THE UNIVERSITY OF
WESTERN AUSTRALIA

Department of Mechanical and Materials Engineering

Renewable Energy Vehicle

Power Steering

Air conditioning

Traction Motor

Dissertation

By

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Supervised by Dr Kamy Cheng

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SYNOPSIS

There is an increasing need to reduce the carbon dioxide levels currently produced in the transportation sector. Currently 23% of worldwide CO2 is due to transportation, of which personal motor vehicles account for 75% of that. The aim is to find a suitable method of transport that is both cost effective and zero emission, and reduce the increasing reliance on fossil fuels.

The renewable energy vehicle is a possible solution to this need, there is an electric drive motor that receives energy from an onboard energy supply or storage. The energy being supplied from renewable sources such as solar, wind or thermal energy sources. There are several problems with this; the current technology uses heavy expensive and bulky batteries to store the energy. Costing more than AU$10,000 per vehicle, the limited range approximately 100km and the long recharge time.

There are safety concerns due to heavier vehicles, braking distance and dynamic handling. There are also issues relating to the safe disposal and effective recycling of used batteries, and other components such as lead and mercury in the electronics. This report investigates some of the aspects relating to the function of Electric Vehicles, the Air-conditioning, Power steering and the primary drive or Traction motor.

LETTER OF TRANSMITTAL

Tim Pyper

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3rd November 2008

Professor Brett Kirk

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Dear Professor

I hereby present this dissertation entitled, "Renewable Energy Vehicle, *Power steering, Air conditioning and Traction motor*", to the Faculty of Engineering, Computing and Mathematics to fulfil part of the requirements of the for award of a Bachelor Degree of Mechanical Engineering.

Yours Sincerely,

....

Timothy John Pyper

ACKNOWLEDGEMENTS

I would like to give thanks to the following people that have provided a valuable contribution to the research process during the course of the year.

- Supervisor Dr Kamy Cheng. For his valuable guidance and support.
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ACRONYMS

A	-	Amps
A/C	-	Air Conditioning
AC	-	Alternating Current
BLDC	-	Brushless Direct Current Motor
CoG	-	Centre of Gravity
DC	-	Direct Current
EHPAS	-	Electro Hydraulic Power Steering
EPAS	-	Electric Power Assist Steering
EV	-	Electric Vehicle
Eyebot	-	A special purpose visual electronic display input/output device
GWN	-	Global Warming Number
GWP	-	Global Warming potential
HPAS	-	Hydraulic Power Assisted Steering
Lion	-	Lithium Ion
PAS	-	Power Assisted Steering
PMOI	-	Polar moment of inertia
REV	-	Renewable Energy Vehicle

CHAPTER 1: INTRODUCTION

Abstract: *This chapter outlines the back ground of the project, the project history at UWA and the aims for this year's project.*

1.1 Project Background

The use of vehicles for transportation is responsible for 23 percent of the world carbon dioxide production, of which personal motor vehicles account for 75% of that. As well as carbon dioxide there are many other toxic pollutants released into the atmosphere that are harmful to the health of living organisms and the global environment. Figure 1 below shows the amount of carbon dioxide production by each sector. The figure shows Electricity Generation as the major contributor followed by Industry and Transport.

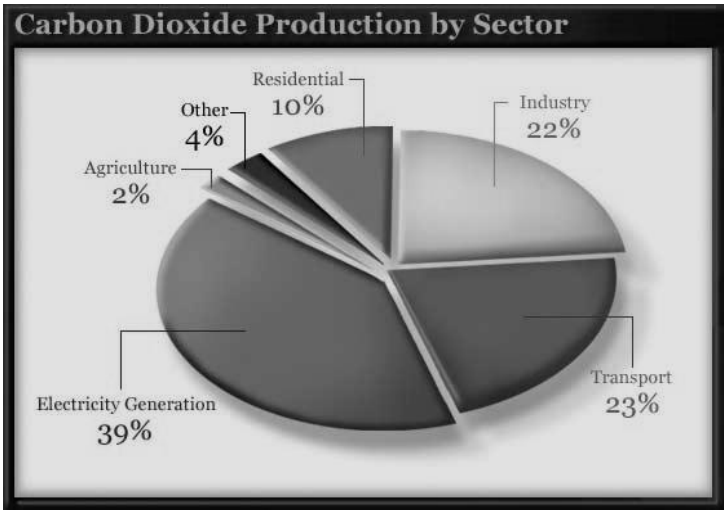

FIGURE 1: GLOBAL CARBON PRODUCTION BY PERCENT

The need to reduce carbon emissions is becoming more apparent as the human race achieves a greater understanding of its impact on the Earth's environment. Realising that the Transport sector accounts for 23% of carbon dioxide emissions globally sees this as a significant target area for researchers and scientists to combat.

Since its invention in 1820, the internal combustion (IC) engine has become increasingly popular as a portable power source. The IC engine is used in a broad spectrum of applications, from agricultural and construction equipment to land, air and water based vehicles. Some of the reasons for the global acceptance of the IC engine, particularly in the transport sector, were its capability to travel vast distances for a relatively low purchase price and minimal running and maintenance costs. The IC engine gave individuals the flexibility to travel wherever and whenever they wanted to go at an affordable price. Currently the primary fuel source for the IC engine is fossil-fuel based. However, the burning of fossil-fuels by the IC engine results in a combination of harmful gas emissions, primarily carbon dioxide.

