ACTUATION SYSTEM DESIGN FOR SOLAR CAR

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SUPERVISOR’S DECLARATION

“I hereby declare that I have read this thesis and in my opinion this thesis sufficient in terms of scope and quality for the award the degree of Bachelor of Mechanical Engineering with Automotive Engineering”

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Date: 06 DECEMBER 2010

STUDENT'S DECLARATION

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

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This work is dedicated to my beloved ones,

Zailaha bte Long

Syed Saleh Syed Drahim

Sharifah Nordalilah Syed Saleh

Sharifah Nurfatin Syed Saleh

Syed Mohd Safwan Syed Saleh

Sharifah Nuratikah Syed Saleh

And

Allies…

Thank you for the endless support and encouragement.

You all always have a special place in my heart.

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ABSTRACT

This report is an explanation about actuation system design for solar car. The word actuation is almost same with propulsion. This actuation system involved motor, motor controller and transmission system. Actuation system is vital in order to make sure solar car able to run smoothly when power is supplied. Without proper actuation system design, the power system design that been developed by other person is useless. This system also crucial to ensure safety to driver when driving solar car. Analyses have been done to select suitable electrical device before the devices have been bought. Besides, in this report, motor mounting bracket have been designed and analyzed in software ALGOR. The purpose is to ensure the bracket can withstand vibration of motor and avoid failure. Comparison between AC motor and DC motor are made to compare the torque and power produced. Solar car use simple transmission which is belt drive. Gear ratio analysis is made to ensure correct ratio and car can move with no problem. Then gear ratio analysis is used to consider which torque converter is suitable. This project is successfully completed when every basic part needed for actuation system is analyzed and designed.

ABSTRAK

Laporan ini ialah penjelasan tentang sistem dorongan untuk kereta. Perkataan dorongan hampir sama dengan menolak atau menggerakkan. Sistem gerakan ini melibatkan motor, kawalan motor dan sistem transmisi.Sistem gerakan ini penting untuk memastikan kereta solar mampu bergerak dengan baik apabila kuasa dibekalkan. Tanpa sistem dorongan yang betul, sistem kuasa yang direka oleh orang lain tidak berguna.Sistem ini sangat penting untuk memastikan keselamatan pemandu semasa memandu kereta solar. Analisis telah dilakukan untuk memilih peralatan elektrik yang sesuai sebelum peralatan itu dibeli. Selain itu, di dalam laporan ini pemegang motor telah direka dan dianalisis menggunakan perisian ALGOR. Ini bertujuan untuk memastikan pemegang motor mampu menampung gegaran motor dan mengelak kepatahan. Perbandingan antara AC (arus ulang alik) motor dan DC (arus terus) motor dibuat untuk membandingkan tork dan kuasa yang dihasilkan. Kereta solar menggunakan transmisi yang mudah iaitu tali sawat. Analisis nisbah gear dibuat untuk memastikan nisbah yang betul dan kereta dapat bergerak tanpa masalah. Kemudian, analisis nisbah gear diguna untuk mempertimbangkan penukar tork yang sesuai. Laporan ini siap dengan sempurna apabila setiap bahagian asas yang diperlukan dalam system dorongan direka dan dianalisis.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Solar power comes from the energy of our Sun. Sunlight is an excellent energy source and the future of using solar power is very exciting. The Sun's energy can be used to heat and cool buildings, generate electricity, operate communication and navigation systems and even power solar cars. The cars use hundreds of photovoltaic cells to convert sunlight into electricity. Each cell produces about one-half volt of electricity.

When the teams design their electrical systems they have to allow for variations in sunlight. The Sun's energy powers the car's motor and charges a battery for use when the Sun is hidden by a cloud. If a car is designed to put all of its energy toward driving and keeps nothing in reserve, it will stop completely in cloudy weather. If too much energy is stored to the battery, the engine runs too slowly to move.

The most exciting part of using solar power as an energy source is that it is pollution free and inexhaustible. If research continues, one day solar energy may replace today's combustion engine cars.

A solar car is an electric vehicle powered by solar energy. This solar energy gained from solar panels on the car. Solar cars are not currently a practical form of transportation as they able to operate only during the day and can only carry one or two passengers.

The main component of a solar car is its solar array, which collect the energy from the sun and converts it into usable electrical energy. Then, the solar cells collect a portion of the sun’s energy and store it into the batteries of the solar car. Before that happens, power trackers converts the energy collected from the solar array to the proper system voltage, so that the batteries and the motor can use it.

After the energy is stored in the batteries, it is available to be used by the motor & motor controller to drive the car. The motor controller adjusts the amount of energy that flows to the motor to correspond to the throttle. The motor uses that energy to drive the wheels.

1.2 PROBLEM STATEMENT

Actuation system for solar car involved electrical part. When dealing with electrical, safety comes first. Failure to select suitable electrical device will cause dangerous and even fire. For mechanical part, selection of transmission influences the speed and efficiency of solar car. Material selection for motor mounting bracket is crucial to avoid failure.

1.3 RESEARCH OBJECTIVE

The objective is to research and find out the simplest actuation system to be used in solar car. Study about suitable of electrical device to be chosen. Design proper electrical connection. Analysis mechanical part such as power to weight, motor mounting bracket and gear ratio.

1.4 SCOPE OF RESEARCH

The scope of this project is divided into two major parts which are electrical and mechanical. Electrical part is limited from battery to motor controller and motor. Instead for mechanical part is limited from motor mounting bracket to wheel circumferences. Actuation system able to be simplified by eliminating some electrical device with some justification and reason. It same goes with mechanical part.

1.5 MAIN FOCUS

The main focus is selecting suitable devices that able to run properly. Before buying that component, study about each device must be done to avoid lost and waste. Besides that, efficiency of the system also has been studied and considered. Connection of each device has been studied to ensure electrical system work properly with no problem in future. Mechanical part also has been studied such as motor bracket and gear ratio for transmission.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nowadays, electrical system has two types of current that widely been used in the world. Alternating Current (AC) and Direct Current (DC) make world becomes a better place to live. There are electrical devices that use AC while others us DC. It depends on application of the system. Actuation system for solar car involves motor, motor controller, and electric pedal. For this system, direct current is selected and used.

2.2 BRIEFLY OVERVIEW ABOUT ELECTRICAL SYSTEM

The sunlight hits the cells of the solar array, which produces an electrical current. The energy (current) can travel to the batteries for storage go directly to the motor controller, or a combination of both. The energy sent to the controller is used to power the motor that turns the wheel and makes the car move.

Generally if the car is in motion, the converted sun light is delivered directly to the motor controller, but there are times when there is more energy coming from the array than the motor controller needs. When this happens, the extra energy gets stored in the batteries for later use.

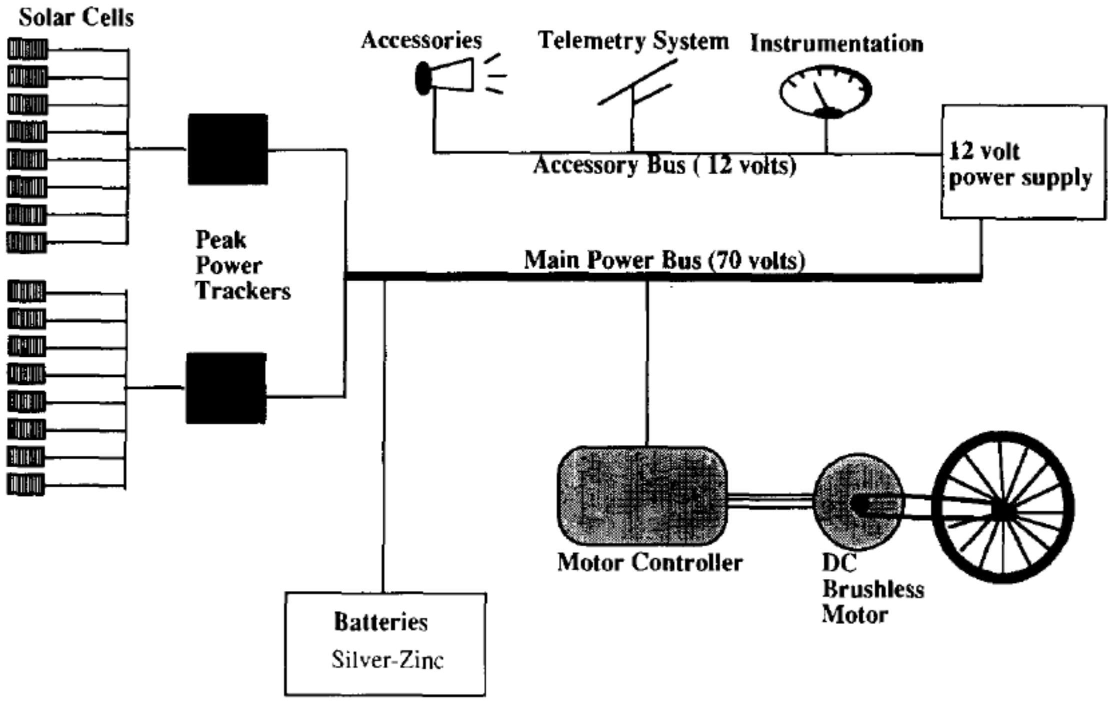

Figure 2.1: Electrical system block diagram

Source: Craig E. Hampson, Carolyn Holmes, Laurence P. Long, Robert F.D. Piacesi and William C. Raynor (1991)

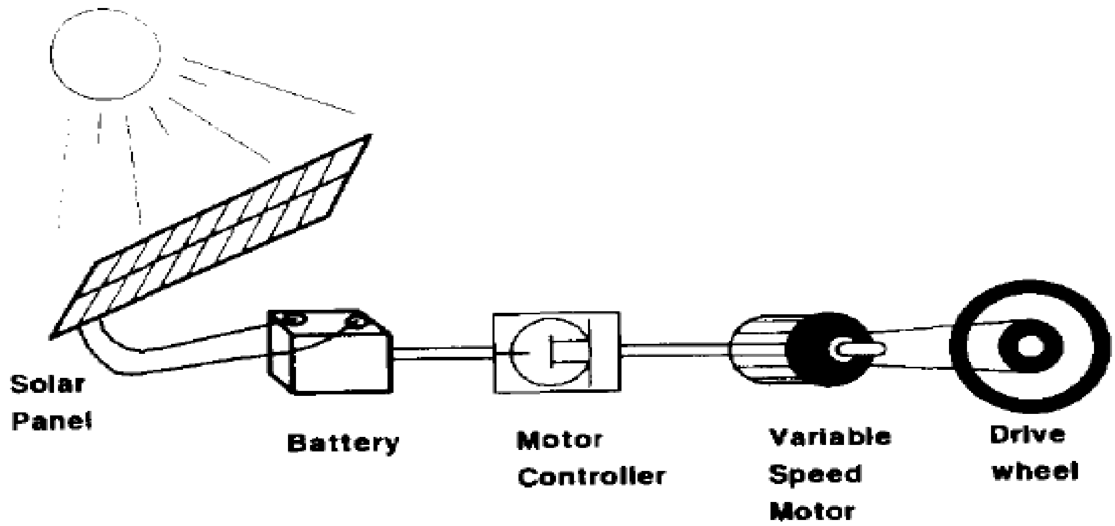

Figure 2.2: Major component of a solar car

Source: Richard J. King (1991)

The advantage of solar race car is it can be driven continuously without having to refuel while the sun is shining. Batteries are used primarily to accelerate and travel at higher speeds. The propulsion system in a typical solar race car is made up of four basic components. Solar cells convert sunlight directly into electricity. Then, the solar fuel is saved in batteries. (Richard J. King (1991))

From the power converted, it goes to motor controller. The electricity powers a variable-speed electric motor with direct drive to the wheels. Electronics are used to control electrical power between the solar cells, battery and motor. The speed is controlled with an accelerator pedal. A solar car race is an exciting sporting event and a challenging learning experience. Those with the capability to collect and convert the most sunlight and use it effectively win the race. (Richard J. King (1991))

2.3 MOTOR

The motor has two functions which are converting the electrical energy to rotating mechanical energy when motoring and mechanical energy to electrical energy when regenerating. There are a number of types of motors are used today, ranging from the induction, switched reluctance, brushed DC and stepper motors. Motors are used in a vast variety of applications ranging from huge crushing mills to pinpoint accuracy mechanisms in space applications. (Andrew James Reghenzani (1998))

2.3.1 Dc Motor

Dc motor consists of brushed DC and brushless DC motor.

