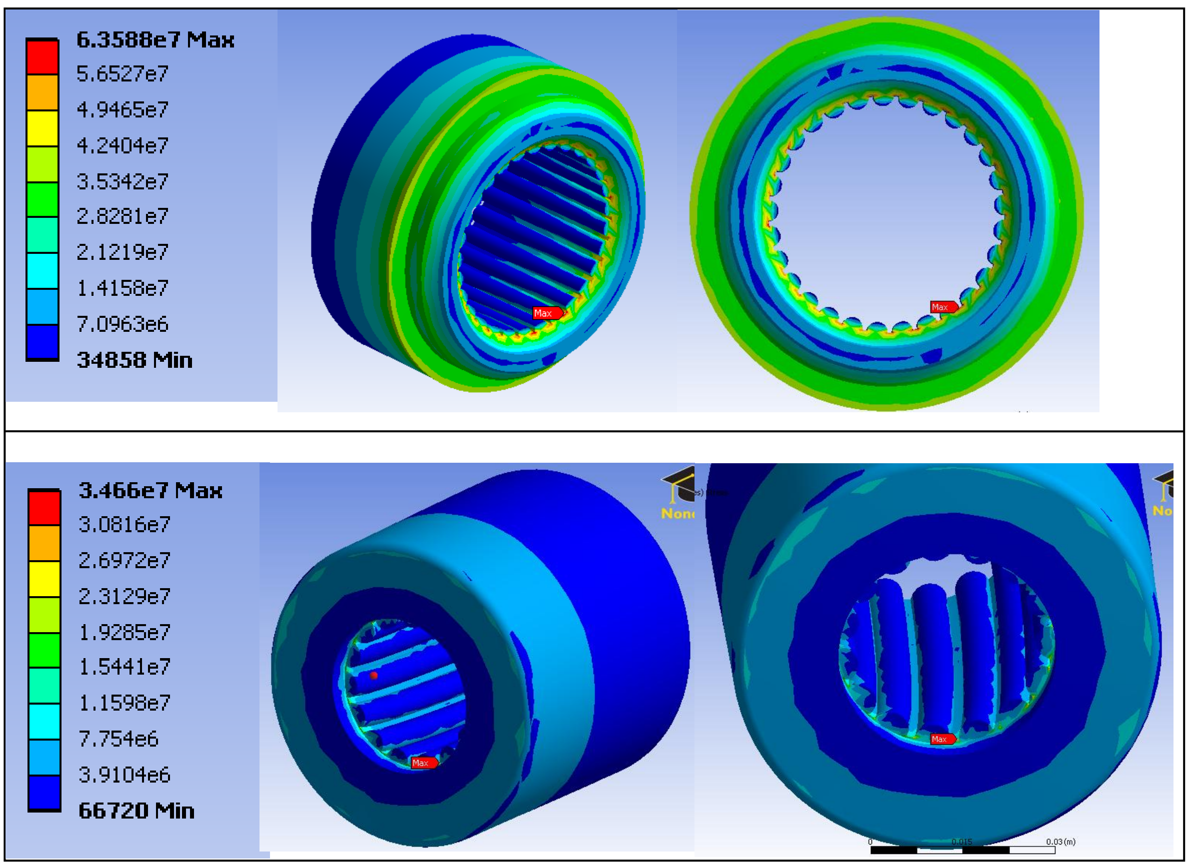


Figure 4.14 Equivalent stresses for transmission-side coupling and motor-side coupling

According to the stress analysis, the maximum stress occurs at the base diameter of the splines particularly the area where the teeth connect to the base diameter. The area at the base of the teeth has sharp corners and hence likely to induce high local stresses.

Transmission-side Coupling			
No. of Elements	**Max. Equivalent Stress (MPa)**	**Difference (%)**	**Max. Yield Strength (MPa)**
9928 (coarse)	**64.99 (Initial mesh)**		353.4
19385 (medium)	68.2	4.9	
45867 (fine)	67	3.1	

Motor-side Coupling			
No. of Elements	**Max. Equivalent Stress (MPa)**	**Difference (%)**	**Max. Yield Strength (MPa)**
12304 (coarse)	**34.66 (Initial mesh)**		353.4
21654 (medium)	36.2	4.4	
50937 (fine)	34.54	0.3	

Table 4.2 Stress analysis result for coupling

The initial mesh of the two couplings is considered to be appropriate for the stress analysis because the meshing has converged. When the initial mesh is refined twice, the maximum equivalent stress does not differ by more than 5% from the initial result.

According to the eFunda.com, the yield strength of carbon steel 1040 is 353.4 MPa at normal air temperature of 25 °C. The maximum equivalent stress experienced at both coupling is below the yield strength of carbon steel 1040. Hence, the transmission-side coupling and motor-side coupling will not experience plastic deformation during operation and will be sufficiently strong. The safety factor for transmission-side coupling and motor-side coupling is 5.44 and 10.2 respectively.

4.6.3 Design and Construction of Primary Rear Support

The main function of primary rear support is to sustain the entire weight of electric motor and to resist some of the torque reaction generated from electric motor. It can be seen as a cantilever system. The primary rear support not only transfers the torque reaction but also transfers the vibrations of electric motor. Hence, a solution to dampen the electric motor vibration must be incorporated into the design.

4.6.3.1 Methodology of Primary Rear Support Design

The mounting location for the primary rear support needs to be determined. The Lotus Elise car has a very compact engine compartment and there are only a few suitable mounting locations. The mounting location must be close to the electric motor and secured to the car chassis. It was found that the best location to mount the primary rear support is at the original mounting location for internal combustion engine. It is close to electric motor, connects to the car chassis, and has a big rubber mount which can be used to dampen vibration.

On the opposite end of the primary rear support, it is to be mounted to on the rear side of the electric motor. It has to be mounted on the strong part of the electric motor to prevent any damage. The electric motor manufacturer recommends utilizing the 5 screws that are embedded in circular pattern at the rear of electric motor. The original screws can be changed to a longer high tensile screw to accommodate the primary rear support bar. The mounting location for electric motor is highlighted in Appendix I.

The distance between the rear of electric motor and the rubber mount need to be measured to design the primary rear support bar. The distance is measured in three dimensional directions. It is very important that the measurements are done very accurately so that the electric motor shaft is perfectly aligned with the gearbox shaft. The measurements can be seen below.

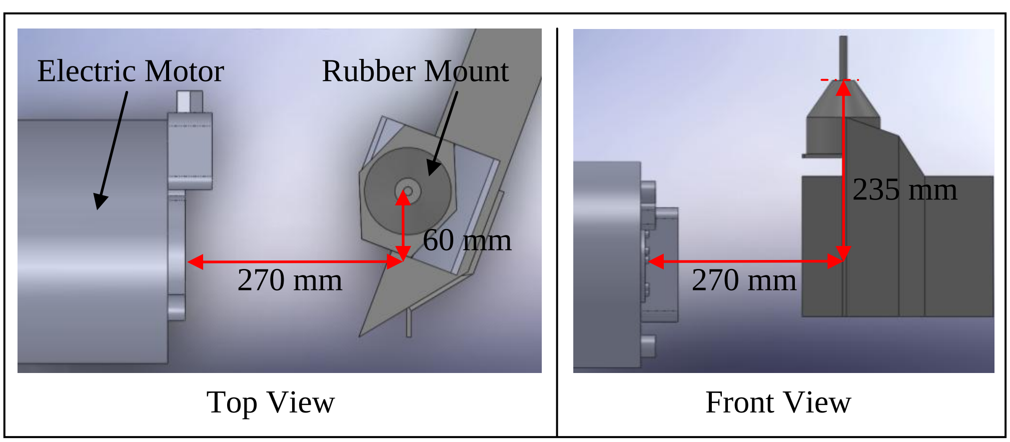
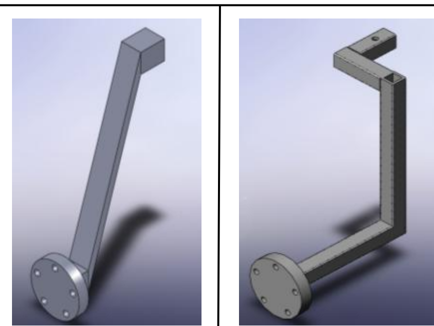


Figure 4.15 Measurement for primary rear support bar

4.6.3.2 Result and Discussion of Primary Rear Support Design



First Design | Second Design

Figure 4.16 Initial design of primary rear support bar

The first design of primary rear support was very simple and does not occupy a lot of space. It has a 20 mm circular plate with 5 holes to mount on to the rear of electric motor. The other end of the bar will be mounted to the rubber mount. However, this design could not support high loading because there is hardly any reinforcing elements on the bar. It is also very heavy because it is going to be made out of solid bar. The second design was more rigid than the first design. It uses the same circular mounting plate method as the first design. Even though the second design fit very nicely in the engine compartment, it requires extra reinforcement bars in order to support the electric motor**.**

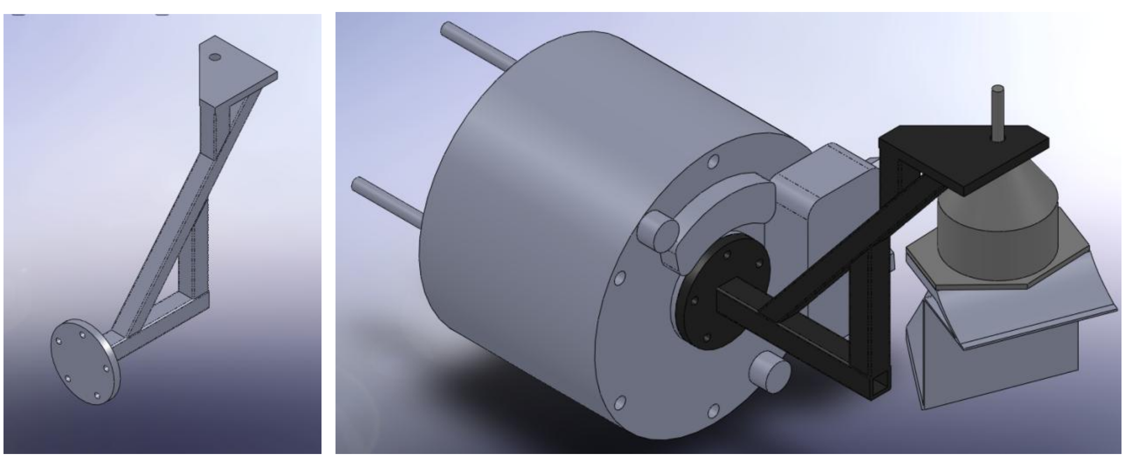


Figure 4.17 The final design of primary rear support

The final design uses a thin circular plate with 5 holes to mount on the rear side of electric motor. The mounting plate for rubber mount is made bigger to maximize the area of contact between rubber mount and primary rear support. This helps to distribute the induced stress evenly on the mounting plate. The design also uses multiple bars to reinforce corners that are prone to high localized stress. A square hollow section tube 25mm x 25mm x 4mm thick is used instead of solid bar to make the rear support bar lighter. The final dimension can be seen in the Appendix G.

