DESIGN AND ANALYSIS BATTERY PACKAGING FOR ELECTRIC VEHICLE

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DESIGN AND ANALYSIS BATTERY PACKAGING FOR ELECTRIC VEHICLE (EV)

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

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> > NOVEMBER 2009

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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

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We certify that the project entitled "(*Design and analysis battery packaging for Electric Vehicle*)" Is written by (*Sibra Mallisi Bin Yussof*.) We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

(Zamri Mohamed) Examiner

Signature

To my beloved mother and father,

Mrs. Rubiah Binti Ghazali Mr. Wan Khairudin Bin Wan Mohamad

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ABSTRACT

Battery packaging is the packaging where the batteries Lead-acid or Lithium-Ion are kept safe. Battery packaging is installed in car such as electric vehicle, hybrid electric vehicle or the car that needs to convert to the electric vehicle. Batteries selection is made depend on the motor specification that install in the car. The battery packaging are important to make the performance of batteries are stable. The cooling system of battery packaging is used to make the heat flow in battery packaging not exceeding the operating temperature of the batteries. The proposed design is made to reach the design specification of battery packaging. Some of battery packaging is made without cooling system. More criteria needs to consider in order choosing the battery packaging such as cost, weight, available space, compact, maintenances and more. The selection of battery packaging must have all the criteria needed by battery packaging, therefore the analysis are made for selection material and heat transfer from battery packaging to outside of the car. The cooling system is effect most on the performance, weight, cost, and maintenances. For example, the liquid cooling system most effective than air cooling system, but liquid cooling have more deficiency in leakage problem, need more mass to complete the circulate of the cooling system and also higher cost of maintenances. The air cooling system less effective, but the cost is low than liquid, easy maintenance and also less mass. So that, this project is focus on cooling system type air to find most effective cooling system by three proposed design of air cooling system. At the end of this project, a new design of proposed battery packaging has been choose by using Solid Work software. There are some improvements have been made in order to reach the design criteria. As the result of this battery packaging design and analysis, the objective to design battery packaging and select the suitable battery packaging, analysis on the faster type design heat transfer from battery packaging to outside of the car can be achieved.

ABSTRAK

Kotak bateri adalah kotak dimana bateri seperti Lead-acid atau Lithium-ion disimpan. Kebiasaannya kotak bateri digunakan untuk kenderaan yang menggunakan tenaga elektrik. Projek ini fokus kepada kereta Proton Iswara dimana kereta ini ingin ditukar daripada menggunakan bahan api petrol kepada elektrik. Elektrik motor telah dipasang dalam kereta proton iswara, oleh itu pemilihan bateri adalah penting supaya jumlah voltan, kuasa dan arus yang sesuai dengan spesifikasi motor tercapai. Sistem penyejukan kotak bateri penting dalam memastikan suhu bateri adalah tidak melebihi suhu operasi bateri. Ini kerana, jika suhu yang berkumpul dalam kotak bateri melebihi suhu operasi bateri, bateri akan rosak dan melibatkan kos yang tiggi untk menyelenggara bateri yang rosak. Projek ini menghasilkan tiga rekaan kotak bateri untuk mencapai rekaan yang sesuai sebagai kotak bateri kenderaan elektrik. Antara kriteria yang perlu ada pada kotak bateri ialah kos yang murah, berat yang sesuai, kekosongan tempat dalam kereta proton iswara dan kos menyelenggara kerosakan bateri dan kotak bateri. Contoh pada sistem penyejukan, kesan pada berat, kos dan penyelenggaraan adalah tinggi. Terdapat dua jenis sistem penyejukan, pertama menggunakan cecair penyejuk dan jenis kedua menggunakan udara sebagai bahan penyejuk. Sistem penyejuk cecair lebih member kesan pada kawalan suhu di dalam kotak bateri, tetapi jenis penyejukan cecair mempunyai banyak kekurangan seperti memerlukan banyak alat untuk siap, kos yang tinggi dalam pemasangan dan juga penyelenggaraan. Sistem ini juga boleh menyebabkan kebocoran pada cecair dan boleh merosakkan kotak bateri jika cecair bertindak balas dengan bahan membuat kotak bateri. Sistem penyejukan yang menggunakan angin kurang keberkesanan berbanding cecair penyejuk, tetapi mempunyai banyak kelebihan seperti kos yang rendah, kurang berat dan juga mudah untuk diselenggara. Oleh itu, projek ini fokus pada sistem penyejukan jenis angin, untuk memilih susunan kipas sedut angin dan kipas bebas angin yang paling memberi kesan pada penurunan dan kawalan suhu di dalam kotak bateri supaya kedua – dua jenis sistem penyejukan memberikan perbezaan yang kecil. Hasil daripada rekaan tiga jenis kotak bateri dan pemilihan kotak bateri yang paling cepat mengeluarkan haba daripada kotak bateri dapat dicapai.

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LIST OF SYMBOLS

- P Power V Voltage
- I Current

LIST OF ABBREVIATION

| EV | Electric vehicle |
|-----|-------------------------|
| FEA | Finite Element Analysis |
| ZEV | Zero Emission Vehicle |

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Today, as human being transportation become an important role for getting a comfortable life. But, human not realize that next 50 years, global population will increase from 6 billion to 10 million and in order aspects, the number of vehicles will increase from 700 million to 2.5 billion [Husain, 1964]. If all these vehicles are propelled or get their sources energy by internal combustion engines (ICEs), then the fuel are out of source. The gloomy answer to these hard questions compel human to strive for sustainable road transportation for 21st century [Husain, 1964].

An electric vehicle (EV) is a vehicle with one or more electric motors for propulsion. This is also referred to as an electric drive vehicle. The motion may be provided either by wheels or propellers driven by rotary motors, or in the case of tracked vehicles, by linear motors. Unlike an internal combustion engine (ICE) that is tuned to specifically operate with a particular fuel such as gasoline or diesel, an electric drive vehicle needs electricity, which comes from sources such as batteries or a generator. This flexibility allows the drive train of the vehicle to remain the same, while the fuel source can be changed [Husain, 1964].

The idea of hybrid vehicles is not a recent development, early 1960s, several companies attempted to develop bipolar lead (acid batteries) for hybrid-electric vehicles [Husain, 1964]. Hybrid vehicles have the potential to increase fuel economy by using a primary engine operating at a constant power to supply average power requirements and a surge power unit for peak power demands and to recover braking energy. But until

now, there have no detailed system optimization analysis has been performed for hybrid electric vehicles.