2.3.1.1 Brushed DC Motor

A brushed DC motor typically consists of stationary fixed permanent magnets (the stator), a rotating (electro) magnet (the rotor) and a metal body to concentrate the flux. Brushed DC (BDC) motors are inexpensive, easy to drive, and are readily available in all sizes and shapes.By attraction of opposite poles and repulsion of like poles, a torque acts on the rotor and makes it turn. As soon as the rotor begins to turn, fixed brushes make and break contact with the rotating segments (commutation) in turn (Reston Condit (2004))

Some applications require motors to operate in harsh environmental conditions, for example flammable gas leaks, where conventional DC brush motors cannot be used due to the risk of sparks forming between the brushes and commutator .
(Andrew James Reghenzani (1998))

2.3.1.2 Brushless DC Motor

The solar car is propelled by an electric motor instead of the usual petrol-powered engines. It does not need gas. Brushless DC motors are similar to Alternating Current (AC) motors since a moving magnet field causes rotor movement. Brushless motors are also similar to Permanent Magnet Direct Current (PMDC) motors since they have predicable linear characteristics (John Mazurkiewicz (2003)).

The famous motor that has very high efficiency and is very reliable is the brushless DC (BLDC) motor. Unlike conventional DC brush motors, the brushless motor, suitable with its name, has no brushes and requires extra electronic circuitry to perform the job of commutation. The BLDC motor can be constructed in many sizes and power ratings, and finds widespread application in many motor drives
(Andrew James Reghenzani (1998)).

Each motor has a number of advantages and disadvantages in particular applications ranging from large industrial roller mills to accurate positioning control. The most popular choice for high efficiency applications such as solar car, is the permanent magnet brushless DC motor, or sometimes known as a synchronous DC motor. The advantages of the BLDC motor include:

- Very high efficiency characteristics over a large power range (98.2% recorded for an optimized Halbach magnet arrangement).
- Require minimal maintenance, due to elimination of mechanical commutator and brushes.
- Long operating life and higher reliability.
- No brushes means no arcing which can be paramount when working in flammable gas locations.
- Number of motor geometry's possible for example interior permanent magnet or surface magnet arrangements.
- High power density and torque to inertia ratio give a fast dynamic response.
- No brushes eliminates need for a high rotor inertia.
- Speed restrictions due to the traditional mechanical commutator are eliminated (Andrew James Reghenzani (1998)).

Table 2.1: Comparing a bldc motor to a brushed dc motor

Feature	**BLDC Motor**	**Brushed DC Motor**
Commutation.	Electronic commutation based on Hall position sensors	Brushed commutation
Maintenance	Less required due to absence of brushes.	Periodic maintenance is required.
Life	Longer.	Shorter.
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load.	Moderately flat – At higher speeds, brush friction increases, thus reducing useful torque.
Efficiency	High – No voltage drop across brushes.	Moderate.
Output Power/ Frame Size	High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better.	Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.
Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response.	Higher rotor inertia which limits the dynamic characteristics
Speed Range	Higher – No mechanical limitation imposed by brushes/commutator.	Lower – Mechanical limitations by the brushes
Electric Noise Generation	Low.	Arcs in the brushes will generate noise causing EMI in the equipment nearby.
Cost of Building	Higher – Since it has permanent magnets, building costs are higher	Low
Control	Complex and expensive.	Simple and inexpensive.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.

Source: Padmaraja Yedamale (2003)

Table 2.2: Typical motor technical specification parameters

Electrical Parameter	**Typical Symbol**	**Unit**	**Definition**
Reference Voltage	V	Volts	This is the rated terminal voltage.
Rated Current.	Ir	Amps	Current drawn by the motor when it delivers the rated torque
Peak Current (stall)	Ipk	Amps	This is the maximum current allowed to be drawn by the motor.
No Load Current	INL	Amps	Current drawn by the motor when there is no load on the motor shaft.
Back EMF Constant	KE	V/RPM or V/rad/s	Using this parameter, back EMF can be estimated for a given speed.
Resistance	R	Ohms	Resistance of each stator winding.
Inductance	L	mH	Winding inductance. This, along with resistance, can be used to determine the total impedance of the winding to calculate the electrical time constant of the motor.
Motor Constant	KM	Oz-in/√W or NM//√W	This gives the ratio of torque to the power.
Electrical Time Constant	τE	ms	Calculated based on the R and L of the windings.

Source: Padmaraja Yedamale (2003)

2.3.2 Ac Motors

AC motors typically feature rotors, which consist of a laminated, cylindrical iron core with slots for receiving the conductors. The most common type of rotor has cast-aluminium conductors and short-circuiting end rings.The speed of an AC motor is determined for the most part by two factors: The applied frequency and the number of poles.

$$N=120\,\frac{f}{p} \qquad \text{(Eq 2.1)}$$

Where:

N	Revolution Per Minute, rad s^{-1}
f	Frequency, Hz
P	Number of poles

Some motors such as in a typical paddle fan have the capability to switch poles in and out to control speed. In most cases however, the number of poles is constant and the only way to vary the speed is to change the applied frequency. Changing the frequency is the primary function of an AC drive (Rakesh Parekh (2003)).

2.3.2.1 Induction motor

Each motor is suitable for different applications. Although AC induction motors are easier to design than DC motors, the speed and the torque control in various types of AC induction motors require a greater understanding of the design and the characteristics of these motors (Rakesh Parekh (2003))

Generally, induction motors are categorized based on the number of stator windings which are:

• Single-phase induction motor
• Three-phase induction motor

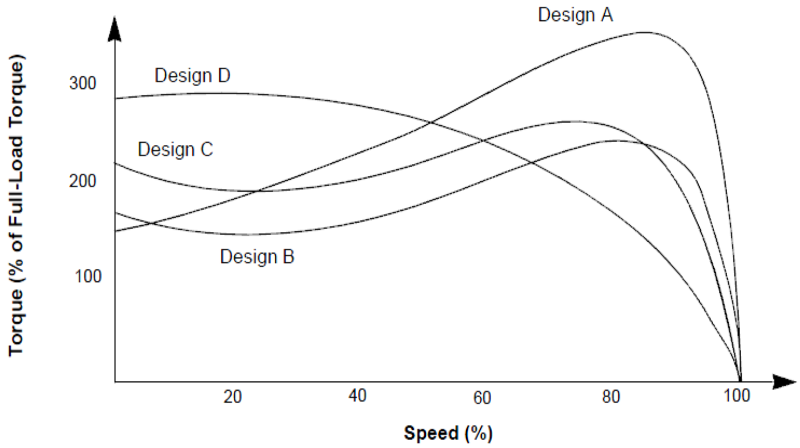

Figure 2.3: Torque versus speed induction motor

Source: Rakesh Parekh (2003)

Design A has normal starting torque (typically 150-170% of rated) and relatively high starting current.Design B is the most common type of AC induction motor sold. It has a normal starting torque, similar to Design A, but offers low starting current. Design C has high starting torque (greater than the previous two designs). Design D has high starting torque (higher than all the NEMA motor types) (Rakesh Parekh (2003))

2.4 MOTOR CONTROLLER

The motor controller is designed to convert the electrical energy obtained from the batteries and solar array to suitable power waveforms to drive the motor .The motor controller also provided for regenerative braking which permits energy normally lost in braking to be recycled to the batteries (Craig E. Hampson, Carolyn Holmes, Laurence P. Long, Robert F.D. Piacesi and William C. Raynor (1991))

Most motor controllers deliver a constant voltage to the motor, which results in a fairly constant motor speed. Pulses of voltage are sent to the motor to make it run slower or faster depending upon the width of the pulse. The pulse width determines the amount of power supplied to the motor which in turn determines how fast the motor will run. A short pulse runs the motor slowly, longer pulses cause it to run faster.
(Lake Skinner (2010))

2.5 MECHANICAL PART

In the classical model solar car, the drive motor has a little gear which meshes with a big gear on the drive wheel or the drive wheel's axle. The most accurate way to select a gear ratio (without access to a full length test track) is by mathematical modeling. Motor speed, Ms (RPM) influences the vehicle speed. (Peter Harley, (1999))

Motor mounting is to hold motor and keep it stable. Motor mounting is the most exacting part of construction if gears are to be used and is the area of construction where poor alignment or fitting will waste a portion of the precious power of the motor. (Peter Harley, (1999))

The simplest transmission system is belt drive. One of the advantages of using a pulley and belt drive mechanism is that accurate alignment of the motor and drive shaft are less important although some means of moving the motor to tension the belt must be provided. (Peter Harley, (1999))

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW CHART

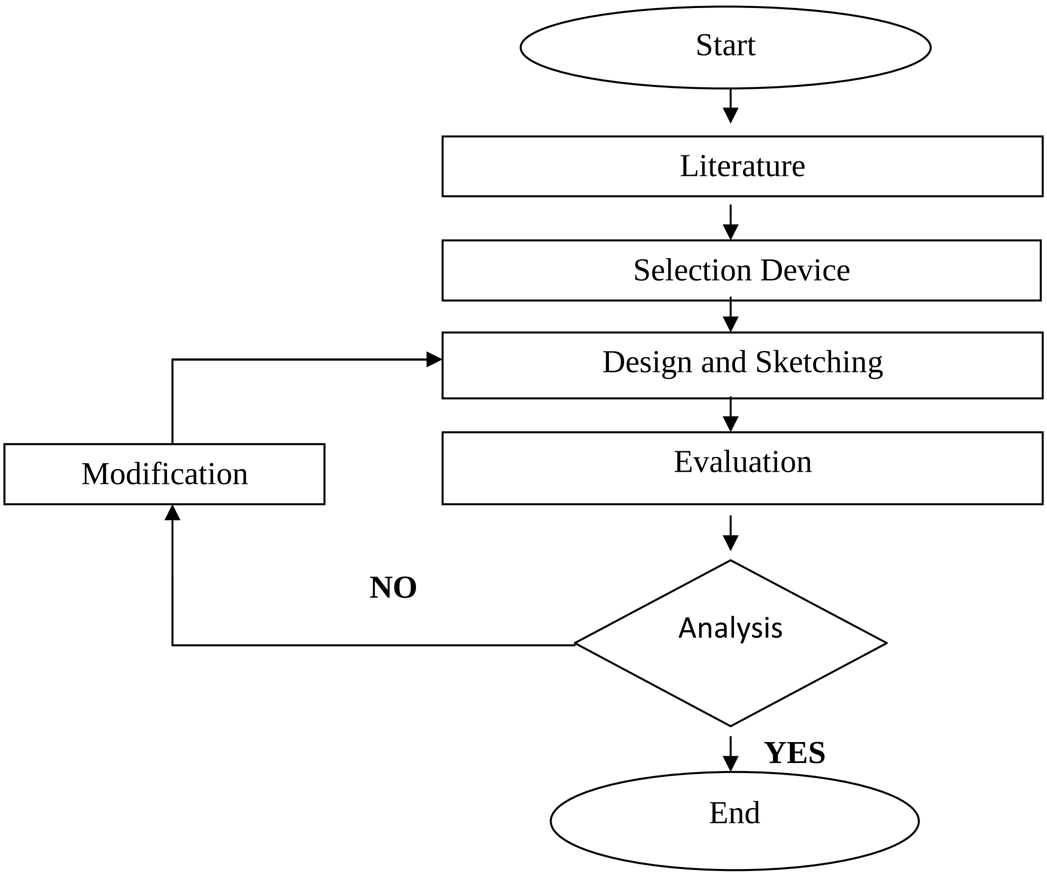

Figure 3.1: Project flow chart

3.2 SYSTEM DESIGN

System design is a consideration of all components and their interaction. In this chapter, system as those major components, that, when functioning properly and together, form a working solar car. There are two major subsystems in actuation systems which are electrical and mechanical.

3.3 METHODS IN PRODUCT SELECTION

The product selection is made by analyzing various products in shopping complex and product stores. All aspect such as project supervisor advice and market situation on products are taking into consideration before selection of the suitable product for the project.

3.3.1 Selection of motor

Within the electrical system, the motor is a key component. A motor may be seems very suitable or may be readily available, but, if refer to technical consideration, if it does not match the available power, if its weight is prohibitively high, if it is not within the budget, if mounting will present too many problems, then this particular motor is not suitable because of system considerations. For this solar car project, the sources of power are:

1. Direct solar energy, received in real time for the sun and converted with solar panels to electricity.
2. Power from the sun received in the same manner but have stored in batteries.

If choosing a motor that is too big, the motor will not have enough power to run it for the full time. If the prop does not match the RPM of the motor, it will be inefficient and waste power. If the drive system has lots of friction, lots of power will be wasted. So now it can be concluded that weight, power, propulsion are key components, which must be matched for this solar car project.

Below are criteria considerations when selecting motor.

- AC motor or DC motor
- Brushed type or brushless type
- Nominal voltage
- Operating voltage range
- Power output
- Torque
- Operating Current
- Efficiency
- Speed
- Weight
- Size

When choosing motor, about 10 motors with motor specification are selected. Those motors are compared to each other and referred to above criteria especially input voltage, operating current and power produce. These parameters are very vital and the values are ensured in between range and suitable. Input voltage that supplied to the motor must be enough to make it move with no problem. Besides, power output produce from this motor is considered to have at least 1000W. It is very important to ensure this motor capable to produce 1000W for supplying enough power to move solar car loads and driver weight.