4.6.3.3 Material Selection for Primary Rear Support Design

The primary rear support must be made out of material that has a high yield strength and high ultimate yield strength because it has to support a heavy load from the electric motor (40 kg) and resist the torque reaction (240 Nm). The most suited material for the design is carbon steel 1040 because it has a good weldability, machinability and high yield strength. Furthermore, carbon steel 1040 is widely available in the market and relatively cheap compared to other material with same strength.

4.6.4 Design and Construction of Secondary Rear Support

The main purpose of using a secondary rear support is to resist the torque reaction produced from electric motor. It can be referred to as the torque arm bar of the car. Even though the primary rear support can resist the torque reaction fully, an additional bar designed mainly for resisting torque reaction will be helpful. It will significantly lessen the induced stress in the primary rear support bar. In addition, it will help to dampen the vibration of electric motor. Thus, the vibration damping method for secondary rear support must also be incorporated in the design.

4.6.4.1 Methodology of Secondary Rear Support Design

The method applied in the primary rear support design is also used in the secondary rear support design. The first step is to find the best mounting location in the engine compartment such that it is close to the electric motor and secures on to the car chassis. The mounting location must also have a damper to dampen the transmitted vibration. Furthermore, the secondary rear support must have sufficient clearance from drive axle of the car.

The Lotus Elise car has a torque arm rod that was previously used to resist the torque reaction resulted from internal combustion engine. It is attached to the rear car chassis and has a rubber mount to the dampen vibration from engine. Since the torque arm rod is close to the electric motor, has a rubber damper and attached to the car chassis, it is suitable to be used as the secondary rear support for electric motor. However the torque arm rod needs to be extended so it can reach the rear of electric motor. This extension bar is the part that will be designed as the secondary rear support.

The method to mount the secondary rear support on to electric motor must also be determined. There is a primary rear support bar mounted already at the back of electric motor. Hence, one way to attach the secondary rear support is to mount it on to the circular mounting plate of primary rear support. It will be fixed on to the electric motor by the same high tensile screws.

The distance between the rear of electric motor and the torque arm rod need to be measured in order to design the secondary rear support. The measurements can be seen in the Figure 4.18.

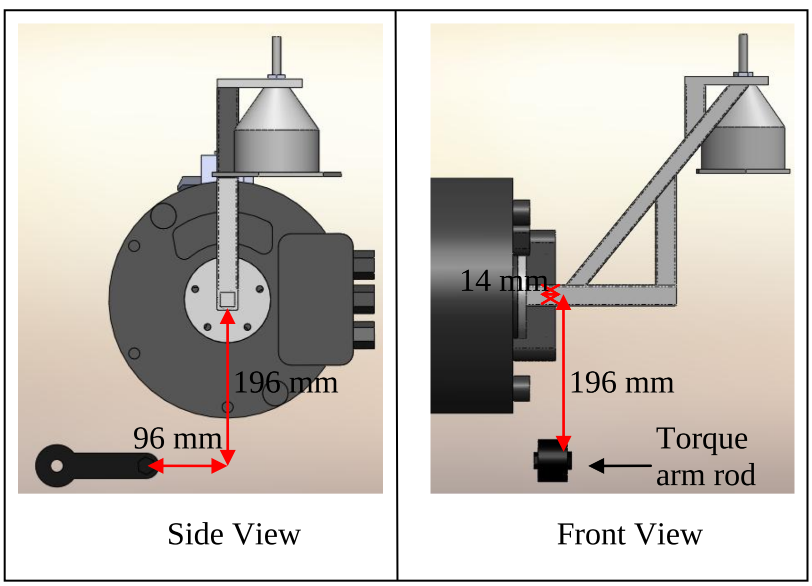


Figure 4.18 The measurements for secondary rear support design

4.6.4.2 Results and Discussion for Secondary Rear Support Design

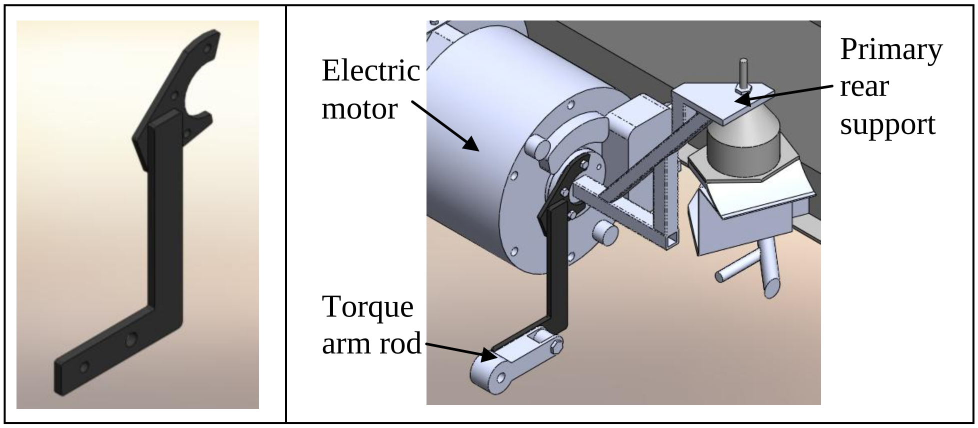


Figure 4.19 The Final design of secondary rear support

The final design of secondary rear support consists of 3 parts that are welded together. Two plates are welded together to make a 90 degrees angle bend. The design has a 90 degrees bend because it must avoid making contact with the drive axle of the car. The drive axle goes through between the torque arm rod and electric motor. At one end of the plate there are two bolt holes to mount on to the torque arm rod. The other end of the plate is welded to a circular mounting plate. This circular mounting plate is to be bolted to the rear of primary rear support mounting plate. It uses the same three high tensile steel bolts to secure on to the electric motor. The final dimension of secondary rear support can be seen in Appendix G.

4.6.4.3 Material Selection for Secondary Rear Support Design

The material for secondary rear support design must have a good weld ability property and high yield strength to resist the powerful torque reaction from electric motor. It is not necessary to have a light weight material because it is small in size. The best material that satisfies the requirement is the carbon steel 1040. It is the same material used for the primary rear support. It also has a good machinability, which is an important factor for the fabrication process.

<u>4.6.4.4 Stress Analysis for Primary and Secondary Rear Support</u>

The primary and secondary rear support bars are drawn as one body in the ANSYS Workbench program because the loadings and torque reaction force are shared between the two rear support bars. It also avoids the complexity of having to calculate the distribution of stresses between the primary and secondary rear support. It is assumed that the 5 bolts shared between the two rear supports are sufficiently strong and tightly screwed. Moreover, all the mountings are secured properly and no other parts are supporting the electric motor.

The loading condition of the rear supports are:

- 240Nm torque reaction force
- 392N load of electric motor (40 kg weight)

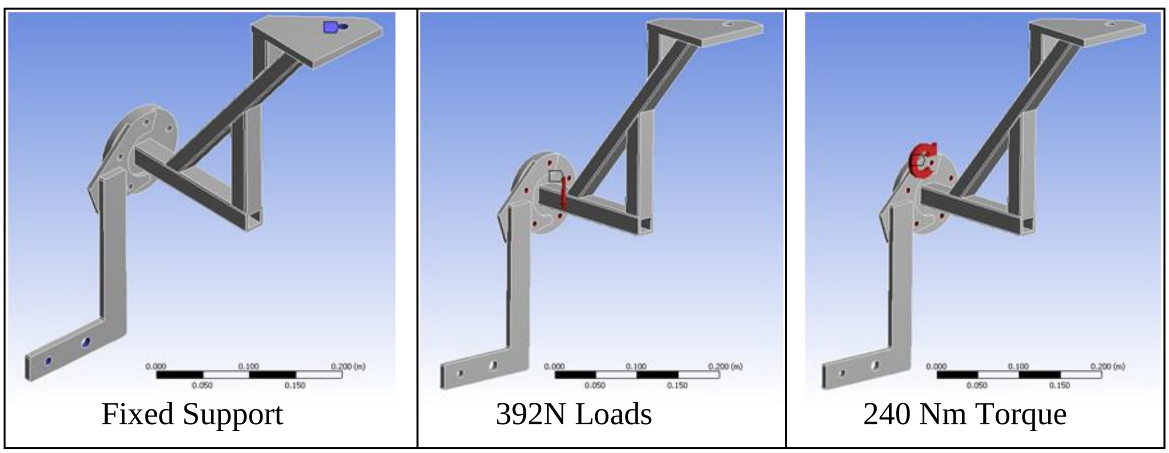


Figure 4.20 The loading conditions for rear support

In order to make sure the calculated stress values are correct and without any calculation error, the meshing for rear support in ANSYS Workbench is refined three times. The size of mesh can automatically be set in the program with three available options: coarse, medium and fine mesh. The three meshing for the rear support is shown in Appendix H.