Transportation becomes the major contributor to multiple global environmental problems such as greenhouse effect-gas emissions and urban pollution. The hybrid vehicle typically achieves greater fuel economy and lower emissions than conventional internal combustion engine vehicles (ICEVs), in terms of fewer emissions being generated. These savings are primarily achieved by four elements of a typical hybrid design. First, recapturing energy normally wasted during braking. Second, having significant battery storage capacity to store and reuse recaptured energy. Third, shutting down the gasoline or diesel engine during traffic stops or while coasting or other idle periods and last one is relying on both the gasoline (or diesel engine) and the electric motors for peak power needs resulting in a smaller gasoline or diesel engine sized more for average usage rather than peak power usage.

These features make a hybrid vehicle particularly efficient for city traffic where there are frequent stops, coasting and idling periods. In addition noise emissions are reduced, particularly at idling and low operating speeds, in comparison to conventional gasoline or diesel powered engine vehicles [M.H., Johns, 1996]. For continuous high speed highway use these features are much less useful in reducing emissions. Vehicles which have significant idle periods and only occasional needs of peak power like railroad switching locomotives or repeated lifting and lowering cycles like Rubber Tire Gantry's are also good candidates for hybrid systems resulting in potentially significant fuel and emission savings. The detail of electric vehicle packaging is discussed in the 1.2 Project background.

1.2 PROJECT BACKGROUND

This project is focus on battery packaging for electric vehicle. Some of the battery packaging is referring to the TESLA car and CHEVROLET VOLT that is the electric vehicle that already available in market.

1.3 PROJECT PROBLEM STATEMENT

The performance of the EV depends on the performance of its high-voltage battery pack. Battery temperatures influences are availability of discharge power (for startup and acceleration), energy, and charge acceptance during energy recovery from regenerative braking. These affect vehicle drivability. Temperature also affects the life of the battery and its replacements frequency. Therefore, batteries should operate within temperature range that is optimum for performance and life.

The optimum operating temperature range varies with battery type. The batteries that could be used for EV's are lead acid, nickel metal hybrid (NiMH), and lithium ion (Li-Ion). Today, Li-Ion is the leading choice because the batteries perform well, are safe, and are durable. Usually, the optimum battery temperature range (according to the battery manufacturer) is much narrower than the vehicle manufacturer's specified operating range. For example, the operating temperature for a lead acid battery should be 25°C–45°C, however, the specified vehicle operating range could be -30°C– 60°C. The goal of a thermal management system in an EV is to maintain an acceptable temperature range in a battery packaging with even temperature distribution. However, the pack thermal management system has to meet the vehicle manufacturer's requirement, it must compact, light weight, low cost, easily packaged, and compatible with location.

A thermal management system may use air for heating, cooling, liquid for cooling/heating, insulation, thermal storage such as phase change materials, or a combination of these methods. The material selection are also important in order to make the battery packaging are meet the requirement of the total heat. Therefore, EV must be thermally managed for hot and cold climates and seasons. They must be cooled (by air or liquid) to maintain an acceptable lifespan [Ahmad Pesaran, 2003].

1.4 PROJECT OBJECTIVES

i. To design the battery packaging of Proton Iswara.

1.5 PROJECT SCOPE

- Measure the available space in Proton Iswara at the University Malaysia
 Pahang mechanical lab.
- ii. Design the battery packaging by using Solid works.
- iii. Identify the type of material selection suitable for battery packaging.
- iv. Identify the best design of a battery packaging.

1.6 OVERVIEW OF THE THESIS

This thesis is about battery packaging system for electric vehicle. In chapter 1, the project background, problem statement of battery packaging, objectives and project scopes will discuss. In chapter 2, overview of electric vehicle battery packaging are detail in the history of electric vehicle and also the type of the battery that will use in electric vehicle. The battery packagings that already exist in industry are also explained in chapter 2. The design criteria are explain in chapter 3, the available space of Proton Iswara car are, material selection for battery packaging and also cooling system type are discuss in chapter 3. For result and discussions of battery packaging is in chapter 4. This chapter 4 is concluding the type of connection between batteries, comparison of the design and also analysis performance. The last chapter is chapter 5, this chapter is conclusion for overall project and also recommendations for future research.

CHAPTER 2

OVERVIEW OF ELECTRIC VEHICLES BATTERY PACKAGING

2.1 INTRODUCTION

This chapter will explain about the idea of propulsion system in electric vehicles which consists of the history of electric vehicle, type of batteries and the detail of the battery that will use and already use in electric vehicle.

2.2 HISTORY OF ELECTRIC VEHICLE

In the late 1890s electric vehicles (EVs) outsold gasoline cars. EVs dominated the roads and dealer showrooms. Some automobile companies like Oldsmobile and Studebaker actually started out as successful EV companies, only later transitioning to gasoline-powered vehicles. In fact, the first car dealerships were exclusively for EVs.

Early production of EVs, like all cars, was accomplished by hand assembly. In 1910, volume production of gasoline powered cars was achieved with the motorized assembly line. This breakthrough manufacturing process killed off all but the most well-financed car builders. Independents, unable to buy components in volume died off. The infrastructure for electricity was almost non-existent outside of city boundaries limiting EVs to city-only travel. Another contributing factor to the decline of EVs was the addition of an electric motor (called the starter) to gasoline powered cars – finally removing the need for the difficult and dangerous crank to start the engine. Due to these factors, by the end of World War I, production of electric cars stopped and EVs became niche vehicles – serving as taxis, trucks, delivery vans, and freight handlers.



Figure 2.1: Some of the newer EV's that made early 1902 by wood [James Larminie, 2003].

In 1916, a man by the name of Woods invented the first hybrid car, combining an electric motor and an internal combustion engine.

In the late 1960s and early 1970s, there was a rebirth of EVs prompted by concerns about air pollution and the OPEC oil embargo. In the early 1990s, a few major automakers resumed production of EVs – prompted by California's landmark Zero Emission Vehicle (ZEV) Mandate.

Those EVs were produced in very low volumes – essentially hand-built like their early predecessors. However, as the ZEV mandate was weakened over the years, the automakers stopped making EVs – Toyota was the last major auto maker to stop EV production in 2003[James Larminie, 2003].

2.3 ELECTRIC VEHICLE BATTERIES

In the past, most electric vehicle has been powered by lead acid batteries. The main shortcoming attributed to these batteries is low specific energy. The thermal properties of lead acid batteries have been considered to be nearly ideal, because they operate near ambient temperature and in most electric vehicle are required to be neither insulated nor cooled. Batteries that must operate at several hundred degrees Celsius are considered to be at a disadvantage compared to those that operate at ambient temperatures.