After selecting 10 motors, a short list of motor selection has been made. 3 best motors have been chosen and the specification and pictures are shown below.

Figure 3.2: 90BLDC125A-640x

Table 3.1 Motor specification 90BLDC125A-640x

Electrical Specifications: Model	**Rated power**	**Rated voltage**	**Current**	**Rated speed**	**Torque @ rated speed**	**Peak torque**	**Length L**	**Weight**
	W	**V DC**	**A**	**rpm**	**N.m**		**mm**	**Kg**
90BLDC**70A**-640x	220	310	0.94	3000	0.7	2.1	71	1.85
90BLDC**100A**-640x	440	310	1.89	3000	1.4	4.2	100	2.6
90BLDC**125A**-640x	660	310	2.83	3000	2.1	6.3	125	4

(Source: www.motionking.com)

For this motor, high specification model which is 125A has been selected instead 70A and 100A.The weight of this motor is 4kg only. Rated speed or rotational speed for this motor is 3000rpm which is enough to move solar car. But the power produced by this motor only 660W. It is not enough to power solar car which has weight around 300kg. A conventional solar car needs at least 1000W to move with no problem. So, this motor is ignored and not be bought.

Figure 3.3: High Power Brushless DC Motor [HPM-5000B]

Model:	HPM5000B
Voltage:	24V/36V/48V/72V
Power:	3kW-7kW
Efficiency:	88%
Speed:	2000-6000 rpm
Weight	11kg
Casing	Aluminium
Length	126mm
Diameter	200mm
Shaft Dia	22mm

Table 3.2: Motor specification for BLDC [HPM-5000B]

(Source: www.goldenmotor.com)

This motor has high power output which is 3kw-7kW.This power is good enough to power solar car.This motor also has high efficiency. This motor has been selected and be bought.

3.3.2 Motor Controller

Basically, there are three ways to vary the speed of DC motors:

1. With the use of mechanical gears to achieve the desired speed. This method is generally beyond the capability of most hobbyist home workshops.

2. Reducing the motor voltage with a series resistor. However this is inefficient (energy wasted in resistor) and reduces torque. The current drawn by the motor increases as the load on the motor increases. More current means a larger voltage drop across the series resistor and therefore less voltage to the motor.

3. By applying the full supply voltage to the motor in bursts or pulses, eliminating the series dropping effect. This is called pulse width modulation (PWM) and is the method used in this kit. Short pulses means the motor runs slowly; longer pulses make the motor run faster.Below are criteria considerations when selecting motor controller.

- Pulse width modulated **(PWM)** technique
- More pulses in a given cycle
- Input and output voltage
- Maximum load (Watt)
- Maximum current (amps)
- Duty cycle adjustment range
- Size
- Dc motor controller type

While selecting motor controller, the same methods were applied when selecting motor as above. Motor controllers are selected from buy online and the best that reliable to this project has been confirmed. Pulse width modulated (PWM) technique is very necessary for motor controller and it had been top priority when choosing controller. Besides, input voltage and output voltage are also important to be considered to make sure it is suitable with motor specification. Maximum load and maximum current through controller also vital and had been taken care off.

Figure 3.4: DC Motor Speed Controller

(Source: www.electronickits.com)

Operating voltage of 9 - 18 VDC, 16Amps, uses NE556 to pulse-width modulate IRF530N MOSFET. Speed control for DC motors up to 100 Volts at 7.0Amps.

Figure 3.5: Motor Controller for High Power Brushless Motors

(Source: www.goldenmotor.com)

Suitable Motor: 48V 3-7KW

Three-phase PMSM motor with hall effect sensor.

Power supply range: 48VBattery, 30-56VDC.

Rated continuous current: 120A

HPC100B brushless motor controller is a driver for Permanent Magnet Brushless Motor. A special DSP (digital signal processor) chip suitable for motor controls is inside, and high frequency power device with sufficient heat-conduction is used. The carrier frequency is 16 kHz, and the output current is SPWM wave. The control is completely sealed (IP66) which with more features such as high-efficiency, little torque fluctuation, low noise, high-reliability. This motor controller is suitable with BLDC with high permanent magnet.

3.3.3 Electric Pedal

Below are criteria considerations when selecting electric pedal.

- Rheostat type
- Potentiometer type
- Voltage (volt)
- Current (amps)
- Spring loaded
- Metal type

Selecting electric pedal was more easy compare to other devices. Rheostat potentiometer type is selected because it is more reliable and easy to be installed. When this device is gained, just cut wire between potentiometer and connects with motor controller. Then do some soldering to ensure the attachment and it can be used. Besides, voltage also had been considered and make sure in between range same with other devices.

Figure 3.6: FSC-010 Foot Throttle

(Source: www.goldenmotor.com)

Output Voltage: 0-5V

Material: casted aluminium

Weight: 0.9Kg

Features: Water resistant

3.4 SELECTION OF DIODE

Diodes are frequently used to conduct damaging high voltages away from sensitive electronic devices. They are usually reverse-biased (non-conducting) under normal circumstances. When the voltage rises above the normal range, the diodes become forward-biased (conducting). For example, diodes are used in (stepper motor and H-bridge) motor controller and relay circuits to de-energize coils rapidly without the damaging voltage spikes that would otherwise occur. Many integrated circuits also incorporate diodes on the connection pins to prevent external voltages from damaging their sensitive transistors.

3.4.1 Diode

A diode is a device that allows current to flow in one direction only. There are two types of direction which are:

- Forward biased have current to cathode, Junction Field gets smaller, current flows.
- Reverse biased have current to anode, Junction Field gets larger, current flow stops

A Diode is also known as a Rectifier. A diode is simply a P-N Junction. The Cathode is the P-Type side, Anode is the N-Type. When current is applied to the Cathode side, the Junction Field remains small and allows the current to flow. Switch and place current on the Anode side, the Junction Field will grow larger and not allow current to flow. The electrical symbol for a diode is an arrow pointing away from the current flow.

3.5 SELECTION OF FUSES

Fuses are simple devices that are placed on a circuit to prevent the circuit from being overloaded by either a power surge or by pulling too much power through the circuit with appliances. Fuses use filament much like a light bulb that will break when it receives more electricity than it is rated for. Automotive fuses can be mounted in fuse blocks, inline fuse holders, or fuse clips.

Automotive fuse holders and blade fuses are excellent for this purpose as the fuses are easily accessible if they need changing, and it is visually obvious if a fuse has blown. Blade fuses are available in many different current ratings, each being a different (standard) colour. For smaller solar systems cylindrical fuses and fuse holders can also be used.

3.6 SELECTION OF TRANSMISSION

There are three basic types of transmissions used in solar cars:

1) Single reduction direct drive
2) Gear Drive
3) Friction drive
4) Variable ratio drive belt

1) Single reduction direct drive

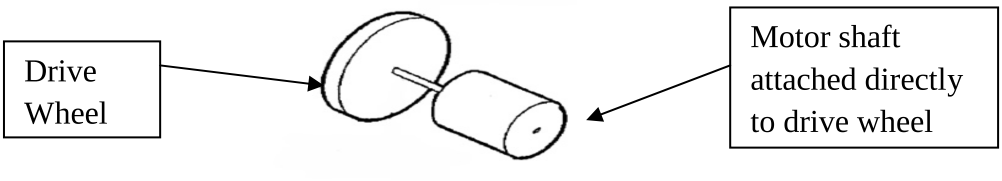

Figure 3.7: Direct drive

2) Gear drive

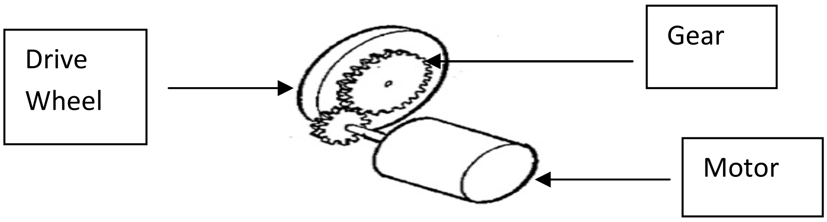

Figure 3.8: Gear drive

3) Friction drive

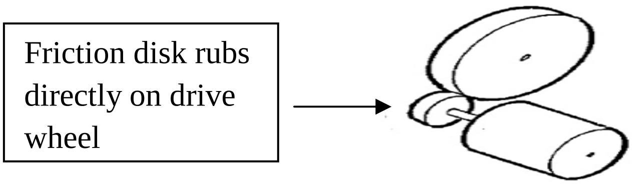

Figure 3.9: Friction drive

4) Variable ratio drive belt

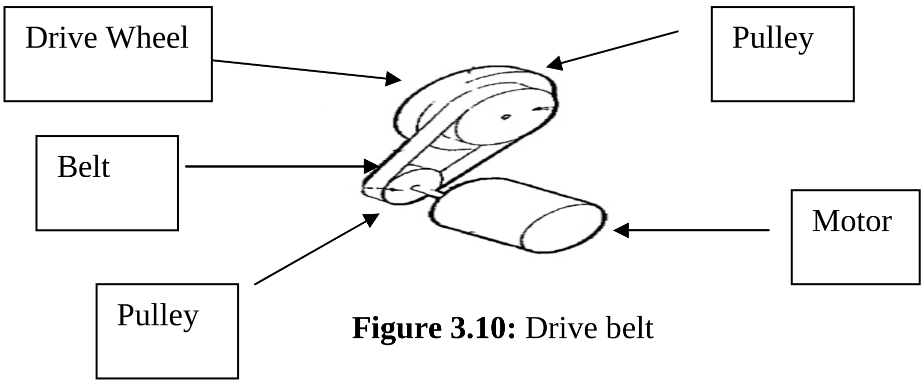

Figure 3.10: Drive belt

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter focuses on the design and analysis of the actuation system design. AC motor and DC motor specification have been analyzed by using manual calculation. It shows there is parameter different between both motor. Other electrical parts such as wire sizes, electrical connection and effect of presence of electronic component have been considered. Besides electrical, mechanical part also have been analyzed such as motor mounting bracket in ALGOR and gear ratio.

4.2 AC MOTOR ANALYSIS

1. Performance Data: Model JMSSEWDM3559T (3 phase motor)
   (Source: www.baldor.com)

Rated output= 3hp= 3x746

= 2240W

No load current= 1.25 Amps

Table 4.1: Rated load and Power factor (3 phase motor)

% of rated load	25	50	75	100	125	150
Power factor (PF)	0.58	0.79	0.87	0.91	0.93	0.94

Real power= Apparent power x PF (Eq 4.1)

Table 4.2: Real power and Speed (3 phase motor)

Real power (kW)	1.29	1.77	1.95	2.04	2.08	2.1
Speed (rpm)	3567	3541	3510	3479	3443	3403

The value of speed (rpm) must be converted by using this formula

$$\text{RPM x } \frac{2\pi}{60} \qquad \text{(Eq 4.2)}$$

After that the value gained is substitute into power equation which is:

$$P=\tau\ \omega \qquad \text{(Eq 4.3)}$$

So the formula for torque is

$$\tau= \frac{P}{\omega} \qquad \text{(Eq 4.4)}$$

Where

P Power, W

τ Torque, Nm

ω Rotational speed, rad s^{-1}

Table 4.3: Full table for Model JMSSEWDM3559T

% of rated load	25	50	75	100	125	150
Power factor (PF)	0.58	0.79	0.87	0.91	0.93	0.94
Real power (kW)	1.29	1.77	1.95	2.04	2.08	2.1
Efficiency (%)	79.7	86.3	87.2	86.9	85.6	83.9
Speed (rpm)	3567	3541	3510	3479	3443	3403
Line Amperes	1.53	2.07	2.78	3.55	4.42	5.4
Load torque (Nm)	3.45	4.77	5.3	5.59	5.77	5.89

Two parameters are selected and graph is plotted.