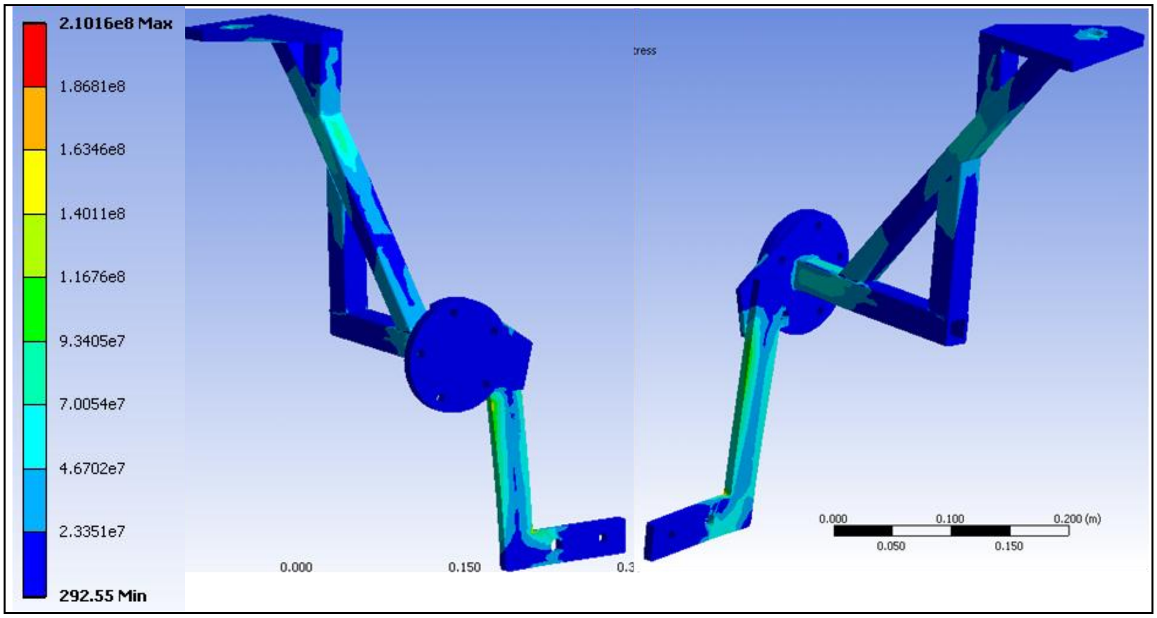


Figure 4.21 The equivalent stresses for the rear support with 392 N load and 240 Nm torque reaction force

The stress analysis result showed that the maximum stress occurs at the secondary rear support particularly at the 90 degrees bend. There is also moderate amount of stress along the plates of secondary rear support. A safety factor analysis is shown in Figure 4.22 to clearly show the section that are experiencing stresses close to the maximum yield strength of material (353.4 MPa).

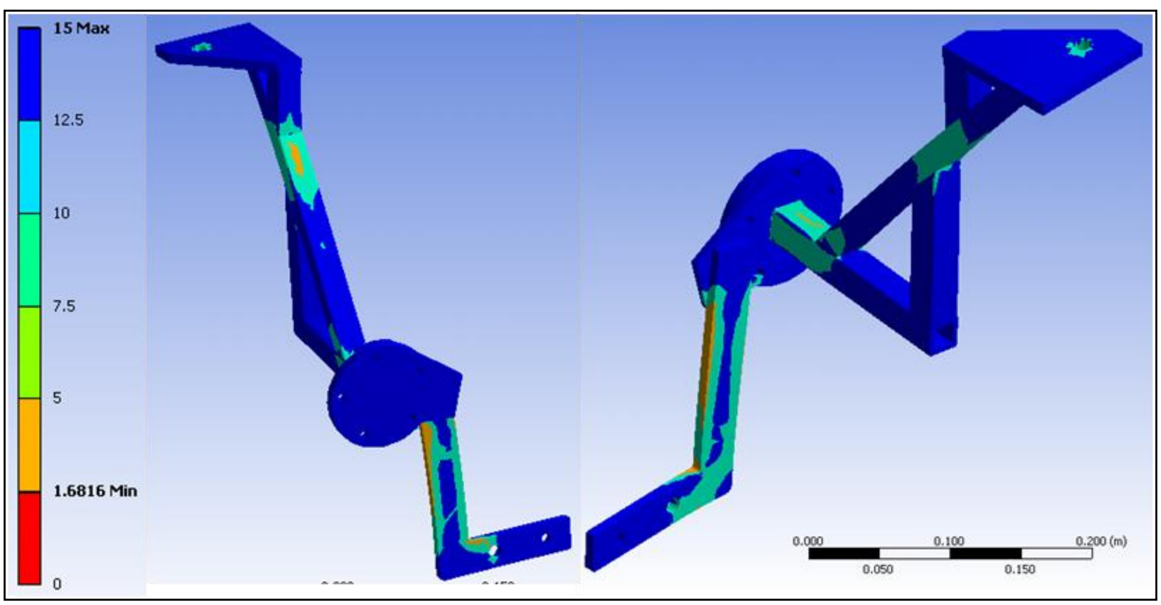


Figure 4.22 The safety factor analysis for rear support

Number of Elements	Max. Equivalent Stress (MPa)	Difference (%)	Max. Yield Strength (MPa)
5493 (coarse)	**210.16 (Initial mesh)**		353.4
7809 (medium)	211.78	0.2	
10524 (fine)	209.66	0.7	

Table 4.3 Stress analysis result for rear support

The maximum equivalent stress for the initial mesh does not differ by much from the other two refined meshing. It is less than 5% difference. Therefore, the equivalent stress value for the initial mesh is proven to be unaffected by the change of mesh size. Hence the mesh is converged. The yield strength of the rear support is 353.4 MPa. The maximum equivalent stress for the rear support is 210.16 MPa and it has a safety factor of 1.68. Hence, the rear support design is more than sufficient to handle the loading conditions and will perform reasonably well.

The loading that has the most effect on the maximum stress of rear support is the torque reaction. A small additional weight on electric motor will not cause the rear support to fail. However, the rear support will likely to fail if the torque reaction is increased. When the car is going over road bumps and cornering at high speed, the rear support will likely to experience twice the loading of motor weight, i.e. 80kg. According to ANSYS Workbench stress analysis in Appendix H, the maximum stress experienced by rear support will be 229 MPa. The maximum stress is located at 90 degrees bend of secondary rear support. Furthermore, the rear support will only fail if the loading of rear support is 340 kg and 240Nm Torque reaction force. In other words, the rear support is able to handle an additional weight of 300 kg before it fails. Hence, the rear support is strong enough and will perform very well without failing.

The rear support will also have to resist torque reaction from an opposite direction when the car is reversing or switching gears. The torque reaction for reversing is assumed to be the maximum torque produced from electric motor, 240 Nm. The loading condition for the rear support is 240 Nm torque reaction force (opposite direction) and 392 N down force. The maximum equivalent stress is found to be 173.68 MPa and has a safety factor of 2 (shown in Appendix H). Therefore, the rear support design is safe to be used for the Lotus Elise car and satisfy the Australian Design Rule 42 regarding about safe operation of the vehicle.

4.6.4.5 Motor Mounts Assembly

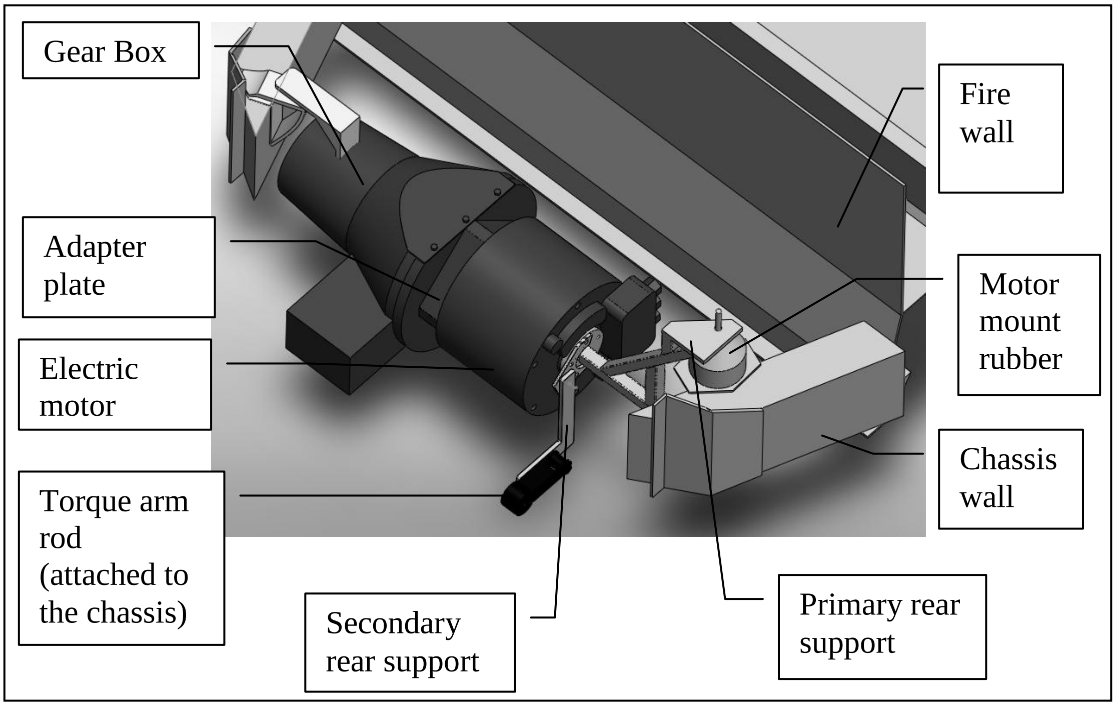


Figure 4.23 The final design of motor mounts inside Lotus Elise engine compartment

Assembling the motor mounts was easy and simple because all the dimensioning was done in advance in SolidWorks program and was made sure to fit inside the engine compartment. All the motor mounts were painted to prevent corrosion except the frontal support because it is made from aluminum. The motor mounts were assembled one by one and followed an order that ensures perfect alignment and excellent fitting. In addition, all the bolts for mounting the motor mounts were made sure that it was tensioned correctly. The final assembly of motor mounts inside the engine compartment is shown in Appendix I.