Now, however as battery developers seek to produce batteries meet the goals set by U.S Advanced Battery Consortium (USABC, 1991), the thermal requirement of batteries are being more critically considered. The need to provide adequate battery power for acceleration after long idle periods under serve, cold weather conditions may require insulation even for "ambient temperature" batteries such as lead acid batteries.

2.3.1 Lead Acid Battery



Figure 2.2: Example of lead acid battery [Pesaran A, 1998].

The lead-acid (Pb) batteries that have been around for over a century are extremely heavy (low energy density), environmentally unsafe (lead is toxic), and can only handle up to 200 full charge/discharge cycles before their capacity dips below 80% of original [Pesaran A, 1998].

2.3.2 Lithium Ion (Li-Ion) and Nickel Metal Hybrid (Ni-MH).

The latest developments in rechargeable battery technology involve compounds derived from lithium; it is the lightest and one of the most chemically reactive metals. This combination holds promising potential: lithium's reactivity allows for high chemical energy storage capacities, and its light weight is conducive to the energy-toweight density required for fully-electric automotive applications. Currently developments have been centered on improving the ideal chemistry of lithium-ion cells, and maximizing the surface area of the anode and cathode in order to raise the energy density and allowable drain rates. The following is a review of the recent research being done with lithium-ion batteries, and the manufacturing developments that have ensued.



Figure 2.3: Lithium Ion battery (LiFeP04) [Keyser, 2001].

Another important factor inhibiting the mass production of batteries suitable for electric vehicle use is safety. Lithium-ion batteries contain a flammable organic electrolyte; if a cell is physically damaged, manufactured of impure materials, improperly charged, drained too quickly, or short-circuited, it could trigger its own fiery meltdown. If the cells are assembled in a battery pack, the heat from one cell melting down can cause the adjacent cells to do the same, thus starting a chain reaction throughout the battery pack. This was a problem with a certain batch of laptop batteries manufactured by Sony; millions had to be recalled because there were impurities in the cell divider alloys. This problem caused some cells to internally short-circuit, leading to cell destruction and, consequently, violent destruction of the entire battery pack (Sony Support, 2007).



Figure 2.4: Nickel Metal Hybrid (Ni-MH) [Keyser, 2001].

Nickel cadmium (NiCd) and nickel metal-hydride (Ni-MH) batteries have been in development for over two decades, and Ni-MH batteries are currently being used in gasoline-hybrid electric vehicles.

They are chosen because of their high discharge rate capability, cycle life (800+), cost, tolerance for abuse, and overall reliability. Ni-MH cells have been around for a long time, and their charge characteristics are predictable enough to green-light their mass production for hybrid vehicles. However, the major drawback of Ni-MH batteries is energy density, a Ni-MH battery pack with enough energy to provide a 300 mile range for an electric vehicle would be very large and heavy, and this added weight would severely detract from the vehicle's overall performance.



Figure 2.5: Comparison lifespan between Ni-MH and Li-Ion [Keyser, 2001].

These safety problems are mitigated by computerized monitoring to control charging and discharging rates, along with temperature controls monitoring certain sectors of the battery pack. Proper cooling and airflow must be provided to prevent overheating, along with cell "firewalls" built into sectors of the battery pack to prevent catastrophic meltdowns. These risks are inherent in electric vehicles, and these safety problems would have still existed with older battery technologies, although to a somewhat lesser extent. Problems like this arise in any situation where there is a concentrated amount of energy stored in a small space; gasoline tank fires are still a problem with internal-combustion automobiles. Proper pack management and safety monitoring are necessary to prevent the over-charging, over-discharging, and temperature fluctuations associated with cell overheating, decreased cycle life, and catastrophic failure.

The element that contributes most to the attractiveness and readability of the thesis is consistency. Consistency in formatting means that the students satisfy a series of convention regarding spacing, heading, sequencing and other aspects of appearance to visually guide the reader throughout the document, thus enabling the reader to concentrate on content. Consistency of thesis preparation is critical, since it influences the examiner's response to its content and ultimately the acceptance of the document by the Center for Graduate Studies [Keyser, 2001].

2.4 BATTERY PACKAGING

In recent years, electric cars using an electric motor as a drive source and hybrid cars using an electric motor and internal combustion engine as drive sources are attracting attention. These vehicles are normally provided with a chargeablebattery and the electric motor is driven by electric energy stored in this battery.

Furthermore, when such a battery is continuously used under a high-temperature condition, the life is generally shortened. For this reason, to protect the battery, the battery may be controlled so as to limit the charge/discharge current when the battery is under a high-temperature condition. However, in this case, sufficient propulsion may not be obtained or in the case of a hybrid car, poor fuel efficiency of the internal combustion engine may result. For this reason, the above described vehicle is often provided with a fan for cooling the battery. The rotation speed of the fan is normally high when the battery is under a high temperature condition and slow under a low temperature condition.

On the other hand, in the case of the hybrid car or the electric car, when the car is parked or when the electric motor is used as a drive source, generally noise in the passenger compartment is often kept to a low level. When noise is at a lowlevel in such a passenger compartment, if the fan is operating for cooling the battery, the operating sound of the fan increases relative to background noise in the passenger compartment, that is, noise other than the operating sound of the fan. Sincepassengers of the vehicle are rarely aware of the reason for the operation of the fan under ordinary circumstances, the passengers feel the operating sound of the fan as offensive to the ear.

Cooling system for battery pack generally controlled internally by several embedded microprocessors that operate both when the battery pack is installed in the car, and when the pack is being transported. An example of passive safety feature is the selection of Aluminum for battery enclosure instead of plastics as in laptop packs. The aluminum provides greater structural strength in case of mechanical abuse tolerance and does not easily melt or burn. Collectively, the high levels of redundancy and layers of protection culminate in the safest large battery seen by the experts in the field with consulted.



Figure 2.6: Tesla roadster battery packaging [Gene Berdichvsky, 2006].

Example for the Roadster, The Roadster pack comprises 11 battery modules, a main control and logic board, and a 12V DC-DC power supply. Each of the 11 modules carries a monitoring circuit board that communicates with the rest of the vehicle microcontrollers, broadcasting the voltage and temperature measurements of its module over a standard CAN bus.

Each of the cells has two fuses (one each for the cell's anode and cathode). This allows the cell to become electrically separated from the rest of the pack if either of its fuses blows. In addition to cell fuses, each of the 11 battery modules has its own main fuse that guard against a short circuit across the complete module. Tesla uses a 50/50 mix of water and glycol for cooling [Gene Berdichvsky, 2006].



Figure 2.7: Battery packaging system of Chevrolet Volt [Zolot., M, 2007].