Table 4.4: Speed and load torque (3 phase motor)

Speed (rpm)	3567	3541	3510	3479	3443	3403
Load torque (Nm)	3.45	4.77	5.3	5.59	5.77	5.89

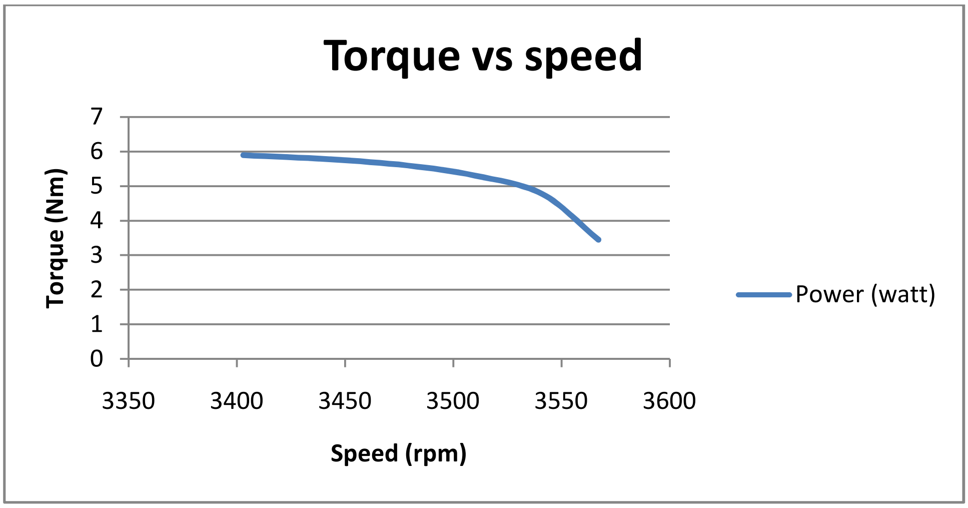

Figure 4.1: Graph torque versus speed for ac motor 3HP 3phase

2. Performance Data: model UCCE570 (Single phase)
   (Source: www.baldor.com)

Rated output= 5hp= 5x746

= 3730W

No load current= 3.5 Amps

Table 4.5: Rated load and Power factor (Single phase)

% of rated load	25	50	75	100	125	150
Power factor (PF)	0.96	0.98	0.98	0.98	0.98	0.97

Real power= Apparent power x PF

=3.73kWxPF

Table 4.6: Real power and Speed (Single phase)

Real power (kW)	3.58	3.65	3.65	3.65	3.65	3.61
Speed (rpm)	3568	3538	3506	3470	3428	3378

The same calculation for 3phase motor is used to proceed analysis for single phase motor. Equation 4.2, equation 4.3, equation 4.4 have been used to get the value of torque at given torque and rotational speed.

Table 4.7: Full table for Model UCCE570

% of rated load	25	50	75	100	125	150
Power factor (PF)	0.96	0.98	0.98	0.98	0.98	0.97
Real power (kW)	3.58	3.65	3.65	3.65	3.65	3.61
Efficiency (%)	68.2	80	83.5	84	83	80.9
Speed (rpm)	3568	3538	3506	3470	3428	3378
Line Amperes	8.7	14.5	20.8	27.5	35	43.4
Load torque (Nm)	9.58	9.85	9.94	10.04	10.16	10.2

Two parameters are selected and graph is plotted.

Table 4.8: Speed and load torque (Single phase)

Speed (rpm)	3568	3538	3506	3470	3428	3378
Load torque (Nm)	9.58	9.85	9.94	10.04	10.16	10.2

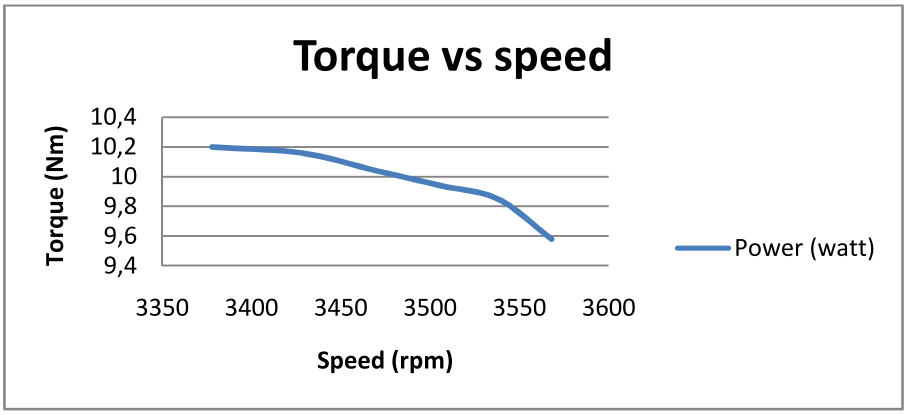

Figure 4.2: Graph torque versus speed for AC motor 5HP 1phase

From figure 4.2, it shows that AC motor with high horsepower produces higher torque. Torque is inversely proportional to speed but it does not mean that higher torque produced at lower speed. Maximum torque happens at approximate speed, in between the range, not at lower speed.

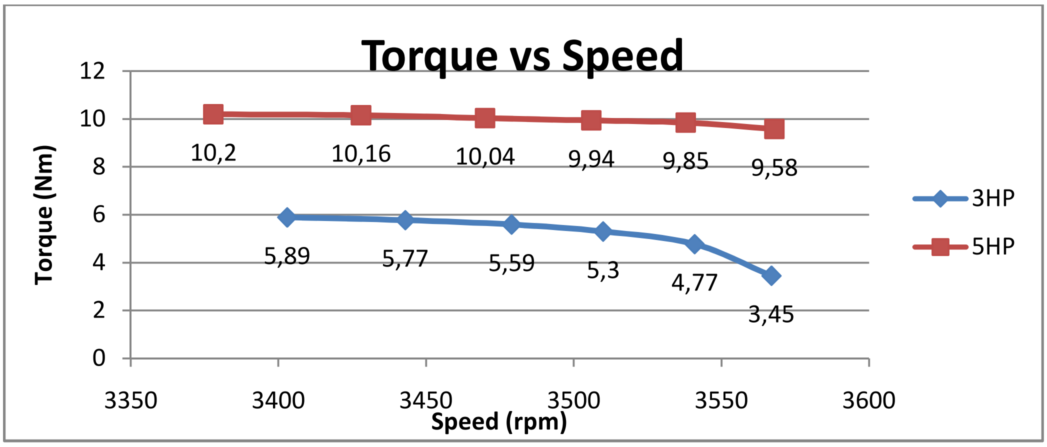

Figure 4.3: Graph torque versus speed for AC motor 3HP and 5HP

Figure 4.3 shows torque produced at given speed from two motor with different horsepower for AC motor.

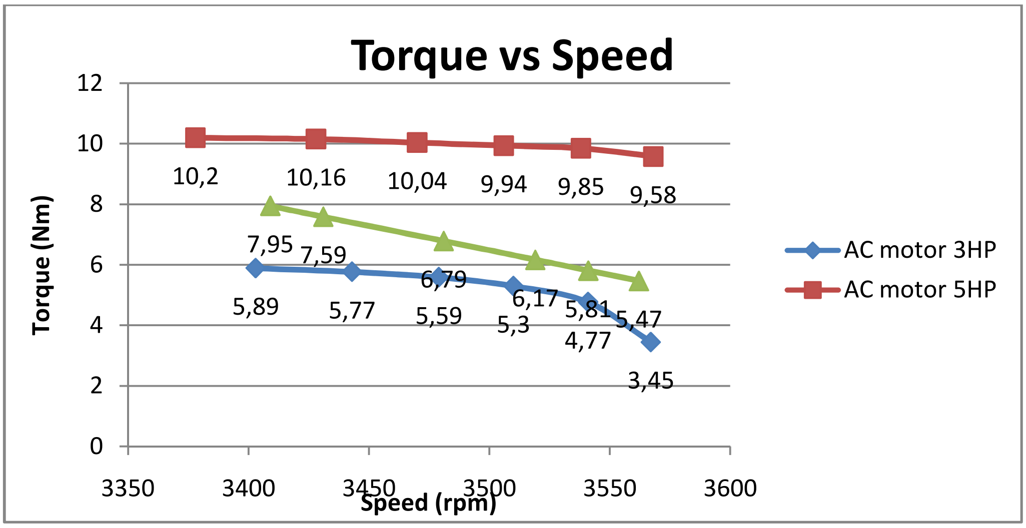

Figure 4.4: Graph torque versus speed for 3HP AC motor, 5HP AC motor and 3HP DC motor.

Figure 4.4 shows that torque for AC motor is lower if comparing to DC motor at the same power. 3HP DC motor with green marked has higher torque compared to 3HP AC motor with blue marked. If using AC motor for solar car and the torque required is higher, then AC motor with high horsepower will be needed. It is already knows that AC motor with high horsepower costs more money because of high price. Hence, using DC motor for solar car is suitable because the price is reasonable and more important thing it produces high torque.

4.3 DC MOTOR ANALYSIS

DC motors comes in many shapes and sizes. Some are standardized electric motors for general-purpose applications. Other electric motors are intended for specific tasks. In any case, electric motor has to be selected to satisfy the dynamic requirements of the solar car without exceeding rated electric motor temperature. Thus, the first and most important step in electric motor selection is determining load characteristics such as torque and speed versus time. Electric motor selection is also based on application, power available, and cost. Starting and running torque are the first parameters to consider when sizing electric motors.

After considering 2motors, HPM-5000B has been selected and be bought. This motor is suitable for this solar car project. This motor has voltage between 24-72V and power between 3kW-7kW.This motor is a brushless DC type.

Table 4.9: HPM-5000B motor specification

Model:	HPM5000B
Voltage:	24V/36V/48V/72V
Power:	3kW-7kW
Efficiency:	88%
Speed:	2000-6000 rpm
Weight	11kg
Casing	Aluminium
Length	126mm
Diameter	200mm
Shaft Dia	22mm

(Source: www.goldenmotor.com)

Table 4.10: HPM-5000B Motor Performance Data

Torque	RPM	Power Output	Voltage	Current	Power Input	Efficiency
3.86	3662	1480.32	47.98	37.03	1777.08	83.3
4.15	3644	1583.73	47.96	39.23	1881.65	84.2
4.49	3623	1703.58	47.93	41.81	2004.11	85
4.8	3604	1811.55	47.9	44.17	2115.63	85.6
5.07	3587	1904.57	47.88	46.22	2212.65	86.1
5.47	3562	2040.65	47.84	49.25	2356.21	86.6
5.81	3541	2154.68	47.81	51.83	2478.06	87
6.17	3519	2273.78	47.78	54.56	2606.91	87.2
6.53	3497	2391.21	47.75	57.29	2735.59	87.4
6.79	3481	2474.97	47.72	59.27	2828.41	87.5
7.24	3453	2617.87	47.68	62.68	2988.85	87.6
7.59	3431	2727.19	47.65	65.34	3113.45	87.6
7.95	3409	2837.99	47.62	68.07	3241.44	87.6
8.3	3387	2944.09	47.59	70.72	3365.7	87.5
8.68	3364	3057.49	47.56	73.61	3500.42	87.3
8.94	3347	3134	47.53	75.58	3592.49	87.2
9.39	3320	3264.36	47.49	78.99	3751.63	86.8
9.76	3297	3369.57	47.46	81.8	3882.26	86.5
10.16	3272	3481.31	47.42	84.84	4023.29	86.3
10.52	3250	3580.1	47.39	87.57	4150.02	86
10.82	3231	3661.15	47.36	89.84	4255.5	85.7
11.26	3204	3777.9	47.33	93.18	4409.98	85.7
11.63	3181	3874.14	47.29	95.99	4539.68	85.3
12.04	3156	3978.71	47.26	99.1	4683.19	85
12.4	3133	4068.73	47.22	101.83	4809.01	84.6
12.69	3115	4140.02	47.2	104.03	4910.24	84.3
13.16	3086	4253.24	47.16	107.6	5074.06	83.8
13.53	3063	4340.36	47.12	110.41	5202.81	83.4
13.73	3051	4386.71	47.11	111.93	5272.33	83.2
13.99	3035	4446.2	47.08	113.9	5362.63	82.9
14.39	3010	4536	47.05	116.93	5501.36	82.5
14.79	2985	4623.72	47.01	119.97	5639.88	82
15.3	2954	4732.56	46.97	123.84	5816.18	81.4
15.68	2930	4811.46	46.93	126.72	5947.31	80.9

(Source: www.goldenmotor.com)

4.3.1 Torque RPM and Power calculation

RPM :

RPM is proportional to voltage, double the voltage and the RPM will double. However, there is a limit to the linear range of RPM versus voltage, because some losses are not linear with speed example windage losses of the armature rotating in air vary with RPM squared. This means at very high RPM, the RPM is not directly proportional to voltage, and in fact significant power may be lost in this additional friction

TORQUE:

Torque is described as the amount of force from any given distance from that force rotational center point. In this case the center point of force will be the exact center of the round motor shaft. Motor torque is directly proportional to current, double the current and the motor torque will double. There is also a limit to this linear relationship imposed by the field strength of the permanent magnet and saturation of the magnetic field of the rotor.

POWER:

The motor when operated at its nominal voltage will produce power up to the maximum stated by the manufacturer. To obtain more power from the same motor it is necessary to increase the supply voltage. Note that running a motor above its nominal power will reduce its life. When estimating the power input to the motor, use the formula involving voltage and current. When estimating the power output from the motor, use the formula involving torque and rotational speed. The difference is wasted energy, which manifests itself as heat produced by the motor.