5. Safety

Students and workshop staffs in universities are required to follow the safety and health policy, introduced at the safety induction session, when working in laboratories or workshops. It is also very crucial that everyone who uses the workshop area must fully abide to the Occupational Safety and Health program to foster a safe work environment.

All the people who are involved in the process of the project are somehow exposed to hazards. Hence, safety considerations and issues for all the procedures throughout this project should be considered in advance to avoid injuries. For this thesis, there are safety issues associated with the design, construction and assemblies of motor mounts. As well as the implementation and operation of motor mounts.

<u>5.1 Safety Issues in Workshop Area</u>

Most of the time, the fabrication of motor mounts is conducted in electrical workshop by the workshop staffs. It is important to list all the safety issues associated with using workshop area to ensure a safe environment for students and workshop staffs. It includes wearing personal protection such as fully enclosed footwear, safety glasses, hearing protection, and protective masks. The staffs and students are also required to familiarize with the workshop rules, safety procedures and safety hazards mounted at the entrance. This helps students to be prepared when fire emergencies, dangerous chemical exposures, and body injuries happened in the workshop area.

Figure 5.1 Some of the safety signs posted in the workshop area

The electrical wiring and connections in the workshop area should be left alone and only be used when it is safe to do so. Usually all the electrical works are carried by person with electrical worker's license. It is also helpful to know where the first aid kit box is located in case of any injuries occurred. The emergency procedures for the workshop should also be familiarized including the emergency telephone contact number. Furthermore, all the equipments and machineries in the workshop should only be used by qualified staffs and people who have the expertise to use it.

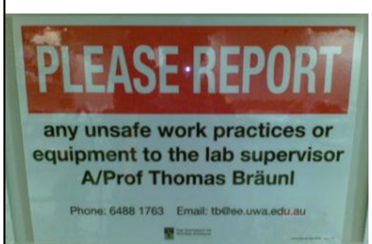
5.2 Safety Issues in G50 REV Laboratory

The Lotus Elise car is stationed in G50 REV Laboratory in the electrical building. There are also safety rules that have to be strictly followed by students who use the area. Some of the signs posted on the walls include no smoking, emergency procedures, and electrical shock hazards. Examples of safety signs can be seen below.

No Smoking sign and Safety Policy paper

Electrical Hazard sign

Emergency Procedures



Safe Work Practices label

Safety reminder for all electrical components

Electrical Warning label

Figure 5.2 Warning and Safety labels in G50 REV Laboratory

The emergency procedures contain a list of appropriate action for various emergency events such as evacuation, fire, bomb threat and earthquake. Students are also encouraged to know the university emergency number (2222), and the location of the nearest exit and fire extinguisher. If the fire alarm went off, the students are required to direct all persons to leave laboratory via the nearest exit, secure premises and evacuate building, move to the assembly area (Maths Courtyard) and wait for re-entry when it's safe to do so. In the case of fire and only if it is safe to do so; students can use the fire extinguisher to put out the fire.

However, it is best to evacuate the area and exit using the emergency door release if the fire became too big.

Figure 5.3 Fire extinguisher and emergency door release button mounted in G50 Laboratory

5.3 Safety Precautions When Taking Measurements of the Engine Compartments

Taking measurements of the engine compartment requires careful actions. Sharp materials and edges of the car chassis can easily inflict injuries and therefore should be kept clear from it. It is also dangerous to be underneath the car when it is lifted up by a car jack because the car may not be jacked up properly. Only do so when all the car jacks are put in place correctly and have been checked by qualified staffs. Furthermore, avoid leaning on other parts of the car while doing measurements because the assembly of the part may be loose. Lastly, avoid removing or disconnecting any electrical components in the engine compartment because it may still have a live connection from the power socket.

5.4 Safety Considerations for Motor Mounts Fabrication Process

During the fabrication process of motor mounts, proper welding should be done so that the strength of motor mounts will not be adversely affected. It is also important for the safety of the workshop personnel to use the correct tools or machineries when fabricating motor mounts. This ensures that all the machineries are working in optimal condition and prevents from inflicting physical injuries in the case of machine failure. In addition, the workshop staffs are required to handle the equipments properly and within the area of their expertise.

Any sharp edges resulted from fabrication should also be chamfered and grinded to avoid cuts. Lastly, the motor mounts must also be painted so that there is no corrosion and does not result in premature failure.

5.5 Safety Considerations for Motor Mounts Assembly Process

Assembling the motor mounts into the Lotus Elise engine compartment also require extreme care. The electric motor is too heavy for one person to lift with his/her own strength. Therefore, ask for help from other staffs or use a hydraulic system to assemble motor mounts into the engine compartment. Furthermore, the workshop staffs should avoid being directly under the electric motor when assembling because the motor mount may be loose or not strong enough. All the nuts and bolts must be screwed and tightened properly using a torque wrench to avoid loose assembly. All the motor mounts must also be assembled according to the proposed design. Avoid leaning on fragile parts of the car such as bumpers, glasses and panels. All the electrical components and wiring of the car in the vicinity of the engine compartment should be well insulated to avoid body contact from students and workshop staffs.

5.6 Safety Evaluation of Motor Mounts

A safety evaluation should be conducted once the motor mounts are assembled and the engine is working properly. Each motor mounts should be checked thoroughly for any signs of yielding or failing. The motor mount may be excessively bent or deformed due to overloading and can impose danger on the driver. If the motor mount produces excessive noise when the engine is running, it may be due to the engine's vibration. It is best to use mount rubber to dampen the vibration. However, the motor mount should be re-designed if the noise still exists. The motor mounts should also have enough clearance between other components to allow for small bending and displacement. Lastly, the motor mounts need to be regularly checked from time to time for any wear or deformation.

5.7 Safety Considerations for the Operation of Motor Mounts

There is also safety issues associated with the operation of motor mount. Since there is a loading limit in the design of motor mounts, putting extra weights or other components on the motor mounts should be avoided. Moreover, the position of each motor mounts in the engine compartment should not be changed in any way and should be assembled according to the proposed design. The car should also be driven carefully to avoid rear collision which may damage the motor mounts. Even though the worst possible driving condition is accounted for in the design, such as cornering at high speed and going over speed humps, a safe driving will ensure that the motor mount will not fail unexpectedly.

6. Conclusion

This project assessed the suitability of using several gearing alternative for Lotus Elise car and carried out a performance modeling when using two different gearing methods. The performance modeling helps to determine the best gearing method and the best gear combination for Lotus Elise electric. The final decision is to retain the original PG1 gearbox because it maximizes the available space in the engine compartment, minimizes the fabrication cost and provide a fast acceleration and top speed of 160 Km/h. The gear combination that provides the fastest acceleration for Lotus Elise electric car is by using the first and third gear combination. However, the second and fourth gear combination will be used instead because it can provide a more practical driving and longer range of the car. It is also the fastest gear combination for accelerating from 0 to 100 Km/h.

The engine compartment of Lotus Elise has been drawn accurately in SolidWorks. The design, construction and assembly of motor mounts were done to achieve a safe operation of the electric car. All the motor mounts had plenty of safety factor included in the design process to provide leeway for unanticipated events such as going over road bumps and hard cornering. Moreover, for each design of motor mounts, a method to dampen the vibration of electric motor was determined. This was achieved by utilizing the rubber mounts that were used for mounting the internal combustion engine. Lastly, this project improved the safety and reliability of the electric car through the design of strong mechanical supports for the electric motor.

7. Recommendation for Future Work

The performance model lacks the effect of reality factor such as windy condition, road elevation, and mechanical losses. Thus, the next development is to incorporate all the factors into the performance model so that a more accurate simulation can be produced. One must also compare the performance model with the actual time test of the car in order to improve the accuracy of the simulation.

The design and construction has been a success but a further performance evaluation is needed. Future work may involve testing the strength of motor mounts while driving under various conditions, checking the severity of motor vibration, and assessing the fatigue life of motor mounts. If the strength of material is not sufficient to support the loading conditions, a greater strength material with lighter weight should be used instead. The vibration of electric motor can be further dampened by using a rubber mount that has a stronger damping effect or by applying more vibration damper materials around the motor mounts.

The attachment between the two shafts couplings can be further strengthened by using vacuum brazing. Also, the transmission-side coupling should be replaced with a longer size coupling that covers the whole length of the transmission shaft. This helps to increase the grips on the shaft and reduce the localized stress around the splines teeth.

8. Reference

Bernard, J.H, Steven, R.S, & Bo, O.J, 2004, *Fundamentals of Machine Elements*, McGraw-Hill Professional.

Brown, M & Prange, S 1993, *Convert It*, Future Books, United States.