The batteries in the 2011 Chevrolet Volt are thus expected to be quite safe, though they must be kept within a specific temperature range. The Volt has a separate liquid-cooling system for that purpose [Zolot., M, 2007]. There is some of the company used to fabricate the battery packaging for lead-acid batteries. These type battery packaging doesn't have cooling system. From faculty of electrical and electronic at UMP, they built battery packaging for savy and these battery packaging are used to kept the lead acid battery. There is to location where the battery packaging are installed, the front side upper motor and the rear side of the savy car.



Figure 2.8: Front side of the battery packaging in savy.

These battery packaging did not have cooling system. The cooling system is important to maintain the performance of the batteries. These battery packaging used to install six number of battery at the front side and other six at the rear side of the car.



Figure 2.9: Rear side of the battery packaging in savy

2.5 CONCLUSIONS

From this chapter, there are three type of battery that suitable use in electric vehicle. The selection of the battery is depending on the electric vehicle motor that will install in car. From this chapter also, it is shown the characteristics of lead-acid, lithiumion and nickel-metal hybrid batteries. Lithium-ion is leading the most suitable batteries for electric vehicle. In this chapter also shown example of the battery packaging that already make today, from Tesla and Chevrolet volt car with water-glycol cooling system and the savy that convert to electric vehicle that does not have a cooling system.

CHAPTER 3

DESIGN CONSIDERATION OF BATTERY PACKAGING

3.1 INTRODUCTION

This chapter explains about the battery packaging requirement. The suitable materials, cooling system type, available space of Proton Iswara are explained in this chapter. The battery packaging that has been produced must have all the safety features to satisfy the user and also minimize problem that will occur during operation system. The flow chart explanation will give more information and explanation from the upper flow to the bottom about this project progress. In this chapter, the explanation is focus on the design requirement of the battery packaging.



Figure 3.1: Flow chart for overall of the project

3.2 DESIGN REQUIREMENT

Designing the battery packaging must considered the previous design by some literature reviews about the electric vehicle and battery packaging. All the information of the design requirement will discuss.

3.2.1 Available space

Figure 3.2, figure 3.3, figure 3.4 and figure 3.5 are shown the available space view in Proton Iswara car. All of the available space are measure and explain in next subchapter.



Figure 3.2: Front view proton iswara


Figure 3.3: Available spaces at front of proton iswara



Figure 3.4: Rear view proton iswara



Figure 3.5: Available space at rear side of proton iswara

There are two sides that have an available space to install battery packaging. The first one is the front of the car and the second one is at the rear side. At the front, the available space are limited because at the front also install motor that replace with engines, so that the front side are not acceptable to install the battery packaging. The figure 3.6 below show the dimension rear sides of ISWARA.



Figure 3.6: Dimensions of rear side Proton Iswara

3.2.2 Specification of Motor in Proton Iswara

The battery packaging are design for Proton Iswara car. The AC motor is already installed in proton Iswara at FKM lab. To make the design, after find the available space that possibly can install the battery packaging, the motor specification needs to know. The power value of the total batteries needs to pass the motor specification power which is 15 kW, so that the motor will use. Table 3.1 below show the specification of AC motor that already install in Proton Iswara.

| MOTOR SPECIFICATION | | | |
|---------------------|---------|--|--|
| Power | 15 KW | | |
| Power | 20 HP | | |
| Rpm | 2930 | | |
| Ampere (I) | 22.5 | | |
| Frequency | 50 Hz | | |
| Voltage | 415 VAC | | |
| Duty | 81 | | |
| Phase | 3 | | |

Table 3.1: Motor specification that already install in Proton Iswara

3.2.3 Types of Material Specification

There are many type of material that possibly use as a material to make the battery packaging. In order to choose the material, the material requirement needs to consider so that the battery packaging are stable. The first consideration of the material is light; it is because the weight by the batteries and the battery packaging give the higher effect in car performance. When the weight is increase, the work needs to move the car are also increase, therefore the total power are also increase. Power of the batteries needs to increase, so that the power supply to the motor is balance to move the car. The second consideration is the material need to strong. This is because the battery packaging are install in car, when there is vibration occur, the batteries will impact to the battery packaging. If the battery packaging are made by soft material, the battery packaging will broken, so that the performance if battery are decrease.

Chemically resistant are important when using wet cell type of battery. Sometime the wet cell broken and the leakage are occur, the battery chemical will react with the battery packaging if the material are easy react with the chemical. The battery packaging will break if the reaction is in a long time, or sometime the battery packaging will crack and this will affect the performance of the battery. Battery packaging material needs to have the ability of resistant in corrosion. The battery packaging will used in a long time, to kept the battery safe. If the battery packaging happens the corrosion, the performance of the cooling system and the batteries is also decrease. The material are also needs to electrically resistant to avoid happen the shock by the higher voltage from the batteries. The higher voltage from the batteries will damage the battery packaging and also for human. Material need be able to contain the batteries and their chemical in a crash withstand flexing also easy to assemble and integrate into donor car. And the last one is relative low cost.

3.2.4 Material Selection

There is various type of material that suitable to make the battery packaging. The better one is steel and aluminum. Material selection is select from the properties of the material that follow the design requirement.

3.2.4.1 Steel and other Material

- i. Use a woven fiber for best strength.
- ii. Carbon fiber is strong, but fiberglass can be made almost as strong, and is much cheaper.
- Kevlar is quite strong, but is expensive, requires curing in an oven and is difficult to work with once cured.
- iv. For large sheets to build in stiffness, use a foam core. This has the added advantage of insulating the batteries
- v. Steel/Aluminum can be used as a stiffener and attachment plates for fiberglass or Kevlar. Only titanium can be used for carbon.
- vi. Fiberglass density is 2.6 g/cm³ resin density is 1.3 g/cm³ composite density is 1.529 g/cm³
- vii. Glass content, by weight is typically 30%, 5/32" strength is 23,000 psi.

3.2.4.2 Aluminum Properties

- i. Higher impact resistance than fiberglass.
- ii. Aluminum is as stiff as steel as and much stiffer than fiberglass.
- iii. High strength to weight ratio over fiberglass.