4 Graphs for HPM-5000B

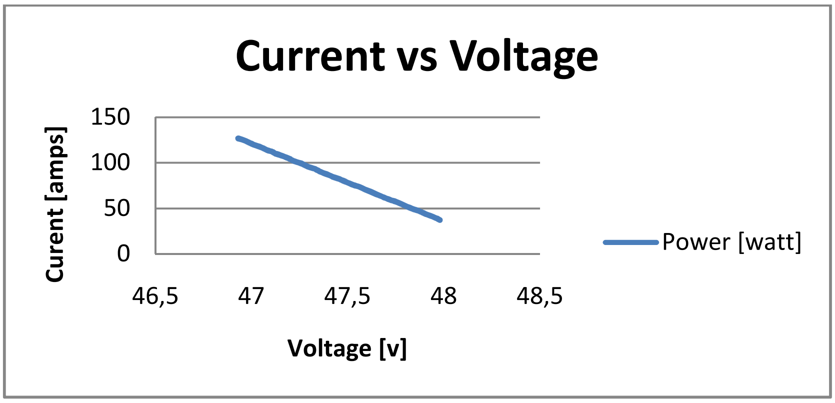

Figure 4.5: HPM-5000B Current versus Voltage graph

The formula for power is

$$P = V \times I \qquad \text{(Eq 4.5)}$$

Power is directly proportional to current and voltage. While voltage is inversely proportional to current. From figure 4.5, it shows that at high current supplied, the voltage produced is lower.

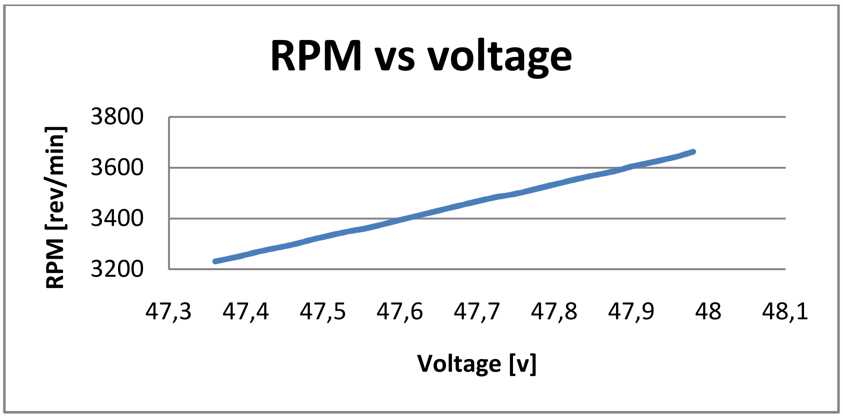

Figure 4.6: HPM-5000B RPM versus Voltage graph

From figure 4.6, it shows that RPM is directly proportional to voltage supplied. . Hence, if double the voltage and the RPM follows and double RPM value. If motor received enough voltage, then it would have higher rotational speed and able to move faster.

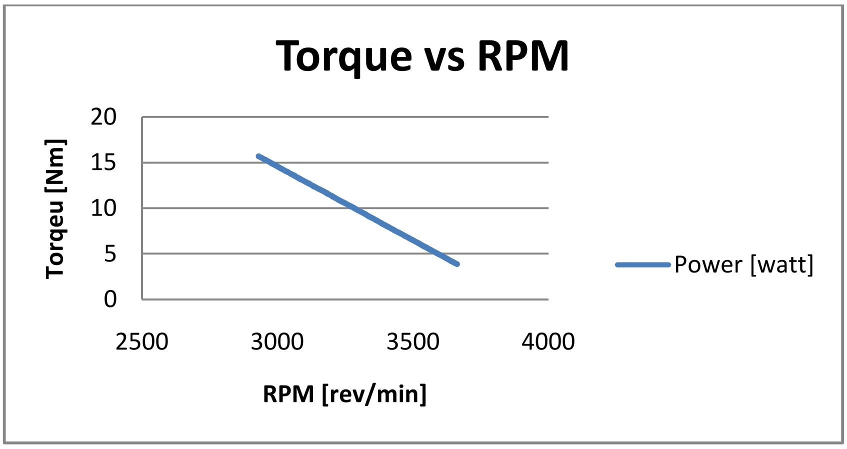

Figure 4.7: HPM-5000B Torque versus RPM graph

The formula for power at given torque and rotational speed is

$$P=\tau\ \omega$$

From figure 4.7, it shows that torque is inversely proportional with rotational speed. Motor would have higher torque at 3000rpm. Power produced by the motor depends on torque and rotational speed.

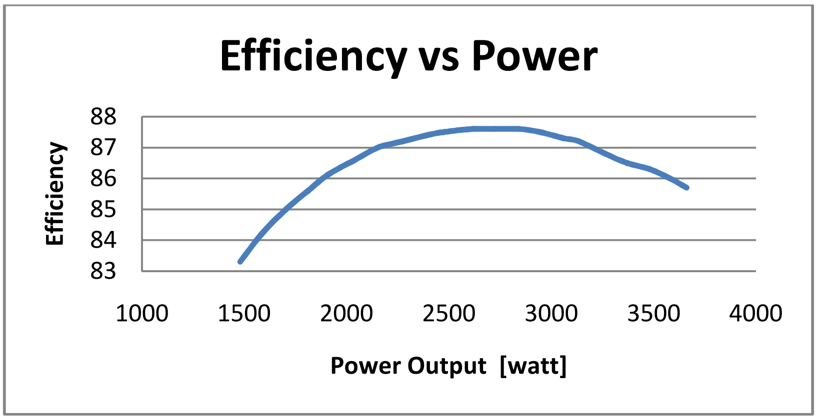

Figure 4.8: HPM-5000B Efficiency versus Power

Efficiency of this motor increases with power output produced. At power equal to 2837.99W it achieved optimum efficiency which is 87.6%. After that, the efficiency of this motor drops a little bit.

4.4 POWER TO WEIGHT

The weight is a direct multiplier on rolling resistance. Twice the weight means twice the rolling resistance for the same wheels, tires and bearings. Remember though, that there must be enough weight on the drive wheels so that they do not spin.

$$\text{Power to weight ratio} = \frac{\text{Power}}{\text{Weight}} \qquad \text{(Eq 4.6)}$$

Power of motor=3000W

Total weight including driver= 300kg

=300x9.81N

=2943N

Power to weight ratio= 3000/2943

=1.019w/N

Solar car need enough power from batteries and solar array to support motor very well. Solar car with high power to weight ratio moves faster than lower power to weight ratio. This calculation is vital to ensure motor that has been bought suitable to this solar car.

4.5 MOTOR CONTROLLER

After considering 2 motor controllers, Motor Controller for High Power Brushless Motors has been selected and be bought.
(Source: Golden Motor Company 2010)

4.5.1 Wiring motor controller

Ensure wire the system as attached drawing. There are 4 colours for motor controller which are red, blue, yellow, green. For motor connection, there are 3 colours which are blue, yellow and green. Ensure the connection of every part is correct as drawing show, and use right wiresand terminals.

4.6 ELECTRICAL CONNECTIONS

Electrical connections are most often made in series or in parallel. Battery to battery are typically not connected in parallel, only in series. Loads, or resistances, are typically connected in parallel, but can be connected either way.

Note that the solar panel and batteries are connected in parallel. Some important rules to remember about series and parallel circuits are:

- Circuit elements that are in series always have the same current flowing through them
- Circuit elements that are in parallel have the same voltage across them

4.6.1 Design Wire Sizes

Wires, generally made of copper, are conductors of electricity. Silver actually conducts electricity better than copper, but is not often used because of its cost. The cross-sectional area of the wire determines the resistance of the wire per unit length: The larger the wire, the smaller the resistance and therefore the more current that the wire can safely carry without overheating.

Size wire is vital for worst case scenario:

- Temperature
- Voltage
- Current

Wire should be capable of carrying more current than fuses at operating temperatures.

The amount of current expected in a circuit determines the size of the wire. More current requires larger wires. Running large amounts of currents through small wires can be done, but this will cause the wires to heat up, resulting in power losses in the system and creating a potential fire hazard. Using a wire that is too large does not create problems other than the fact that the wire costs and weighs more.

4.6.2 Analysis Wire Sizes

Take example from specification provided by manufacturer.

Power input=3365.70 W

Voltage= 47.59 V

Use formula power,

$$P = V \times I \qquad \text{(Eq 4.7)}$$

So, $I=\frac{P}{V}$

$=\frac{3365.70}{47.59}$

$=70.72A$

So the cable selected must be higher than 70.72amps in order to ensure safety and make sure the cable can withstand the current flow.

4.7 BLOCK DIAGRAM OF ELECTRICAL CONNECTION

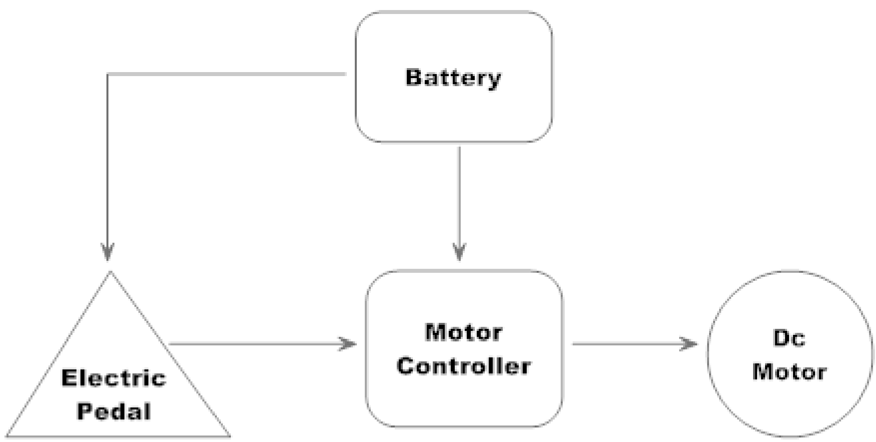

Figure 4.9: Block diagram

4.7.1 The Purpose of Switches

Add switches when it makes sense for added safety.

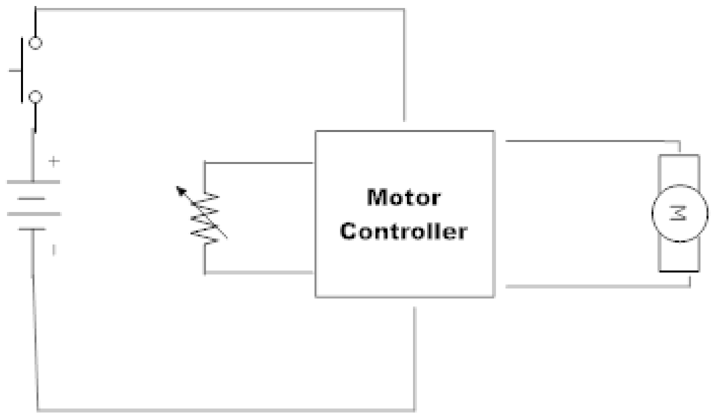

Figure 4.10: Switch electrical circuit

4.7.2 The Purpose of the Diode

The Purpose of the diode in this circuit is related to the its function to allow current to flow in one direction only. So, if the direction is wrong, the current would not flow in circuit. Should the end of the negative cable touch any exposed metal of the positive cable or vise versa, a short circuit will occur. Huge amounts of electric current will flow potentially causing sparks, melting the cable, and even causing the battery to explode. If any cable connection failure is happen near the wire cable or at the battery, the circuit would not work. The purpose of diode is to added safety to the electrical circuit.

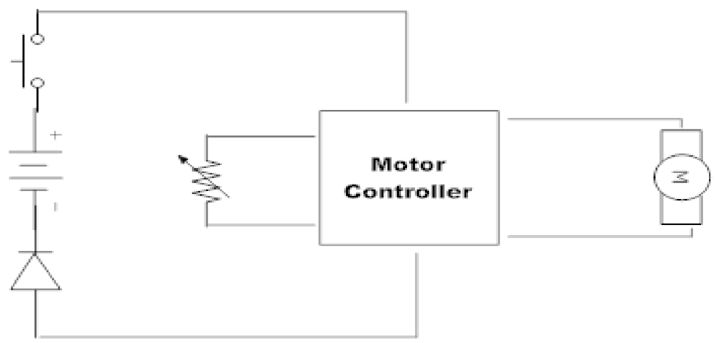

Figure 4.11: Diode electrical circuit

4.7.3 The Purpose of the Fuses

With an appropriately rated fuse fitted in the positive cable as near to motor as possible any short circuit will be over within a split second before any serious damage can be done. The fuse chosen should be rated at approximately 120% of the absolute maximum output current rating of the motor to ensure it will immediately blow in short circuit conditions, but will never blow in normal operation. Furthermore, if the worst scenario happens such as the motor is stuck and do not spin when switch is on, the current supplied will have high amps. These high amps will damage motor controller system. The fuses installed between motor and motor controller could save the system and avoid anything dangerous happen.