Brownout.com, 2008. Available from: http://www.brownout.com [20 September 2009].

Canadian Electric Vehicles 2001, *S10 Motor Mounts*. Available from: http://www.canev.com/KitsComp/Components/S10MotorMount.html [12 September 2009].

Department of Climate Change 2009, *Australia's National Greenhouse Accounts*.

Australian Government. Available from: www.climatechange.gov.au [10 September 2009].

Department of Planning and Infrastructure, 2007, *Minimum Requirements for Individual Custom Built Vehicles*, Perth.

eBay, 2009, Available from: www.ebay.com.au [13 September 2009].

EcoBridge *Causes of Global Warming*, Available from: http://ecobridge.org/ [10 September 2009].

eFunda Engineering Fundamentals, 2009, *AISI 1040*. Available from: http://www.efunda.com/Materials/alloys/carbon_steels/show_carbon.cfm?ID=AISI_1040&show_prop=all&Page_Title=AISI%201040 [15 September 2009].

Electric Car Conversion Kit, 2009. Available from: http://www.electric-cars-are-for-girls.com [15 September 2009].

Electric-cars-are-for-girls.com, 2009, *Electric Car Conversion Kit (for beginners)*, Available from: http://www.electric-cars-are-for-girls.com/electric-car-conversion-kit.html [13 September 2009].

Electric Vehicle Solutions, *S10 Conversion Kits*. Available from: www.electricvehiclesolutions.com [24 September 2009].

Electro Automotive 2009, *DC Kits*. Available from http://www.electroauto.com/catalog/kits.shtml#deluxe [10 September 2009].

Emerson Power Transmission 2009, *Function of Coupling*, Kop-Flex. Available from: http://www.emerson-ept.com [20 September 2009].

Government Initiatives. Available from: www.greenvehicleguide.gov.au [10 September 2009].

Green Vehicle Guide 2008, *Understanding Emissions from Motor Vehicles*, An Australian

Group Lotus, 2008, *The Lotus Elise*, Available from: http://www.lotuscars.com [10 September 2009].

Gull, 2009, *Gull Western Australia*, Gull Group of companies, Available from: http://www.gullpetroleum.com.au [10 September 2009].

HowStuffWorks, 2009, *Introduction to How Differentials Work*, Available from: http://auto.howstuffworks.com/differential.htm [15 September 2009].

Information Bulletin 74, 2005, *Conversion to Electric Drive,* Government of South Australia

KW Historics 2003, *2002 Lotus Elise*. Lotus. Available from: www.lotus.co.nz [18 September 2009].

Leitman, S & Brant, B 2009, *Build Your Own Electric Vehicle*, 2nd edn, McGraw-Hill, USA

Mathew, R 2008, *Welcome to the REV Project*, The Renewable Energy Vehicle Project. Available from: http://www.therevproject.com [20 September 2009].

Lotus Service Notes, 2000, *Dimensions*, Lotus Cars Ltd, England

Minnesota Pollution Control Agency 2009, *Motor Vehicle Pollution.* Available from: http://www.pca.state.mn.us/ [18 September 2009].

National Code of Practice for Light Vehicle Construction and Modification 2006, *National Guidelines for the Installation of Electric Drives in Motor Vehicles*, NSW.

PowerPhase 75 Traction System, 2009, UQM Technologies Inc

Safety and Health 2009, *Occupational Safety and Health Policy*, The University of Western Australia. Available from: http://www.safety.uwa.edu.au [10 September 2009].

Safety and Health 2009, *Safety Risk Management Procedures*, The University of Western Australia. Available from: http://www.safety.uwa.edu.au [10 September 2009].

Simon Family 2008, *Mating the Motor to the Transaxle*. Available from: www.simonfamily.us/FocusEV/MatingTheMotor.htm.[24 September 2009].

Tan, D.Z 2008, *Design and Construction of Motor Mounts for Renewable Energy Vehicle*, The Renewable Energy Vehicle Project, Perth, Available from: http://www.therevproject.com [20 September 2009].

Tesla Motors 2009, *Tesla Motors Selects BorgWarner for Production of New Gearbox for The Tesla Roadster*. Available from: http://www.teslamotors.com/media/press_room.php [10 September].

Tesla Motors, will the real, original founder step forward?, 2009, Clarity Digital Group LLC. Available from: http://www.examiner.com/x-7226-Electric-Car-Examiner~y2009m8d29-Tesla-Motors-will-the-real-original-founder-step-forward [13 September 2009].

The REV Project, 2009, Available from: www.therevproject.com [15 September 2009].

Third Edition Australian Design Rule, 2006, Australian Government Department of Infrastructure, Transport, Regional Development and Local Government, Available from: http://www.infrastructure.gov.au/roads/motor/design/adr_online.aspx. [20 September 2009].

9. Appendix

Appendix A: Tires and Gearbox Information

Tyres:

Type: Yokohama Advan
Size: 225/45/R17
Diameter: 634.3 mm
Circumference: 1992.71 mm

Gearbox

Type: Rover PG1 B4BP manufactured by Powertrain Limited, 5 Speed constant mesh gearbox with helical gear
Capacity: 2.2 Litres
Dry Weight: 36 Kg
Max Torque Capacity: 240Nm@1900Kg
Final Drive Ratio: 4.2:1
Maximum Speed: 8000 rpm

Gear	1	2	3	4	5	Reverse
Ratios	2.92	1.75	1.31	1.03	0.85	3

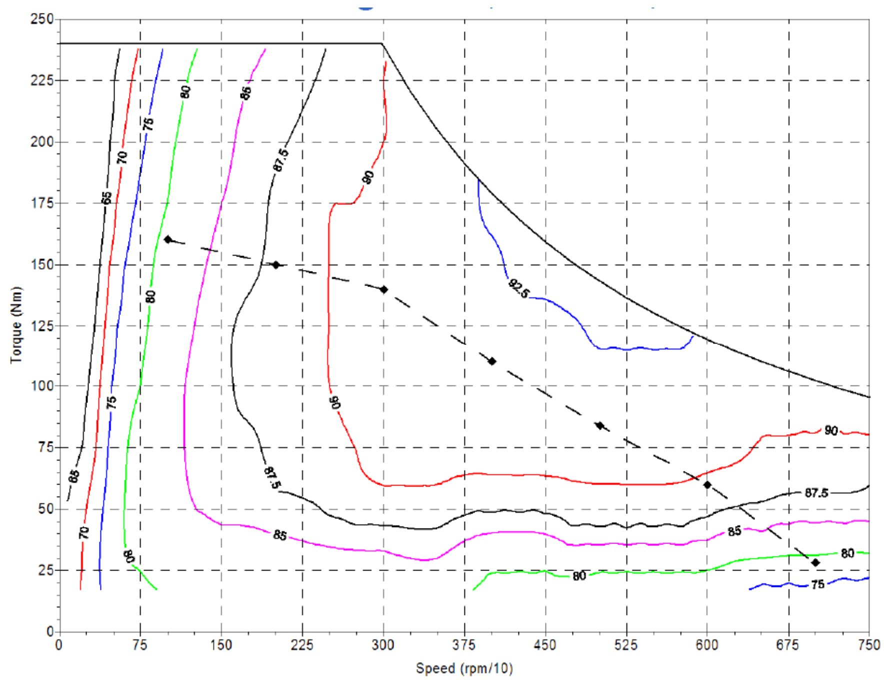
Gear ratio for PG1 gearbox

Gear	Km/h per 1000 RPM	Km/h @8000 RPM
1	9.75	78
2	16.27	130
3	21.73	174
4	27.64	221
5	33.49	268

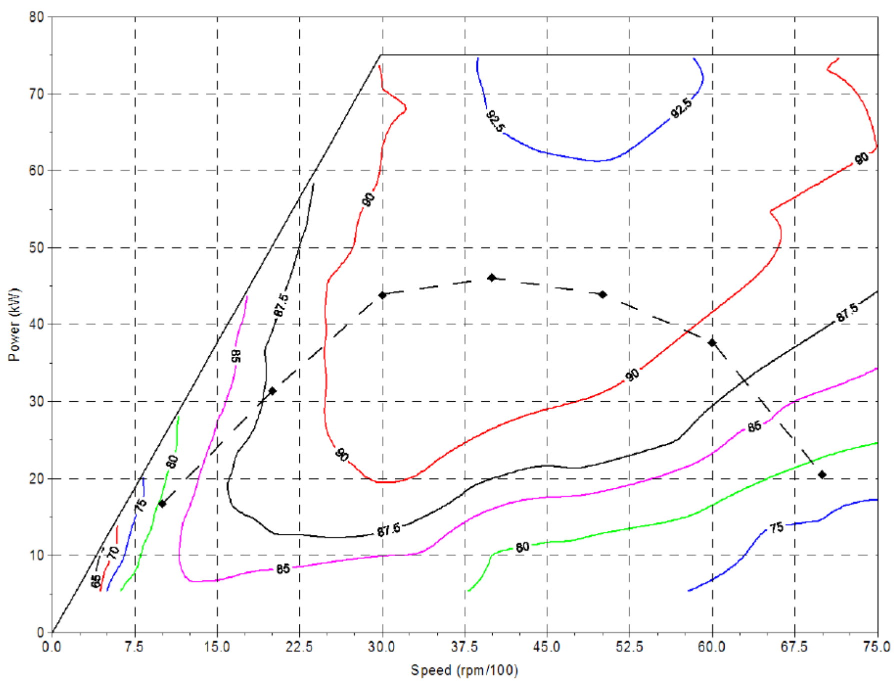
Theoretical speed without drag force and frictions

Appendix B: Electric Motor Information

Type:	PowerPhase 75 Traction System
Performance:	240 Nm Peak Torque
	75kW peak, 45kW Continuous Motor Power
	Regenerative braking
	Full power