The good material to make the battery packaging is aluminum. It is because, the aluminum are lighter more than steel. Aluminum and aluminum alloys are lightweight, non-ferrous metals with good corrosion resistance, ductility and strength [Bard., A.J, 1993]. The Aluminum provides greater structural strength in case of mechanical abuse tolerance and does not easily melt or burn. Collectively, the high levels of redundancy

and layers of protection culminate in the safest large battery seen by the experts in the field with who consulted. Table 3.2 shows the aluminum detail properties.

| Physical Properties | Metric | English |
|---------------------|-----------|------------------------|
| Density | 2.78 g/cc | 0.1 lb/in ³ |

| | Mechanical Properties | |
|---------------------------|------------------------------|-----------|
| Hardness, Brinell | 47 | 47 |
| Ultimate Tensile Strength | 186 MPa | 27000 psi |
| Tensile Yield Strength | 75.8 MPa | 11000 psi |
| Elongation at Break | 20 % | 20 % |
| Elongation at Break | 22 % | 22 % |
| Modulus of Elasticity | 73.1 GPa | 10600 ksi |
| | | 50000 psi |
| Ultimate Bearing Strength | 345 MPa | |
| Bearing Yield Strength | 131 MPa | 19000 psi |
| Poisson's Ratio | 0.33 | 0.33 |
| Fatigue Strength | 89.6 MPa | 13000 psi |

30 %

28 GPa

124 MPa

30 %

4060 ksi

18000 psi

Machinability

Shear Modulus

Shear Strength

Table 3.2 (a): Aluminum Mechanical Properties [Bard., A.J, 1993]

| | Electrical Properties | |
|------------------------|------------------------------|------------------|
| Electrical Resistivity | 3.49e-006 ohm-cm | 3.49e-006 ohm-cm |

| Table 3.2 (| (b): | Aluminum | Electrical | Properties | [Bard., A.J, 1993 |] |
|-------------|---------------|----------|------------|------------|-------------------|---|
|-------------|---------------|----------|------------|------------|-------------------|---|

| Thermal Properties | | |
|----------------------|--------------|----------------|
| CTE, linear 68°F | 23.2 μm/m-°C | 12.9 µin/in-°F |
| CTE, linear 250°C | 24.7 μm/m-°C | 13.7 µin/in-°F |
| Heat Capacity | 0.875 J/g-°C | 0.209 BTU/lb- |
| | | °F |
| Thermal Conductivity | 193 W/m-K | 1340 BTU- |
| | | in/hr-ft²-°F |
| Melting Point | 502 - 638 °C | 935 - 1180 °F |
| Solidus | 502 °C | 935 °F |
| Liquidus | 638 °C | 1180 °F |

Table 3.2 (c): Aluminum Thermal Properties [Bard., A.J, 1993]

3.3 COOLING SYSTEM

There are two type of cooling system that can be use in battery packaging to control the temperature of batteries.

3.3.1 Liquid cooling system

The heat transfer medium has a significant impact on the performance and cost of the battery thermal management system. Heat is transferred with air by directing or blowing the air across the modules. Heat is transferred with liquid through discrete tubing around each module with a jacket around the module by submerging modules in a dielectric fluid for direct contact, or by placing the modules on a liquid heated or cooled plate (heat sink). Using air as the heat transfer medium may be the simplest approach, but may be less effective than heat transfer by liquid.

For the same flow rate, the heat-transfer rate for most practical direct-contact liquids such as oil is much higher than with air because of the thinner boundary layer and higher fluid thermal conductivity. However, because of oil's higher viscosity and associated higher pumping power, a lower flow rate is usually used, making the oil heat transfer coefficient not only 4 times higher than with air [P.A.Nelson, 1995]. Indirect-contact heat transfer liquids such as water or water/glycol solutions generally have lower viscosity and higher thermal conductivity than most oils, resulting in higher heat transfer coefficient. However, because the heat must be conducted through walls of the jacket/container or fins, indirect contact effectiveness decreases.

Although liquid cooling is more effective and takes up less volume, it has drawbacks. It could have more mass, may leak, may need more components and could cost more. Maintenance and repair of a liquid cooled pack is more involved and costlier. Indirect liquid cooling, with either jackets or cold plate, is easier to handle than direct liquid cooling. On the positive side, a liquid cooled system offers the flexibility of placing the pack in areas that air could not be easily available or should be sealed from the road environment.

3.3.2 Air cooling system

An air-cooling type battery cooling system has been adopted for cooling the traction batteries. This system uses blowers fan to direct the external air, which is introduced through an air intake in the quarter panel, into the battery carrier, thus cooling the batteries [Ahmad Pesaran, 2003]. After passing between the battery cells, the cooling air is discharged through the bottom of the carrier.



Figure 3.7: Example of air cooling system [Ahmad Pesaran, 2003].

3.4 CONCLUSION

From this chapter the available space of the Proton Iswara car to install the battery packaging are shown. All of the motor specification that already install in Proton Iswara car are listed in this chapter. Type of material requirement and selction of material also are made in. The Aluminum is the suitable to make the battery packaging because of the specification of aluminum that suitable with the material requirement to make electric vehicle. There are two type of cooling system that will use in battery packaging, the fisrt one is water-glycol cooling system and the second one is air cooling system. The difference of these two type cooling system are also listed in this chapter.

CHAPTER 4

FINAL DESIGN OF PROTON ISWARA BATTERY PACKAGING

4.1 INTRODUCTION

This chapter discusses the result and analysis of the battery packaging. The result is based on the selection material and selection design. There are 4 designs that will compare in this chapter. The first one is water/glycol type cooling system and the rest are air type cooling system. Selection design is consider the design requirement in chapter 3. Battery packaging that suitable with the available space in Proton Iswara is defined by the maximum total area of the batteries. There are maximum 12 number of battery are fix with the available space of Proton Iswara. The cooling system possible for electric vehicle is water/glycol type and air cooling type. Both cooling system have their specification and advantages. All of the proposed battery packaging design and analysis will discuss in this chapter.

4.2 LEAD ACID CONNECTION

There are two type of connection between batteries. The first one is series connection, and the second one is parallel connection. The suitable connection is finding by some calculation below. Table 4.1 listed the Lead acid specifications

| Lead-Acid | Specification | |
|--------------|---------------|--|
| Type of cell | Wet cell | |
| Voltage | 12 V | |
| Current | 60A | |
| Length | 230 mm | |
| Width | 125 mm | |
| Height | 200 mm | |
| Weight | 5 Kg | |

Table 4.1: Lead-acid battery [Winks., F, 1993]

4.2.1 Series

$$V_{total} = Battery \text{ voltage X Number of battery}$$

= 12 X 12
= 144 V (4.1)

I
$$_{total} = 60 \text{ A}$$
 (no changes in series circuit) (4.2)

Substituting Eq. (1) and Eq. (2) into Eq. (3), obtain

$$P_{\text{total}} = V_{\text{total}} X I_{\text{total}}$$
$$= 144 X 60$$
$$= 8.64 \text{ KW}$$
(4.3)

The output from batteries is DC, but the motor specification is AC. To convert from DC to AC, two types Converter are used. The first one is CONVERTER that converts DC to AC and then to reach 3 phase used the INVERTER. From the transmission of power, there is efficiency loss.