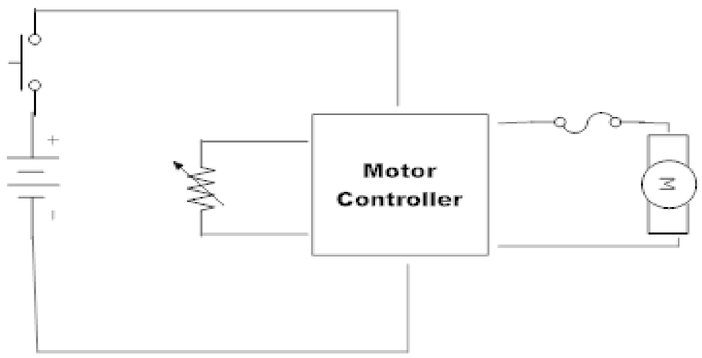

Figure 4.12: Fuses electrical circuit

4.7.4 Complete Electrical Design for Actuation System

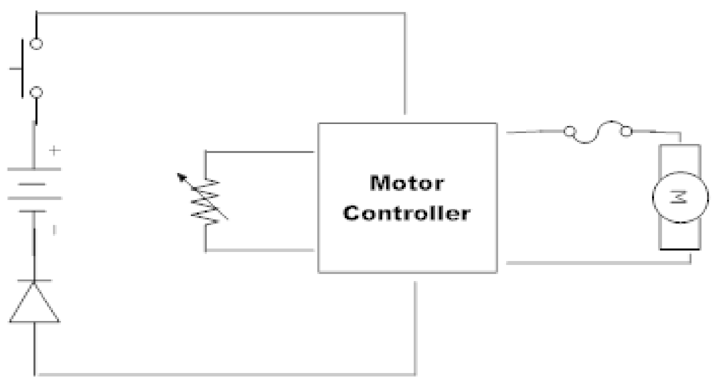

Figure 4.13: Complete electrical circuit

4.8 MOTOR MOUNTING BRACKET RESULT

The function of motor mounting bracket is to hold motor and keep it stable. The rotor rotates frequently in motor and contributes to higher vibration. Motor mounting bracket has to withstand the vibration and heat produced by motor when it is functioning. The purpose of the design and analysis is to provide a motor mounting bracket which reduces or isolates motor vibration. Another purpose is to provide such a bracket which isolates blade imbalance. The designed considered has to be economical to produce and simple to apply.

There are two materials have been selected to be used in motor mounting bracket for this solar car. The materials are Aluminium AL6061 and Steel (ASTM-A36).

Aluminium AL6061 is one of the most famous of the heat-treatable aluminium alloys. It is one of the most common alloys of aluminium for general purpose use. It has combination of high strength, corrosion resistance and good formability. This has make it become attractive for use in a wide variety of mechanical applications. Aluminium AL6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. This material has excellent joining characteristics and good acceptance of applied coatings. Instead, it combines relatively high strength, good workability, and high resistance to corrosion.

Steel (ASTM-A36) is one of the most widely used carbon steel plate specifications for constructional purposes.It is a standard steel alloy and standard carbon steel and without advanced alloying.

4.8.1 Natural frequency analysis for Aluminium AL6061

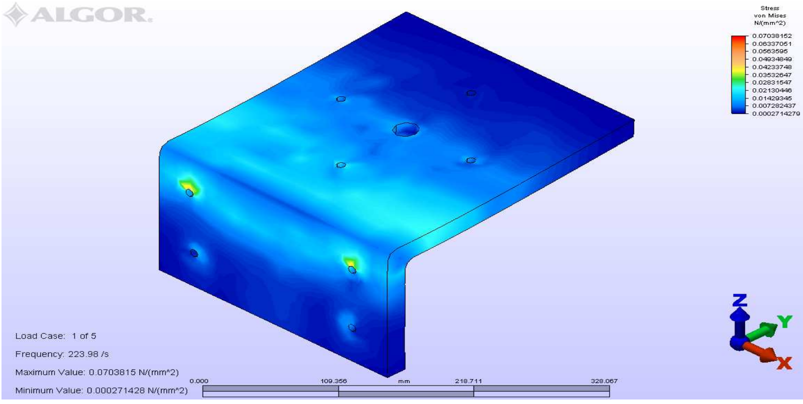

Figure 4.14: Mode 1 Aluminium AL6061

Mode 1:

Frequency : 223.98 s^{-1}

Maximum value is 0.0703815 Nmm^{-2}

Minimum value is 0.000271428 Nmm^{-2}

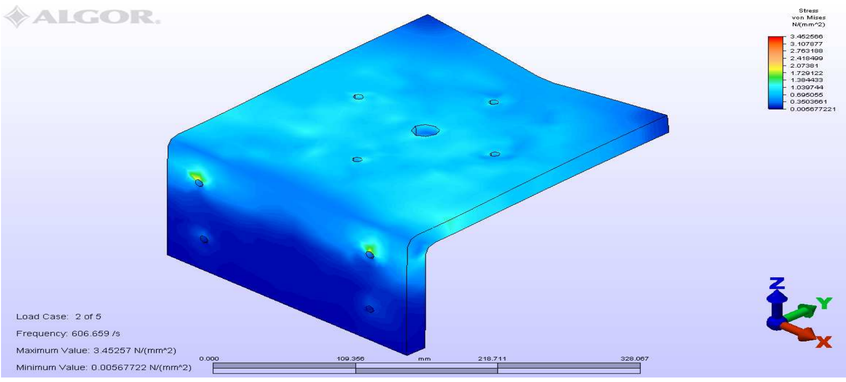

Figure 4.15: Mode 2 Aluminium AL6061

Mode 2:

Frequency : 606.659 s^{-1}

Maximum value is 3.45257 Nmm^{-2}

Minimum value is 0.00567722 Nmm^{-2}

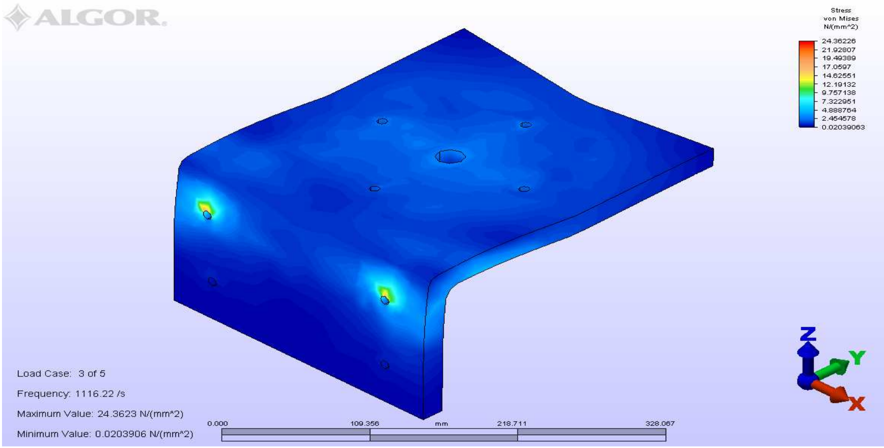

Figure 4.16: Mode 3 Aluminium AL6061

Mode 3:

Frequency : $1116.22s^{-1}$

Maximum value is 24.3623 Nmm^{-2}

Minimum value is 0.0203906 Nmm^{-2}

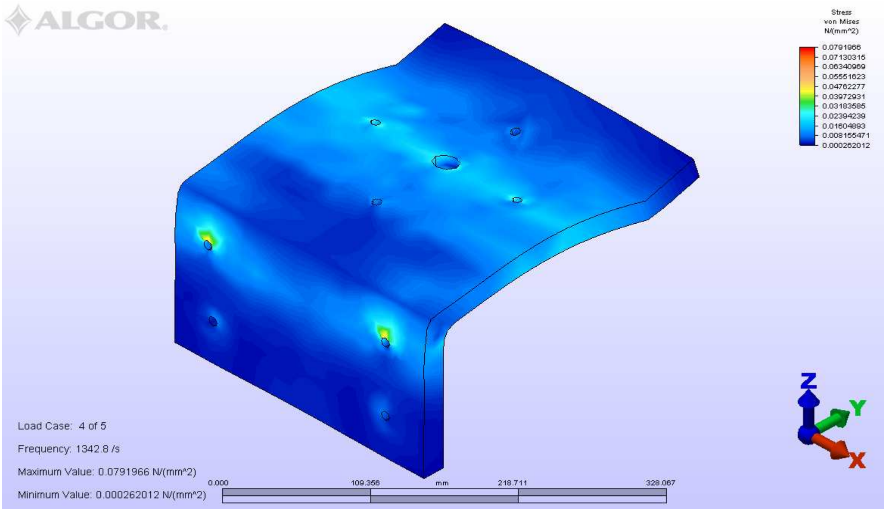

Figure 4.17: Mode 4 Aluminium AL6061

Mode 4:

Frequency : 1342.8 s^{-1}

Maximum value is 0.0791966 Nmm^{-2}

Minimum value is 0.000262012 Nmm^{-2}

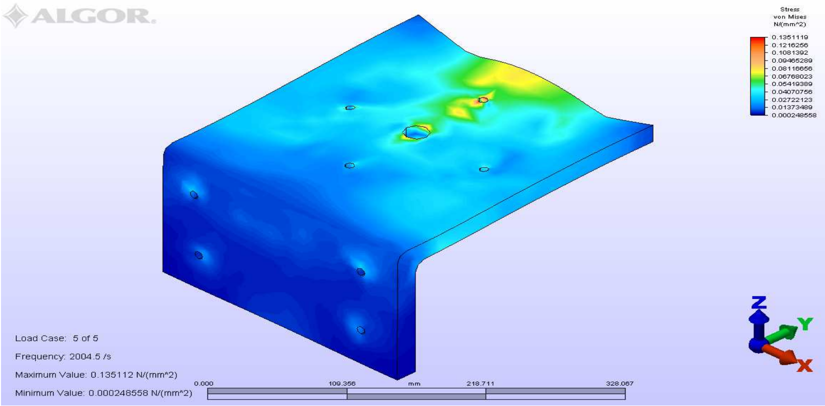

Figure 4.18: Mode 5 Aluminium AL6061

Mode 5:

Frequency : 2004.5 s^{-1}

Maximum value is 0.135112 Nmm^{-2}

Minimum value is 0.000248558 Nmm^{-2}

4.8.2 Natural frequency analysis for Steel (ASTM-A36)

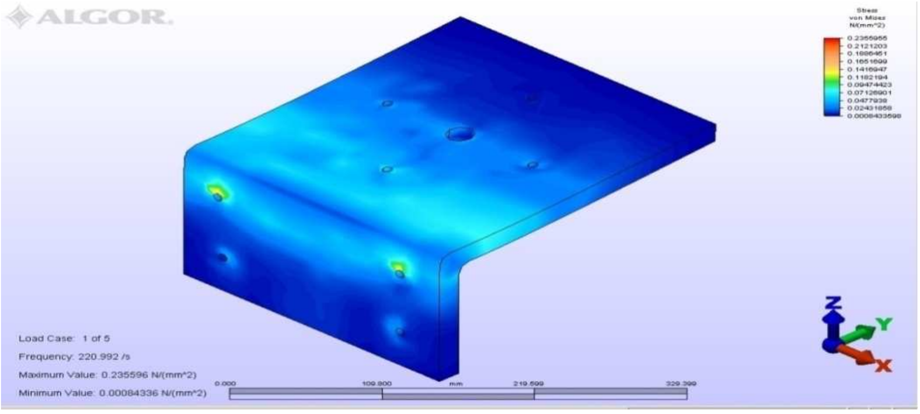

Figure 4.19: Mode 1 Steel (ASTM-A36)

Mode 1:

Frequency : 220.992 s^{-1}

Maximum value is 0.235596 Nmm^{-2}

Minimum value is 0.00084336 Nmm^{-2}

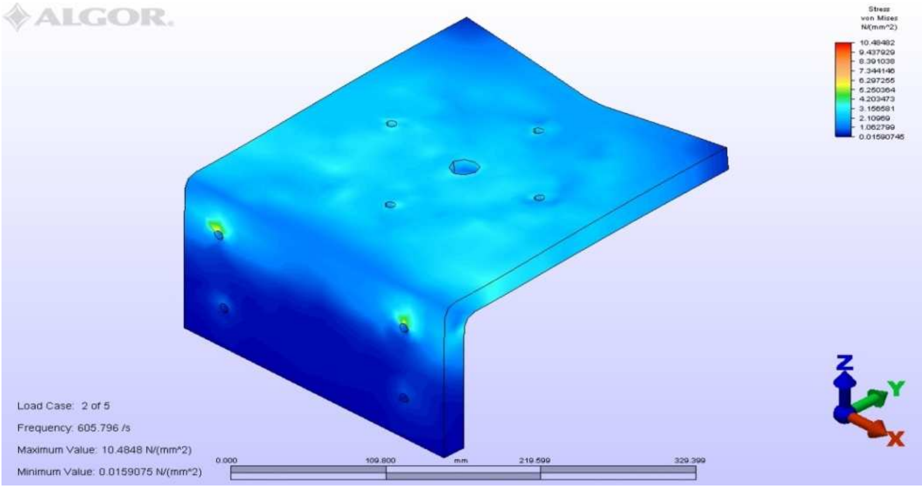

Figure 4.20: Mode 2 Steel (ASTM-A36)