Torque Curve



Power Curve

Appendix C: Motor Shaft RPM for Various Speeds

Speed (Km/h)	Rev of Motor (rpm)				
	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
10	1026	615	460	362	299
20	2051	1229	920	724	597
30	3077	1844	1381	1085	896
40	4103	2459	1841	1447	1194
50	5129	3074	2301	1809	1493
60	6154	3688	2761	2171	1792
70	7180	4303	3221	2533	2090
80		4918	3681	2895	2389
90		5533	4142	3256	2687
100		6147	4602	3618	2986
110		6762	5062	3980	3284
120		7377	5522	4342	3583
130		7992	5982	4704	3882
140			6442	5065	4180
150			6903	5427	4479
160			7363	5789	4777
170			7823	6151	5076
180				6513	5375
190				6875	5673
200				7236	5972
210				7598	6270
220				7960	6569
230					6868
240					7166
250					7465
260					7763

Appendix D: Drag Force and Rolling Resistance Calculation Result

V (Km/h)	Drag Force	Drag power (kW)	Rolling Resistance	Roll power (kW)	Mech. Power (kW)	Net Power (kW)
10	2.75	0.007638889	98.1	0.2725	0.280138889	0.294883041
20	11	0.061111111	98.1	0.545	0.606111111	0.638011696
30	24.75	0.20625	98.1	0.8175	1.02375	1.077631579
40	44	0.488888889	98.1	1.09	1.578888889	1.661988304
50	68.75	0.954861111	98.1	1.3625	2.317361111	2.439327485
60	99	1.65	98.1	1.635	3.285	3.457894737
70	134.75	2.620138889	98.1	1.9075	4.527638889	4.765935673
80	176	3.911111111	98.1	2.18	6.091111111	6.411695906
90	222.75	5.56875	98.1	2.4525	8.02125	8.443421053
100	275	7.638888889	98.1	2.725	10.36388889	10.90935673
110	332.75	10.16736111	98.1	2.9975	13.16486111	13.85774854
120	396	13.2	98.1	3.27	16.47	17.33684211
130	464.75	16.78263889	98.1	3.5425	20.32513889	21.39488304
140	539	20.96111111	98.1	3.815	24.77611111	26.08011696
150	618.75	25.78125	98.1	4.0875	29.86875	31.44078947
160	704	31.28888889	98.1	4.36	35.64888889	37.5251462
170	794.75	37.52986111	98.1	4.6325	42.16236111	44.38143275
180	891	44.55	98.1	4.905	49.455	52.05789474
190	992.75	52.39513889	98.1	5.1775	57.57263889	60.60277778
200	1100	61.11111111	98.1	5.45	66.56111111	70.06432749
210	1212.75	70.74375	98.1	5.7225	76.46625	80.49078947
220	1331	81.33888889	98.1	5.995	87.33388889	91.93040936
230	1454.75	92.94236111	98.1	6.2675	99.20986111	104.4314327
240	1584	105.6	98.1	6.54	112.14	118.0421053
250	1718.75	119.3576389	98.1	6.8125	126.1701389	132.8106725
260	1859	134.2611111	98.1	7.085	141.3461111	148.7853801

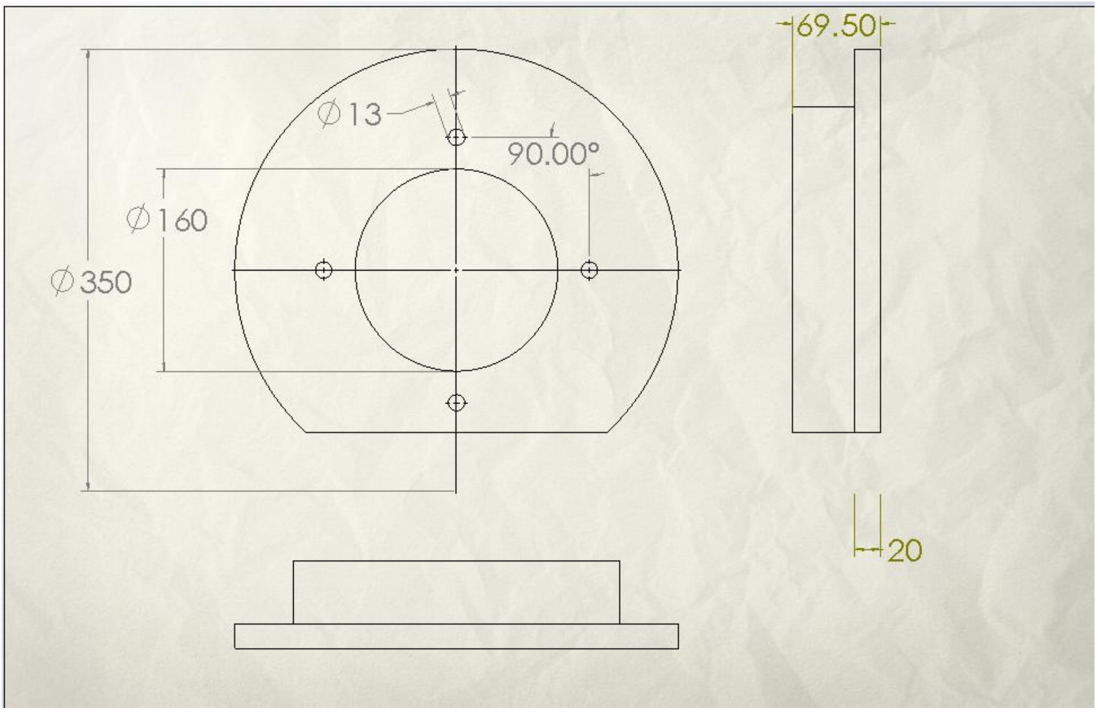
Appendix E: Performance Modeling Result When Using PG1 Gearbox

	1st and 3rd Gear	**2nd and 4th Gear**	**3rd and 4th Gear**	**3rd Gear Only**	**All Gear**
Speed (Km/h)	**Time (s)**	**Time (s)**	**Time (s)**	**Time (s)**	**Time (s)**
0 ---10	0.302628	0.876533	0.684548	0.684548	0.302628
10 ---20	0.302772	0.509299	0.685282	0.685282	0.302772
20 --- 30	0.306389	0.510386	0.687238	0.687238	0.306389
30---40	0.35388	0.512019	0.690198	0.690198	0.35388
40---50	0.456467	0.514213	0.694196	0.694196	0.456467
50---60	0.574187	0.56582	0.699258	0.699258	0.574187
60---70	2.70 (Shift)	0.697607	0.729538	1.229538	0.70 (Shift)
70---80	0.82903	0.826306	0.82903	0.82903	2.826306
80---90	0.967668	0.947145	0.967668	0.967668	0.947145
90---100	1.100742	1.122385	1.100742	1.100742	1.122385
100---110	1.295208	1.298806	1.295208	1.295208	1.298806
110---120	1.511264	1.507075	1.511264	1.511264	1.507075
120---130	1.722761	3.711549	1.722761	1.722761	1.711549
130---140	2.037081	2.062 (shift)	2.037081	2.037081	4.062(Shift)
140---150	2.466006	2.505119	2.505119	2.466006	2.505119
150---160	2.997059	2.912487	2.912487	2.997059	2.912487
Performance	**Time (s)**	**Time (s)**	**Time (s)**	**Time (s)**	**Time (s)**
0 - 60 Km/h	2.296323	3.48827	4.140719	4.140719	2.296323
0 - 100 Km/h	7.900123	7.081714	7.767697	8.267697	7.89852
0-160 Km/h	19.9295	21.07908	19.75162	20.29708	21.89589
Top Speed (Km/h)	170	200	200	170	170
Shifting time (s)	2	2	2	2	2

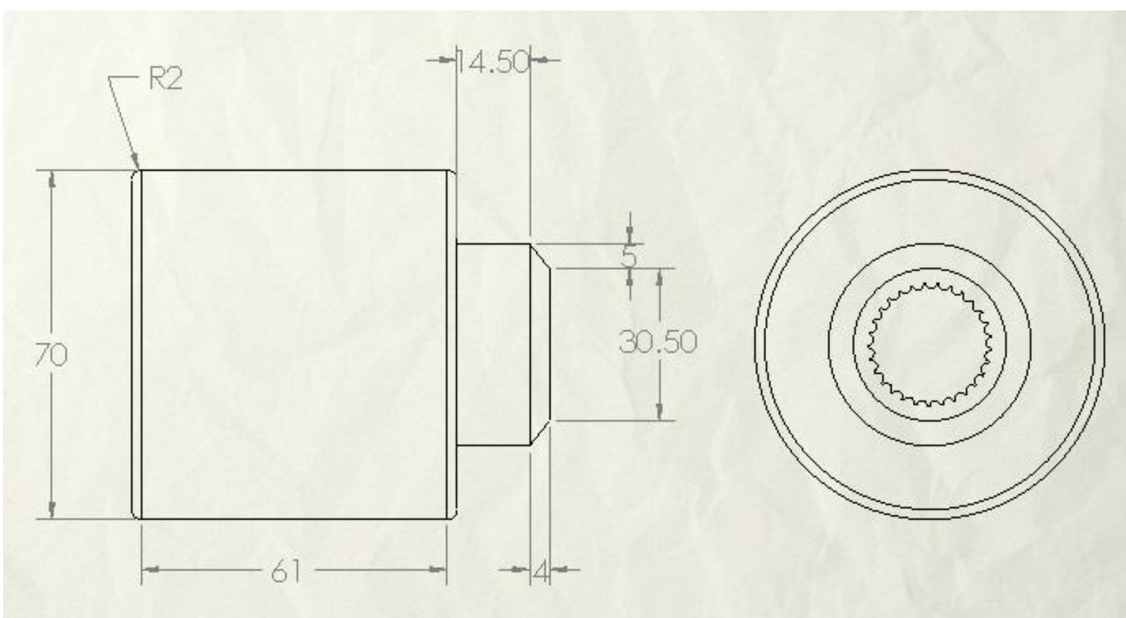
Appendix F: Performance Modeling Result When Using a Differential