Assume that loss by CONVETER
$$= 10\%$$

 $= 0.10$
Loss by INVERTER $= 10\%$
 $= 0.10$

Power loss by converter =
$$8.64 \times 10^3 \times 0.10$$

= 864 Watt (4.4)

Power loss by Inverter =
$$8.64 \times 10^3 \times 0.10$$

= 864 Watt (4.5)

Total loss = Eq. (4) +Eq. (5)
=
$$864 + 864$$

= 1.728 KW (4.6)

Total power that receive by motor from batteries is Eq. (4.3) - Eq. (4.6)

$$P_{total} = 8.64 \text{ KW} - 1.728 \text{ KW}$$

= 6.912 KW

 $P_{total} < P_{motor}$, the value of power that produce by Lead-acid battery is not suitable to use as the source of motor power.

4.2.2 Parallel

$$V_{total} = Battery \text{ voltage}$$

$$= 12 \text{ V (no changes in parallel circuit)}$$
(4.7)
$$I_{total} = Battery Current X Number of battery$$

$$= 60 \text{ X } 12 \text{ A}$$

$$= 720 \text{ A}$$
(4.8)

There is no change in voltage by parallel connection of the batteries, so that the parallel connection is not suitable as a connection between batteries in electric vehicle.

4.3 LITHIUM-ION CONNECTION

For LiFeP04 also have two type connections. Same as Lead-acid, the calculation are done to find the suitable batteries and connection as source for electric vehicle motor. Table 4.2 listed the specification of LiFeP04 (Lithium-Ion)

| Lithium-Ion | Specification | |
|--------------|---------------|--|
| Type of cell | Dry cell | |
| Voltage | 48 V | |
| Current | 40 A | |
| Length | 280mm | |
| Width | 230mm | |
| Height | 180mm | |
| Weight | 25 Kg | |
| | | |

Table 4.2: Lithium-ion specification

4.3.1 Series

| V total = Battery voltage X Number of battery | (4.9) |
|---|--------|
| = 48 X 12 | |
| = 576 V | |
| | |
| I $_{\text{total}} = 40 \text{ A}$ | (4.10) |

Taking Eq. (4.9) and Eq. (4.10) to find the total power produce by Lithium-ion batteries.

$$P_{\text{total}} = V_{\text{total}} X I_{\text{total}}$$
$$= 576 X 40$$
$$= 23.04 \text{ KW}$$
(4.11)

Assume that loss by CONVETER
$$= 10\%$$

 $= 0.10$
Loss by INVERTER $= 10\%$
 $= 0.10$

Power loss by converter =
$$23.04 \times 10^3 \times 0.10$$

= 2.304 KW (4.12)

Power loss by Inverter =
$$23.04 \times 10^3 \times 0.10$$

= 2.304 KW (4.13)

Total loss = Eq.
$$(4.12)$$
 + Eq. (4.13)
= 2.304 KW + 2.304 KW
= 4.608 KW (4.14)

Total power that receive by motor form batteries is Eq. (4.11) - Eq. (4.14)

$$P_{total} = 23.04 \text{ KW} - 4.608 \text{ KW}$$

= 18.432 KW

 $P_{total} > P_{motor}$, the value of power that produce by Lithium-ion batteries is more than motor specification power, therefore Lithium-ion batteries is suitable use for Electric vehicle battery.

4.3.2 Parallel

$$V_{total} =$$
 Battery voltage
= 48 V (no changes in parallel circuit) (4.15)

I
$$_{total}$$
 = Battery Current X Number of battery
= 40 X 12 A
= 480 A (4.16)

There is no change in voltage by parallel connection of the batteries, so that the parallel connection is not suitable as a connection between batteries in electric vehicle. In case of parallel or series connection of batteries, the consideration that has to take is the voltage and current in motor specification. The voltage needed to run the motor is 415 VAC or in DC is 249 V and the current is 22.5 A. From the result, parallel connection is not suitable for connection. It is because the voltage are very low than motor voltage.

4.4 BATTERIES ARRANGEMENT

There are twelve numbers of batteries that satisfied the power of the motor. The arrangements of batteries are important with the available space in Proton Iswara to fix with the available space. From the calculation in 4.3 Lead acid and 4.4 Lithium-Ion, the most suitable batteries that meet the specification of motor in Proton Iswara is Lithium-Ion batteries.



Figure 4.1: Arrangement of batteries in Battery Packaging

From figure 4.1, the total number of the batteries that suitable for availbale space in Proton Iswara car is twelve. The batteries are devide by two layer which is six in the upper layer and six in lower layer. For the total dimension and total weight by the batteries are shown in table 4.3 below.

Table 4.3: Total batteries dimension in battery packaging

| Length(mm) | Width(mm) | Height(mm) | Weight(Kg) |
|------------|-----------|------------|------------|
| 8500 | 4600 | 3600 | 319.6 |

4.5 DESIGN SPECIFICATION

There are two type of cooling system. The first one is water/glycol cooling system and the second one is air cooling system. For example TESLA ROADSTER is already using the first type of cooling system. Although liquid cooling system is more effective and takes less volume, it could have more mass, may leak, may need more components comparing with the air type cooling system and could cost more. Maintenance and repair of liquid cooled pack is more involved and costlier. So that, the air type cooling system are design to avoid the problem [Ashtiani., C, 2001].



Figure 4.2: Schematic of liquid cooling system [Ashtiani., C, 2001]

Figure 4.2 are shown the schematic of cooling system by water glycol. The different of color are used to difference every part and process in liquid cooling system. From this figure, the liquid system has more components to make the cooling system on.



Figure 4.3: Schematic of air cooling system [Ashtiani., C, 2001]

Figure 4.3 show the schematic of air cooling system. There are two type of fan will use in these type cooling system. The first one is suction fan which is suck the cold air into the battery system, and the second one is exhaust fan which is to suck the hot air form battery packaging to the outside of the car. This type of cooling system is less effective than liquid cooling system, but it has more benefit than liquid cooling system.

4.5.1 Installing location

There are three proposed designs that will choose on this chapter. All of the design used drawer to keep the batteries. The drawer also are used to make the maintainer are easy, for example if one of the battery are broken, no need to take out the battery packaging to the outside of the car, but just pull the drawer and take out the broken battery. The type of cooling system of the three proposed design are air cooling system but difference in places that will install the fan. All of the proposed design is installing at the rear side of the Proton Iswara car as shown as figure below.