Mode 2:

Frequency : 605.796 s^{-1}

Maximum value is 10.4848 Nmm^{-2}

Minimum value is 0.0159075 Nmm^{-2}

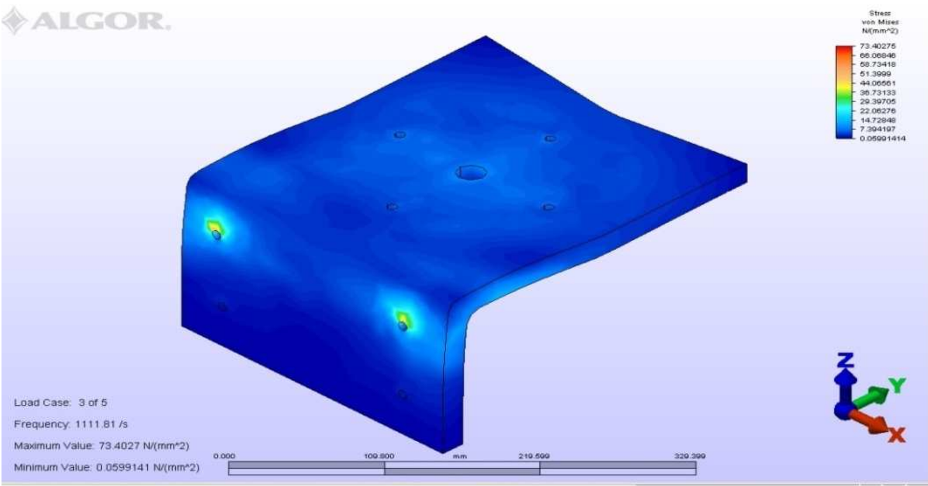

Figure 4.21: Mode 3 Steel (ASTM-A36)

Mode 3:

Frequency : 1111.81 s^{-1}

Maximum value is 73.4027 Nmm^{-2}

Minimum value is 0.0599141 Nmm^{-2}

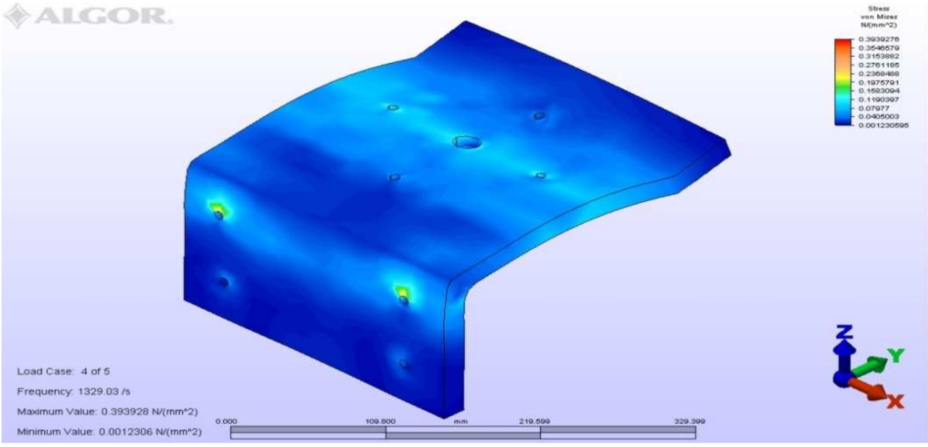

Figure 4.22: Mode 4 Steel (ASTM-A36)

Mode 4:

Frequency : 1329.03 s^{-1}

Maximum value is 0.393928 Nmm^{-2}

Minimum value is 0.0012306 Nmm^{-2}

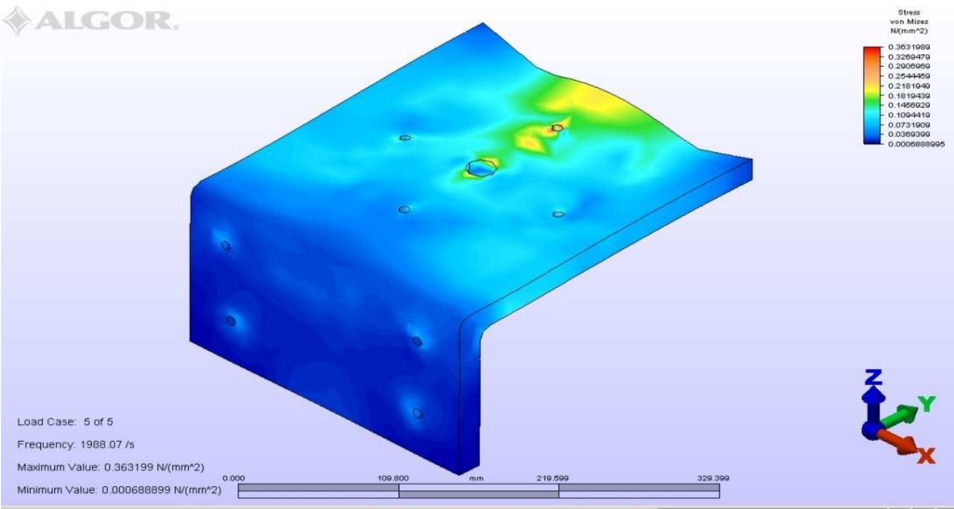

Figure 4.23: Mode 5 Steel (ASTM-A36)

Mode 5:

Frequency : 1988.07 s^{-1}

Maximum value is 0.363199 Nmm^{-2}

Minimum value is 0.000688899 Nmm^{-2}

4.8.3 Analysis Motor Mounting Bracket

Natural frequency is frequency at which a mechanical system will vibrate freely. If a varying force with a frequency equal to the natural frequency is applied to such an object the vibrations can become violent, a phenomenon known as resonance. The basic theory of natural frequency is material with high frequency value can withstand vibration better than lower value. The highest value for Aluminium AL6061 in mode 5 where the natural frequency is $2004.5s^{-1}$. While for Steel (ASTM-A36), the highest value in mode 5 where the natural frequency is $1988.07s^{-1}$.

The difference between two values is very small which is $16.43s^{-1}$. From this analysis algor, it shows that both material Aluminium AL6061 and Steel (ASTM-A36) can be used for motor bracket because both have high value of natural frequency. But Aluminium AL6061 is better because it is higher than Steel(ASTM-A36). Furthermore, the maximum value Stress Von Mises for Aluminium AL6061 is 0.135112 Nmm^{-2}which is lower than Steel(ASTM-A36) which is 0.363199 Nmm^{-2}. Material with lower Stress Von Mises is good and withstands vibration very well.

4.9 TRANSMISSION

Between 4 transmissions available for solar car which are drive belt, single reduction direct drive, gear drive and friction drive, drive belt has been selected. The drive train can waste energy too. Gears can be particularly wasteful if they are not precision made. Some form of belt drive may be best, but be sure the belt does not slip, and that it is not overly tight. The drive ratio is important. The one drawback is that the belts come in fixed lengths and thus the relative position of the motor and shaft becomes very important. Large belt losses at low revolutions per minute. It is important to have of proper tensioning to maintain high efficiency at all motor speeds.

If the wheel is too big, the motor will be overburdened and the wheel will never get up to speed. In essence, it is in too high of a gear. If the wheel is too small, or the pitch too flat, it will spin and will be very ineffective.

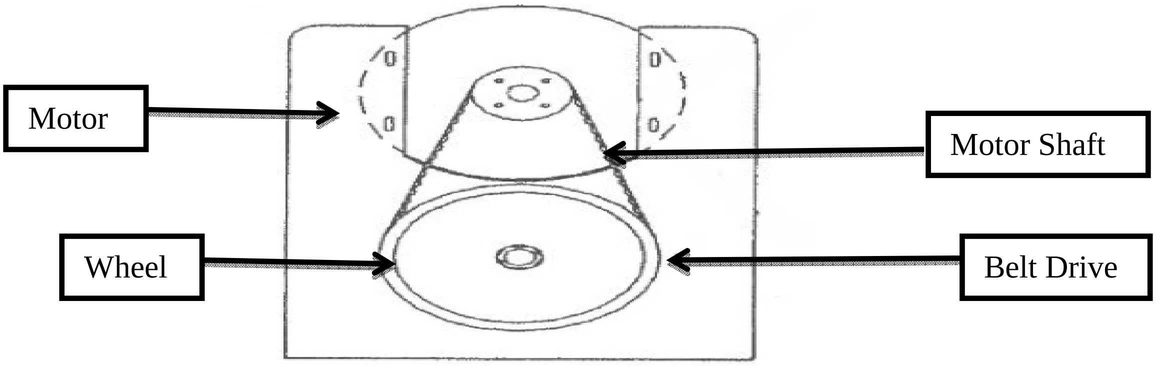

Figure 4.24: Belt drive diagram

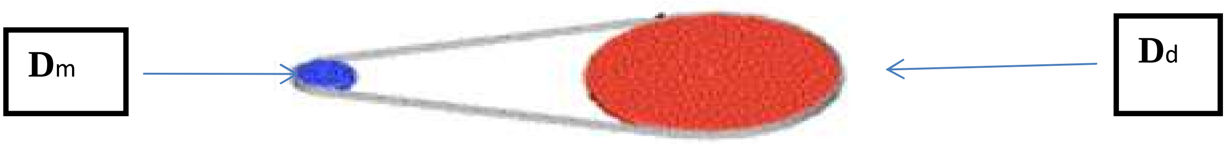

Figure 4.25: Gear ratio diagram

The variable D is the diameter of the pulley. The subscript d refers to the gear or pulley attached to the drive axle and the subscript m refers to gear or pulley attached to the motor.

For a Pulley System the gear ratio (GR) is:

$$R=\frac{Dd}{Dm} \qquad \text{(Eq 4.8)}$$

4.9.1 Analysis gear ratio for 6 inch =152.4mm driven pulley

Driver diameter

$\frac{3}{4}$ inch =19mm and1 inch =25.4mm

Table 4.11: Driven pulley 6inch

Driver diameter, Dm (mm)	**Driven pulley diameter, Dd (mm)**	**Gear ratio**
19	152.4	8.02
25.4	152.4	6

(Source: www.gokartsupply.com)

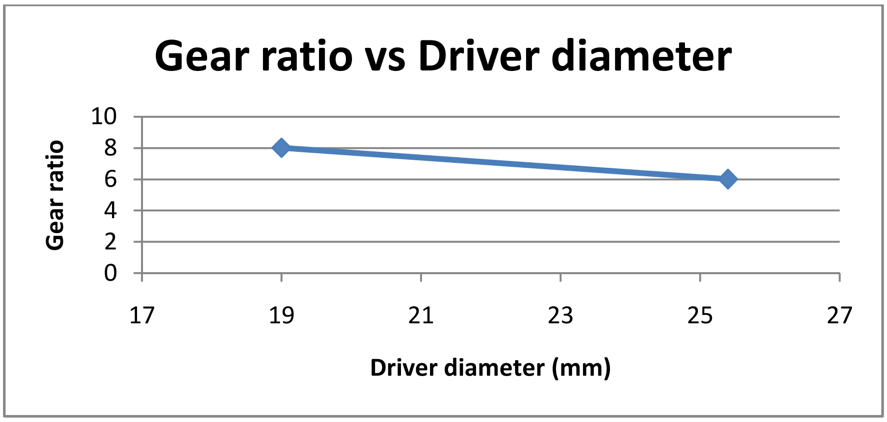

Figure 4.26: Gear ratio versus driver diameter for 6inch

4.9.2 Analysis gear ratio for 7 inch =177.8mm driven pulley

Driver diameter

$\frac{3}{4}$ inch =19mm and1 inch =25.4mm

Table 4.12: Driven pulley 7inch

Driver diameter (mm)	**Driven pulley diameter (mm)**	**Gear ratio**
19	177.8	9.36
25.4	177.8	7

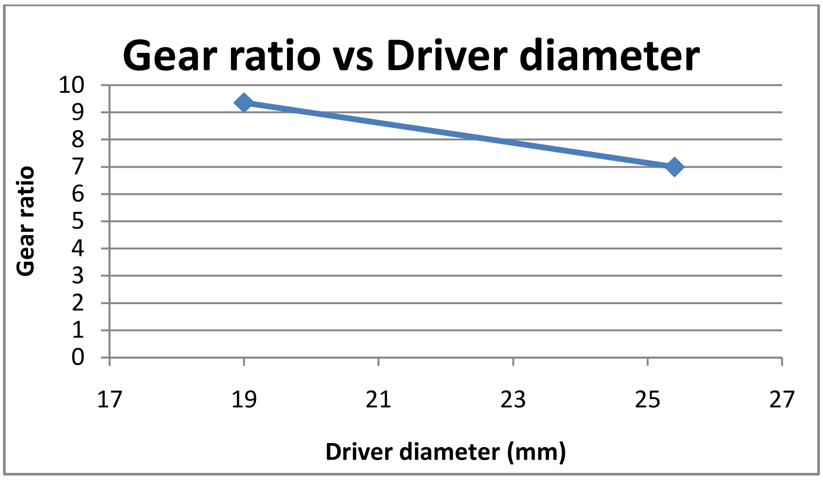

Figure 4.27: Gear ratio versus driver diameter for 7inch

From both figure 4.26 and figure 4.27, 19mm driver diameter with 177.8mm or 7inch driven pulley diameter has higher gear ratio.