	5.5:1	6:1	6.5:1
Speed (Km/h)	**Time (s)**	**Time (s)**	**Time (s)**
0 ---10	0.684548	0.626138	0.5769066
10 ---20	0.685282	0.626752	0.5774275
20 --- 30	0.687238	0.628395	0.578821
30---40	0.690198	0.630875	0.580924
40---50	0.694196	0.634213	0.5837518
50---60	0.699258	0.638435	0.6070648
60---70	0.729538	0.665463	0.694856
70---80	0.82903	0.758859	0.8311841
80---90	0.967668	0.897907	0.969547
90---100	1.100742	1.017809	1.1366524
100---110	1.295208	1.163549	1.3170436
110---120	1.511264	1.355568	1.5010096
120---130	1.722761	1.55151	1.717776
130---140	2.037081	1.776481	2.0312722
140---150	2.466006	2.072068	4.4942523
150---160	2.997059	2.520059	
Performance	**Time (s)**	**Time (s)**	**Time (s)**
0 - 60 Km/h	4.140719	3.784809	3.5048957
0 - 100 Km/h	7.767697	7.124848	7.1371352
0-160 Km/h	19.79708	17.56408	18.198489
Top Speed (Km/h)	170	160	145

Appendix G: Detailed Drawings for Final Motor Mount Designs

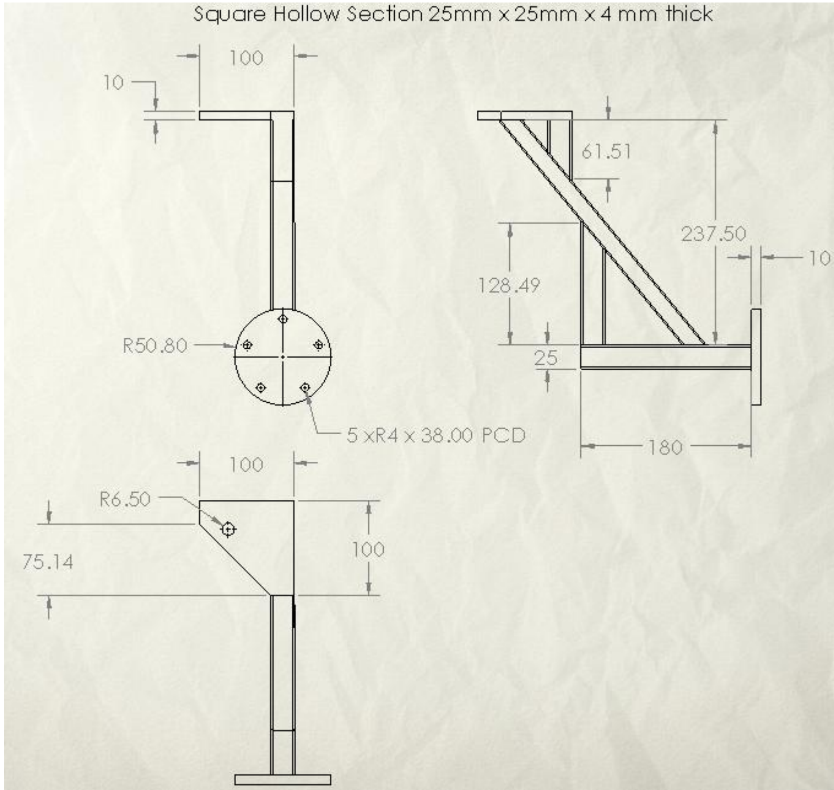


Frontal Support

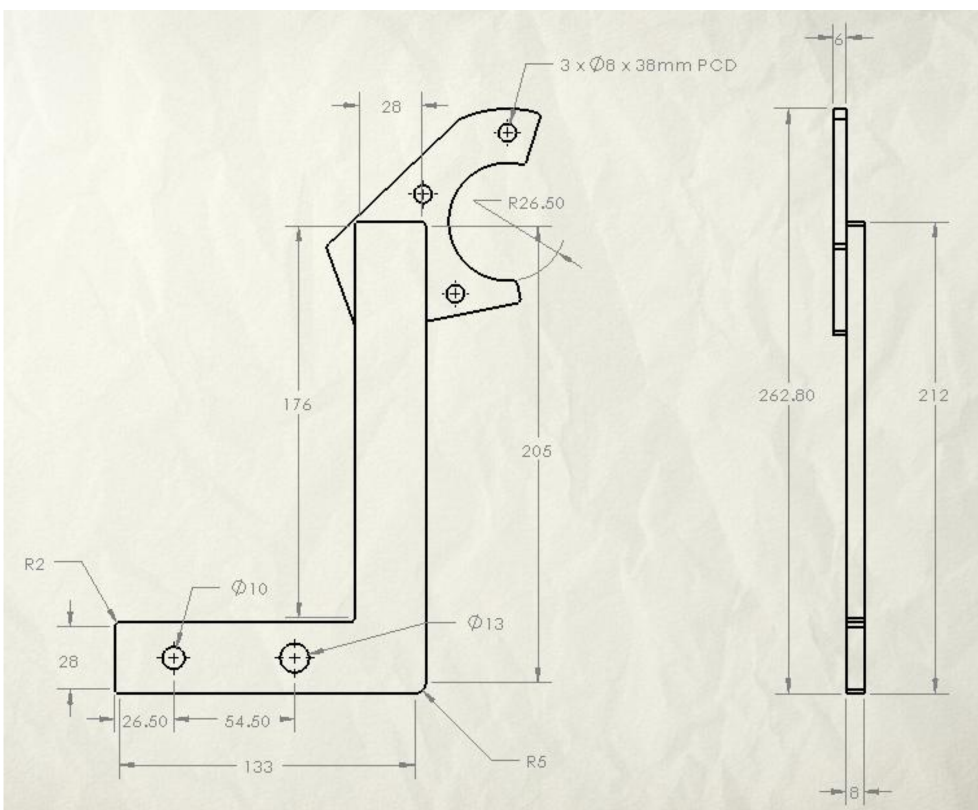


Coupling

Appendix G: Detailed Drawings for Final Motor Mount Designs

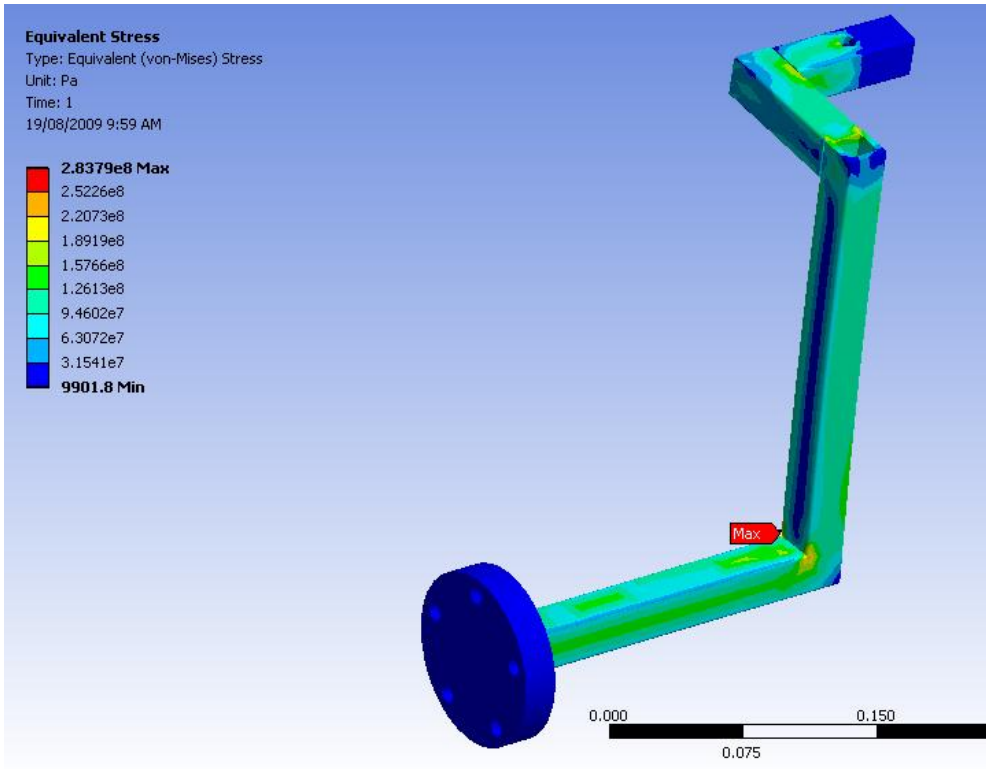


Primary Rear Support

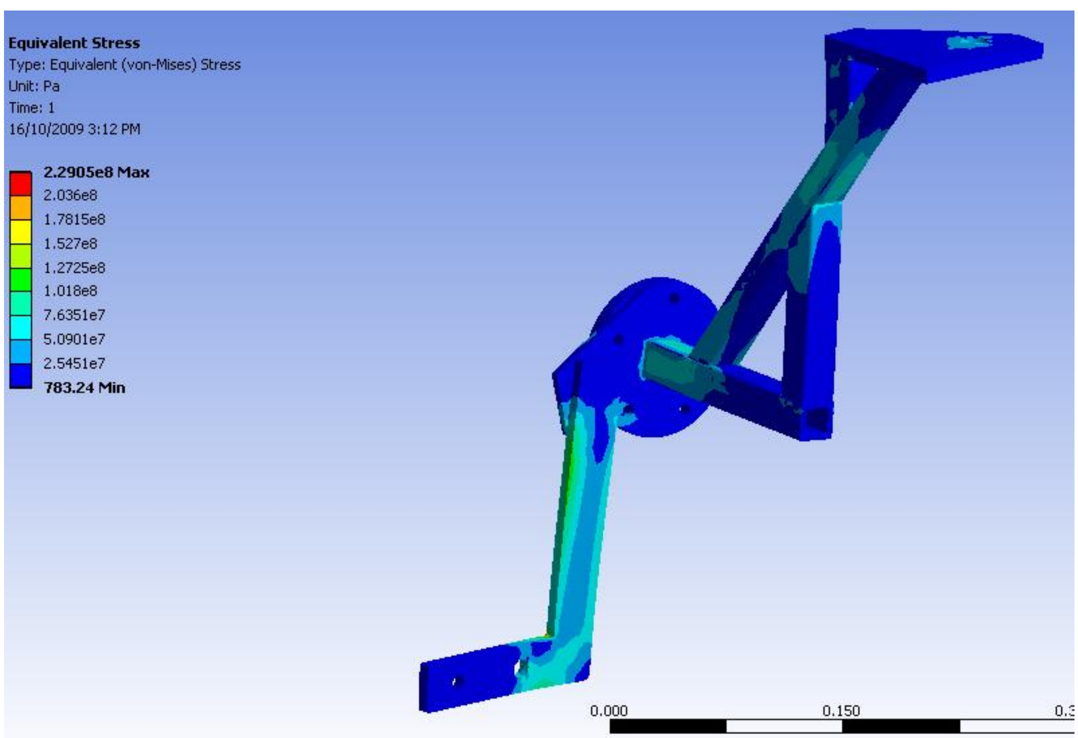


Secondary Rear Support

Appendix H: Stress Analysis Result for Motor Mounts

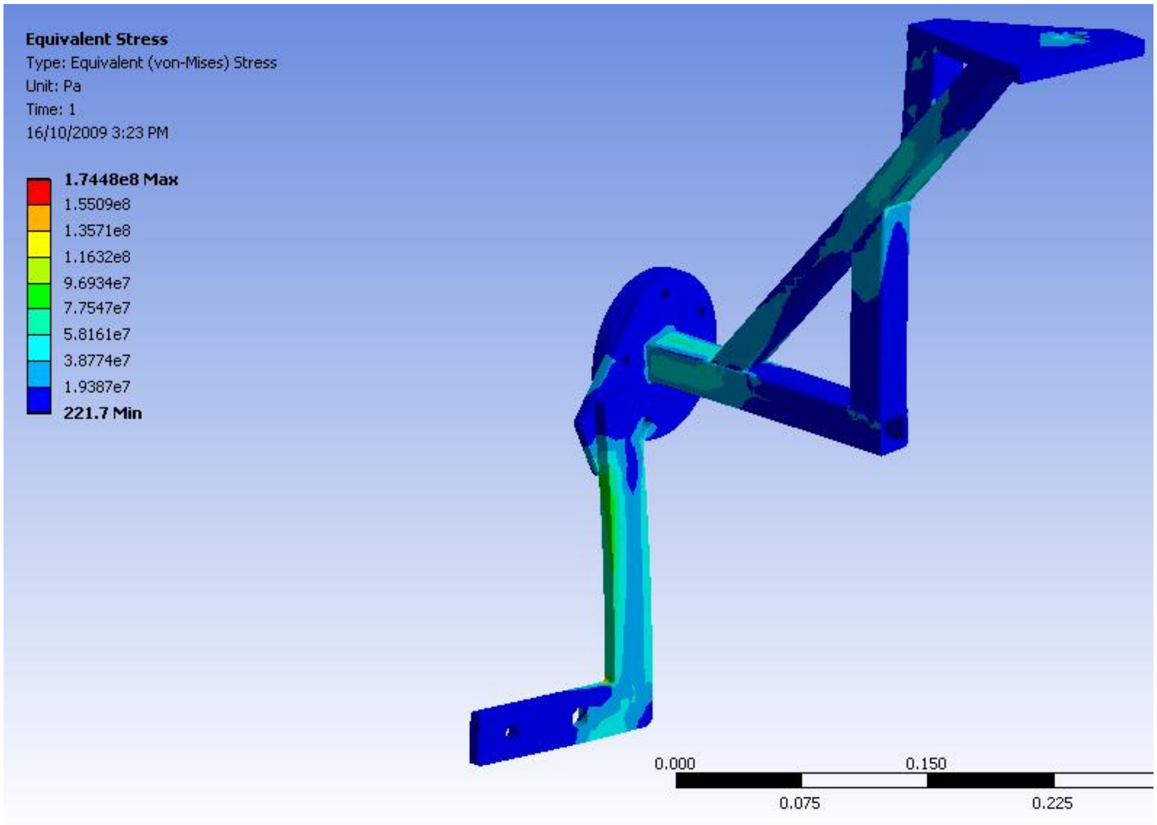


Second design of primary rear support bar

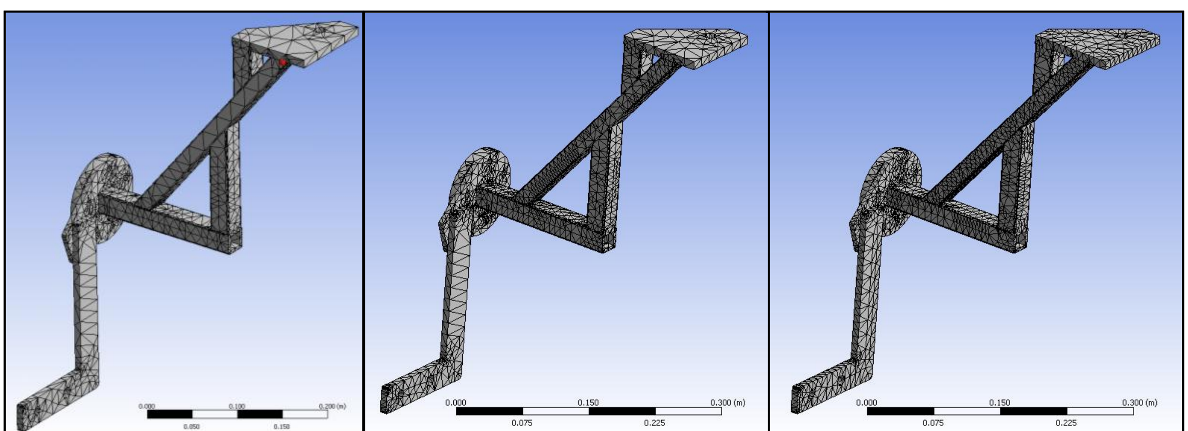


80 kg weight of motor

Appendix H: Stress Analysis Result for Motor Mounts



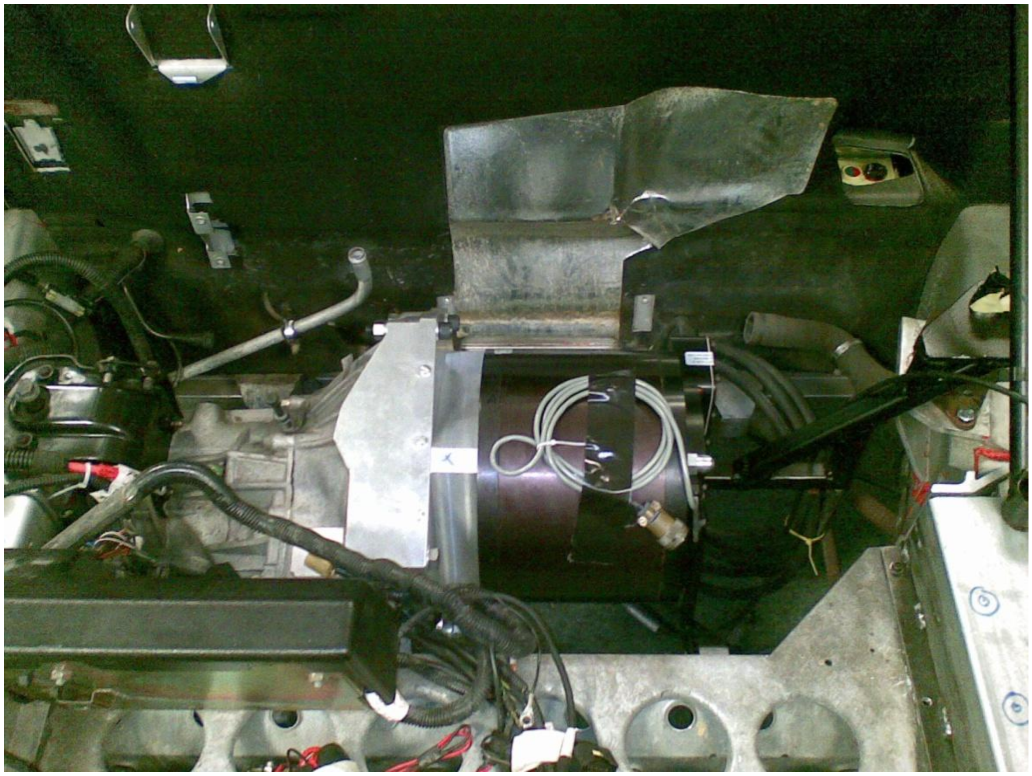
Torque reaction in opposite direction



Coarse Mesh	Medium Mesh	Fine Mesh

Meshing for Primary Rear Support

Appendix I: Photographs of Lotus Elise Car



Final assembly of motor mounts

The mounting location for electric motor