Figure 4.4: Rear view of Proton Iswara where the Battery Packaging installed

4.5.2 Design one



Figure 4.5: Isometric view of design one

From the figure 4.5, the suction fan is installed at the side of the battery packaging. The suction fan is sucking the cold air at the side of the car and flow through in battery packaging so that the batteries temperature is stable; it is because the batteries temperature is important in performance of the batteries. The exhaust are used to protect the fan from thing that will make the fan are not function. From the design one, the suction fan didn't have the pipe to protect the fan, so that the suction fan is easy to broken. If the suction fan is broken, the performance of the batteries is not stable because the temperature inside battery packaging is not stable.



Figure 4.6: Transparent view of design one



Figure 4.7: Back and side view of design one

4.5.3 Design Two



Figure 4.8: Isometric view of design two

Design two using four fans as a cooling system on the battery packaging. Two fans are used as cooling air suction fans from outside the car (bottom of the car) into the battery packaging and two more are used as exhaust fans that remove hot air from the battery packaging to the area outside the car. The fans suck air from outside into the packaging. Anyways, there is a shortage in the cold wind suction fan because when flooding occurs and water increases occurred more than water level, suction fan will be clogged and cause the battery cooling system packaging is not running as normal and can cause the flow of hot air outside is not functional.



Figure 4.9: Transparent view of design two



Figure 4.10: Side, bottom and back view of design two

4.5.4 Design three



Figure 4.11: Isometric view of design three

In Design three, it is the same as design three and three that using the fan as a cooling system. Differences are found in design three is the position Suction fan on both the side of battery packaging. Suction fan located at side of the battery packaging are sucking wind from the air-conditioner of the car. Benefits obtained from the air inhaled from the air-conditioner car is lower than the temperature outside the car, so that the batteries will receive good air suction. When the air-conditioner is closed, suction fan will suck the wind from the car where the wind is coming from outside the car through the open windows. Design three have both suction and exhaust pipe to protect the fan.



Figure 4.12: Transparent view of design three



Figure 4.13: Side and back view of design three

4.6 PERFOMANCE ANALYSIS

There are two type analyses which are to find the suitable material as the material to make the battery packaging and to choose the design one, two and design three.

4.6.1 Stress Analysis

Two type of material are choose as a material for battery packaging. The first one is Steel and the second one is Aluminum. The force are applied to the plate are the total weight of six batteries which is weight of the batteries in drawer one. The force applied to the plate is 1569.638 N.



Figure 4.14: Stress analysis on steel

Stress Von Mises is the total force that acting in surface area. The maximum value of the plate of steel can support the force of 1568.638 N is $5.53948 \text{ N/ (mm^2)}$.



Figure 4.15: Stress analysis on Aluminum

The maximum value of Stress Von Mises that can support the force by aluminum plate is $5.26369 \text{ N/ (mm^2)}$. This is mean the maximum value of stress by steel are higher than the aluminum, but the differences are found very small which is $0.27579 \text{ N/ (mm^2)}$. To choose the perfect material as a material to make battery packaging, some criteria needs to consider such as weight, resistant to chemical, corrosion resistance. Aluminum are lighter than steel, have better thermal conductivity and also the aluminum have good corrosion resistance better than steel. The Aluminum provides greater structural strength in case of mechanical abuse tolerance and does not easily melt or burn.

4.6.2 Thermal Analysis

There are three proposed design, all of the design have the difference criteria. The thermal analysis is to know the maximum temperature that the packaging will support before melt and the maximum heat flux which is to know how faster the hot air from inside of the battery packaging remove by the cooling system.



Figure 4.16: Temperature of design one and two

From the figure 4.16, the maximum temperature that the design three can support before melt is 298.418 K. The red color of inside of the battery packaging is shown the higher temperature, and the blue color is the coolest side at battery packaging. The applied temperature at the outside of battery packaging is 315 K (room temperature), and the inside of the battery packaging is 330 K which is the maximum temperature of the Lithium-Ion batteries operating.



Figure 4.17: Heat flux of design one and two

The maximum heat flux in design one and design two battery packaging is $0.41733 \text{ J/}(\text{mm}^2 \text{ s})$. For the analysis of the temperature and heat flux by design one and two, the surface area of these two designs are same and the air that sucking from the outside have a same temperature (room temperature). Therefore design one and design two used a same result in temperature and heat flux analysis.



Figure 4.18: Temperature of design three

From the figure 4.18, the maximum temperature that the design three can support before melt is 473.589 K. The red color of inside of the battery packaging is shown the higher temperature, and the blue color is the coolest side at battery packaging. The applied temperature at the outside of battery packaging is 300 K (Air-conditioner temperature), and the inside of the battery packaging is 330 K which is the maximum temperature of the Lithium-Ion batteries operating.



Figure 4.19: Heat flux of design three

The maximum heat flux in design three battery packaging is 0.416527 J/ (mm² s). The heat flux show how much heat is occurring at inside and outside of battery packaging. The higher of heat flux, the period to remove the heat are also increase. It is mean the less the better of heat flux. From the analysis, design three used to remove the heat from batter packaging more faster than design one and two because the heat that occur in surface area are lower than design three and two.

4.7 **DESIGN DIMENSIONS**

All of the design has a same dimension of the drawer, exhaust fan. The differences are at the suction fan size. The dimensions of the three proposed designs are shown in this figure below. Start with the design three because design three is the suitable proposed design of battery packaging. All of the design use to have tolerances 5mm in every side of the drawer and where the cooling system fan is installed.



Figure 4.20: Battery packaging without drawer dimensions for design three



Figure 4.21: Battery packaging without cooling system dimension for design three

Same for design one, two and three, all of the design use drawer to kept the battery safe. Because of the using tolerance are 5mm, the total length of the drawer that will contain six number of LiFeP04 battery is 890 mm. Total height of the battery packaging are same for all design which is 395mm. The aluminum sheet thickness is 5mm. For the design one and three, the suction fan is same placed installed, but the design three have suction pipe that protect the fan. Design one use to have same diameter fan as design three which is 200 mm diameter hole for fan in battery packaging.


Figure 4.22: Dimension of exhaust pipe for design one, two and design three

The exhaust pipe for all designs is same in dimension. These exhaust pipes are design so that the fan is always in protected.



Figure 4.23: Dimension of suction pipe for design three

Figure 4.23 shows the design for suction pipe of design three. The suction pipe of design three are used to sucking the air from inside of the car. It is also to protect the fan.



Figure 4.24: Dimension of suction fan pipe for design two

Figure 4.24 shows the dimensions of suction fan pipe for design two. The dimension is bit different from the dimension of exhaust fan.



Figure 4.25: Design one proposed battery packaging sketching paper view

Figure 4.25, figure 4.26 and figure 4.27 are shown the battery packaging overview in dimensions paper.