4.9.3 Analysis for suggested torque converter

Design for belt drive for motor transmission can be applied by installing torque converter.

G3 Asymmetric Torque Converters

For 3 to 8 Horsepower

Figure 4.28: Example torque converter

(Source: www.gokartsupply.com)

Specification:

Specification:

Engagement Range: Minimum 1200 RPM Maximum 3100 RPM

Horsepower =3 to 8 Horsepower

Driver (motor) diameter =1inch

Driven pulley diameter = 6inch

Analysis

1) Considering horsepower value:

4hp =4x746watt =2984W compare with HPM5000B Motor Power =3kW-7kW

2) Considering diameter shaft motor:

Driver (torque converter) diameter =1inch =2.54cm=25.4mm compare with Diameter HPM5000B motor shaft=22mm. The diameter for driver torque converter is greater than diameter HPM5000B. Hence it fixes approximately.

4.9.4 Calculation For Wheel Speed

Step 1:

Determine the gear ratio (GR)

For a pulley system the gear ratio is:

$$\mathbf{R}=\frac{Dd}{Dm}$$

$$=\frac{152.4}{25.4}$$

$$=6$$

Step 2:

Find out the speed of the wheel. From motor performance data provided by manufacturer, at maximum efficiency which is 87.6%, the power equal to 2837.99W. At this power, the motor speed is 3409rpm**.** If the motor spins at 3409 rpm then the wheel will spin at:

$$\omega d = \frac{RPM}{GR} \qquad \text{(Eq. 4.9)}$$

$$\omega d = \frac{3409\text{ rpm}}{6} = 568.2\text{ rpm}$$

When considering gear ratio, make sure the diameter of wheel is bigger than the diameter of the drive gear (motor).

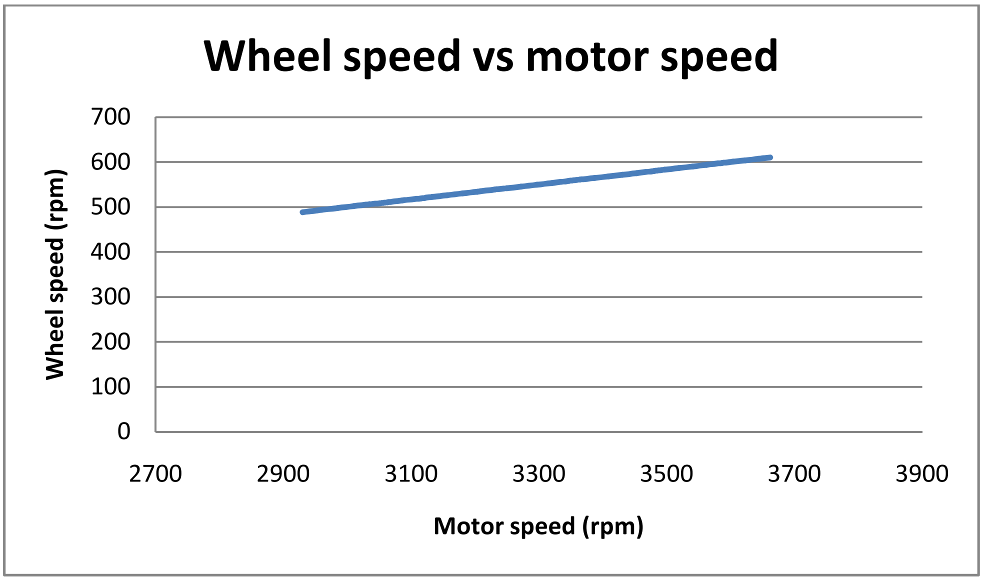

Figure 4.29: Wheel speed versus motor speed

From figure 4.29, it shows that wheel speed is directly proportional to motor speed. As motor speed increasing, the wheels speed also increasing.

4.9.5Wheel Circumferences

Circumference is the distance, or perimeter, around a circular object.Wheel circumference is the distance the car will travel each time the wheel turns one full revolution. Each turn of the wheel the car travels circumference of the drive wheel. If doubling wheel radius also doubles circumference which will make the car goes twice as far in one rotation. The formula for wheel circumferences is:

$$C = \pi D \qquad \text{(Eq. 4.10)}$$

Where:

C wheel circumferences

π 3.14

D diameter of wheel, m

For this solar car project, two diameter of wheels has been analyzed which are 14 inch and 15 inch.

4.9.5.1 Wheel circumferences for 14 inch diameter

D= 14inch= 0.35m

So the value of $C= \pi D$

$=3.14 \times 0.35$

$=1.09$

The formula for velocity is

$$V = \omega d \times C \qquad \text{(Eq. 4.11)}$$

Where:

ωd wheel speed, rad s^{-1}

C wheel circumferences

At maximum efficiency, wheel speed gained as calculated above is 568.2 rpm.

Then convert 568.2 rpm to rps :

$\frac{568.2}{60}$ = 9.47 rad s^{-1}

Hence the velocity for 14 inch diameter is V= ωd x C

=9.47 x 1.09

=10.32 ms^{-1}

Then convert 10.32 ms^{-1} to kmh^{-1}, the result is 37.16 kmh^{-1}

4.9.5.2Wheel circumferences for 15 inch diameter

D= 15 inch= 0.38m

So the value of **C= πD**

=3.14 x 0.38

=1.19

At maximum efficiency, wheel speed gained as calculated above is 568.2 rpm.

Then convert 568.2rpm to rps :

$\frac{568.2}{60}$ = 9.47 rad s^{-1}

Hence the velocity for 14 inch diameter is V= ωd x C

=9.47 x 1.19

=11.27 ms^{-1}

Then convert 11.27 ms^{-1} to kmh^{-1} , the result is 40.57 kmh^{-1}

From the result gained, wheel with 15 inch diameter has higher velocity which is 40.57 kmh^{-1} compared to 14 inch diameter which is 37.16 kmh^{-1}. Solar car is not suitable to use really big wheels because the motor performs best at a certain speed. Furthermore the bigger wheel has higher coefficient of friction which able to slow the car.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter discusses the conclusion of the research and the finding based on the literature review and from the design and analysis conducted. The objectives of the research will also be evaluated in this chapter. The recommendations in improving the research for the future will also be discussed.

5.2 OBJECTIVE ACHIEVED

The actuation system has been designed to be used in solar car. Then, proper electrical connection has been considered. DC motor has been selected because has high torque compared to AC motor. Aluminium AL6061 has been selected to use for motor mounting bracket. The safety factor is crucial and important. Hence, some electronic devices are used to ensure safety to driver and other road users. Belt drive is selected for transmission and must has higher gear ratio to ensure good speed.

5.3 RECOMMENDATION

The design of a solar car is not an easy job, and it does not end with putting down some calculated parameters or even producing the first prototype. It is a continuous job with changes and modifications even after producing the commercial type. This work is the first step on a long track, and it concerns the energy parameters of the car. The optimal driving strategies are needed for future project.

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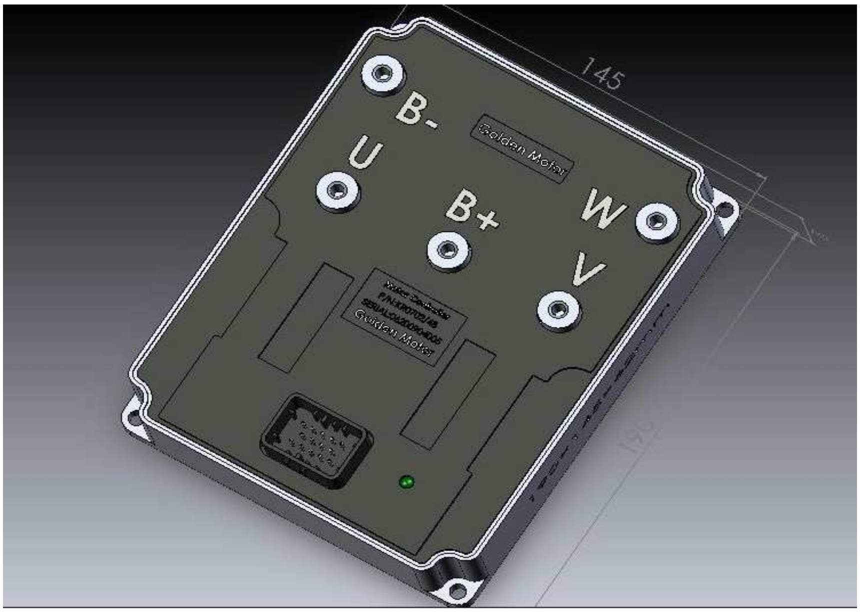
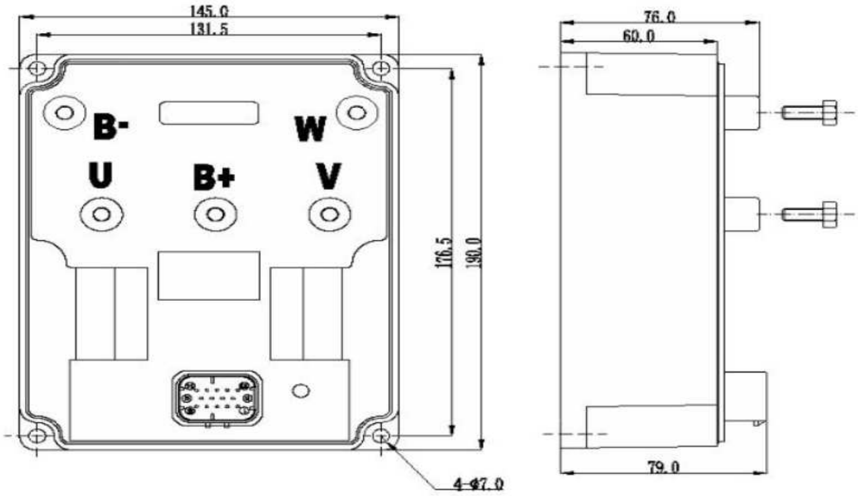
APPENDIX

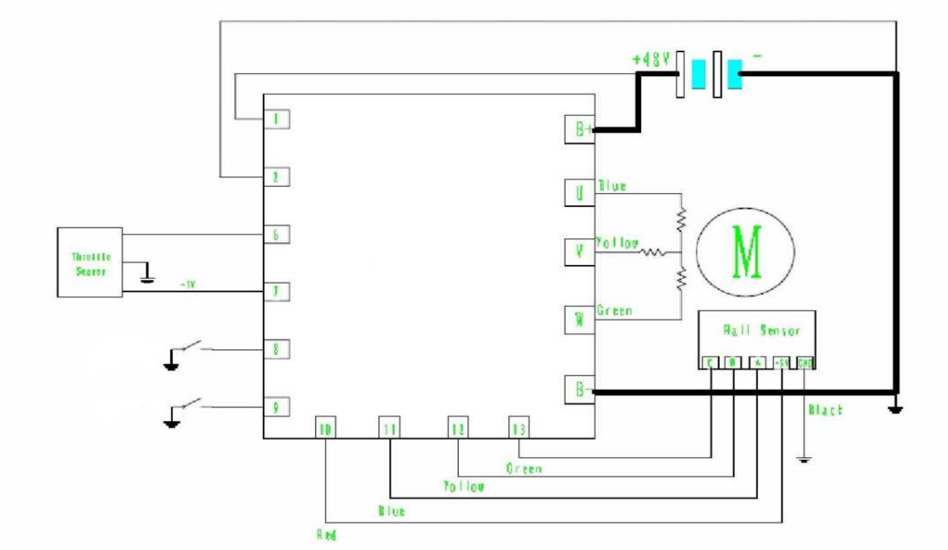
HPM5000B Brushless DC Motor



Picture of motor controller



Dimensions of motor controller



Motor Controller Wiring

Gantt Chart for FYP 1

Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Received title															
Project objective															
Project scope															
Problem statement															
Literature review															
Methodology research															
Report writing (chapter 1,2,3)															
Report submission															
PSM 1 presentation															

Gantt Chart for FYP 2

Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Literature study															
Draw and design															
Analysis															
Result & discussion															
Conclusion															
Final Presentation															
Report Preparation															