Figure 4.26: Design two proposed battery packaging sketching paper view



Figure 4.27: Design three proposed battery packaging sketching paper view

4.8 CONCLUSION

From this chapter, the selection of the design battery packaging for Proton Iswara is done. The batteries analysis are make by do the calculation weather series or parallel connection are fixed with motor specification. The result is the series connection is most suitable because the power supplied by this batteries connection is higher than the motor specification power. In this chapter also the analysis of strength are perform weather to choose aluminum or steel as a material to make the battery packaging. From the FEA (Finite Element Analysis), the aluminum are the suitable most material to make battery packaging because the difference von misses stress of aluminum and steel are very small. The best design also is choose using FEA in thermal analysis. Design three show the faster heat remove from inside battery packaging to outside of the car.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter will give a short and briefly summary for overall of the project and also recommendations for future research.

5.2 Conclusions

Battery packaging is a device where the battery of lead-acid or lithium-ion kept safe in car. These projects are focus on Proton Iswara available space where the Proton Iswara needs to convert to electric vehicle. The specification of the motor that already install in Proton Iswara are listed, than the total power, voltage, current and other value that needed to run the motor are find.

There are three proposed design that will fixed with Proton Iswara. All of the design has own type specification. For design 1, the cooling system is installing at the side battery packaging and will sucking air at side of the car. Design 2 used to sucking air at the bottom of the car, and for design 3 the air are sucking from inside of the car which is air-conditioner air. From these all type proposed design, the design 3 are better than other two design. It is because, the air-conditioner air are lower temperature than room temperature. For example, Malaysia has standard room temperature about 30° C, with the intake air form air-conditioner that will reach temperature about 20° C, the batteries will have more effective cooling system.

For design 1, there is no protection on suction fan. The suction fan is easy to broken if there is a foreign thing stuck on the fan and the cooling system are fail. The performance of the batteries will decrease. For design 2, the suction fan have a pipe for protection, but there is a deficiency where if flood are happen. The suction fan will stick because the pipe suction is stuck in flood. This problem effect on the cooling system, cause the suction fan is not functional.

After ALGOR analysis, there is some conclusion that will make on the design selection and the material selection. For stress analysis, the aluminum has better specification than steel to make the batter packaging. Some of the battery itself uses to make by aluminum sheet. All of the result is in chapter 4. And for heat analysis on the design, the design 3 has better than design 1 and 2. Design 3 is faster than design 1 and 2 to release the heat from the battery packaging to the outside of the car.

5.3 Recommendations for the Future Research

Battery packaging can be the solution of performance batteries in electric vehicle. This field of study suggested that battery packaging are build so that all problem and future for these battery packaging will find. There are more thing need to consider to build the battery packaging.

In future study, the project scopes should be change so that it is more specific and distinctive. Since in this project battery packaging are investigated and focus on Proton Iswara car at Universiti Malaysia Pahang, for further study it is recommended to identify and investigate the type of battery packaging for more type car and more type of electric vehicle motor.

This research is only focus on selection design and material for battery packaging in order to minimize the cost, maintenance for batteries and effective cooling system for battery performance. It is also focus on selection batteries where two type of battery are used in electric vehicle, but the battery power and voltage are depend on the motor specification. So, to prove the proposed design of battery packaging is good or not and whether the batteries are stable in car, more analysis need so test.

The first analysis is about vibration test. The battery packaging is installed at the rear of the car, upper by car tire. When the car in the rough road, the battery packaging will vibrate and may cause shock for the batteries in battery packaging. It is also can make batteries broken or leakage if use leads acid type battery. So that, the vibration test need to applied so that we can avoid damage of the battery of Lithium ion battery will support before broken. The value of maximum vibration makes it easy to find the constant value of spring. Spring is used to support the bottom battery packaging, so that is the vibration occurs, the spring will suck the vibration and batteries inside battery packaging are stable.

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| Research | | Janı | uary | | | Feb | mary | | | N | ſac | | | A | linc | |
|----------------|----|------|------|----|----|-----|------|----|-----|-----|-----|-----|-----|-----|------|--|
| activities | W2 | W3 | W4 | 5W | 9M | TW7 | W8 | 6M | W10 | W11 | W12 | W13 | W14 | W15 | W16 | |
| Receive PSM | | | | | | | | | | | | | | | | |
| title from | | | | | | | | | | | | | | | | |
| supervisor | | | | | | | | | | | | | | | | |
| Briefing with | | | | | | | 4 | | | | | | | | | |
| supervisor to | | | | | | | | | | | | | | | | |
| get the | | | | | | | | | | | | | | | | |
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| outside | | | | | | | | | | | | | | | | |
| source | | | | | | | | | | | | | | | | |
| Comparing | | | | | | | | | | | | | | | | |
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| product | | | | | | | | | | | | | | | | |
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| the design | | | | | | | | | | | | | | | | |
| and drawing | | | | | | | | | | | | | | | | |
| Identify the | | | | | | | | | | | | | | | | |
| cooling | | | | | | | | | | | | | | | | |
| system | | | | | | | | | | | | | | | | |
| Preparation | | | | | - | | | | | | | | | | | |
| for | | | | | | | | | | | | | | | | |
| presentation | | | | | | | | | | | | | | | | |
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| submitting for | | | | | | | | | | | | | | | | |
| PSM 1 | | | | | | | | | | | | | | | | |

Gantt Chart for FYP 1

APPENDIX A1

| 5 | | | | | | | | | | | | | | | | | |
|------------------------|-----|------------|----------------|--------|------------|---------|-----------|-----------------|--------|-------------|----------|-------------|--------|--------------|-------------|---------------|--|
| | W15 | | | | | | | 2 | | | | | | | | | |
| Octob | W14 | | | | 2 | | | 2 2 2 | | | | | 100 | | | | |
| | W13 | | | | | | | | | | | | | | | | |
| | W12 | | | | 1 | | | 7 | | | | | | | | | 2 |
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| | W19 | | | | | | | | | | | | 5 6 | | | | |
| | 8M | | | | | | | | | | | | | | | | |
| lgust | TW7 | | | | | | | | | | | | | | | | |
| Au | 9M | | | | | | | | | | | | | | | | |
| | W5 | | | | | | | | | | | | | | | | |
| | W4 | | | | | | | | | | | | | | | | |
| July | W3 | | | | | | | | | | | | | | | | |
| | W2 | | | | 1 | | | | | | | | | | | | |
| | WI | | | | | | | | | | | | | | | | |
| Research activities | | Select the | simple cooling | system | Design the | battery | packaging | Choose the best | design | Thermal and | strength | analysis on | design | Presentation | preparation | Documentation | Report submitting for PSM 2 |

Gantt Chart for FYP 2

APPENDIX A2