Other non fossil-fuel sources are available such as hydrogen which has similar portability benefits to fossil-fuel based fuels except its products of combustion is water (H2O). Also, this technology is still in its infancy and has some major obstacles to overcome due to the high fuel cell costs and establishment of infrastructure (fuelling stations).

With personal transportation accounting for 17% of the global carbon dioxide emissions, there is a need to find a viable replacement/alternative for the IC engine powered by fossil fuels. An emerging technology is the mixture of two different power sources, the main permutation being the amalgamation of the Internal Combustion engine and Electric Motor. This combination is commonly known as a Hybrid and this technology lends itself ideally to the motor vehicle. Figure 2 illustrates one particular variant of a Hybrid type vehicle.

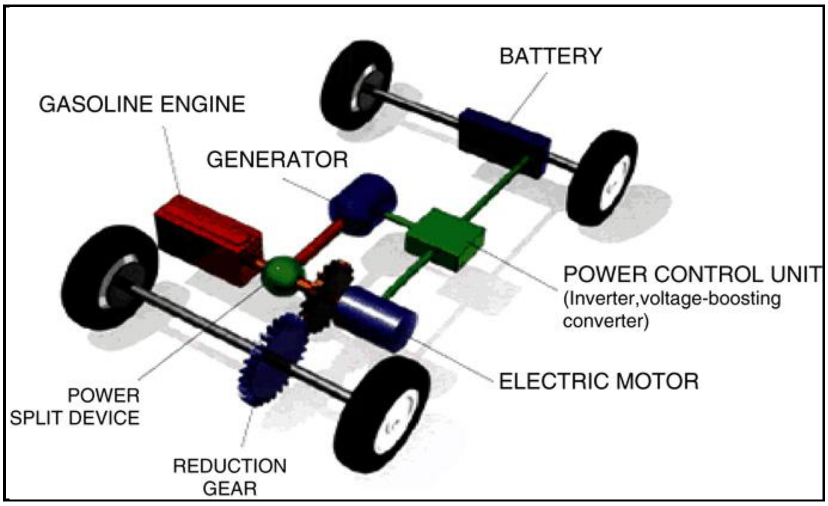

FIGURE 2: TYPICAL HYBRID CONFIGURATION,(PROKHOROV, 2008)

The Hybrid has some major advantages in fuel economy and satisfying emissions targets. This interim technology may enable a smoother transition from a conventional IC vehicle to a full Electric Vehicle (EV) thus giving the community time to adjust whilst still reducing carbon dioxide emissions. The hybrid vehicle has many advantages over the IC engine vehicle. It has the ability to switch between the IC engine and Electric Motor when it is advantageous for efficiency reasons. For example, at low speed such as in heavy traffic, the IC engine switches off and the vehicle is driven by the Electric Motor. However, when demanded for on highway use the IC engine is used.

Although the hybrid vehicle is more efficient than the conventional IC engine vehicle, it still uses fossil fuels for its fuel source. An alternative to both the IC engine and Hybrid vehicles is the EV. The EV carries its energy source in the form of batteries, which are housed within the vehicle. This gives the EV some important advantages over both the IC and hybrid vehicles, the obvious one being the vehicle itself produces zero emission. When the batteries are charged via an external energy supply from a renewable source such as the sun, then it will be a zero emission vehicle. This type of vehicle is then known as a Renewable Energy Vehicle (REV).

The EV is dependent on batteries for its primary energy supply. The density with which the energy can be stored is a significant limitation to the EV. The problem with current technology batteries is they are very expensive and have a limited life cycle and also the battery life is dependent on the demand placed upon it. This battery life limitation can be minimised by reducing the energy demand on them. This can be done by improving the efficiency of the devices that use this energy.

With improved battery energy density and lower capital cost the Electric Vehicle has the potential to become a viable replacement to IC engine-powered vehicles. This could therefore help to reduce the 23 percent global carbon emissions contribution from the transport sector.

1.2 Project History

The UWA Renewable Energy Vehicle project has been an area of research for several years, with much of the work previously undertaken being of a theoretical nature. There has been much research done previously in the area of fuel cells, where hydrogen fuel is converted into electricity onboard the vehicle and then used to power the electric drive motor or charge the batteries. This offered a noticeable advantage over the EV in its ability to travel greater distances, however there is a high cost associated with this system.

In 2007 the implementation of the theory began with the decision to build a hydrogen fuel cell vehicle, where a significant amount of work had been done. The vehicle was prepared by removing the original IC engine and auxiliary devices in readiness for the new electric motor, batteries and fuel cell. The project was later discontinued due to rising cost of the fuel cell and long lead times.

Beginning in 2008 the decision was made to build an electric vehicle which required fewer expensive components and could utilise the electric motor, controller and batteries purchased for the 2007 REV. A new Hyundai "*GETZ*" was purchased as a platform from which to commence the build. The grounding was set for the 2008 UWA REV project to get underway. The work previously carried out and the recommendations made in previous year's theses will be investigated to assess the merits of any recommendations made for the inclusion in this project.

1.3 Project Aims

The objective of the UWA REV project is to conduct research in the area of full electric vehicles as it is the aim for the future to have a zero emission vehicle; i.e. one that uses no fossil fuels as its power source. Additionally it is hoped that in the future the manufacture of the vehicle and all its components will also be from zero emission power sources. For this reason the 2008 UWA REV team proposed to build a fully electric vehicle, with commercially manufactured and readily available components. This would ensure a working prototype is ready for road tests at the end of 2008.

The primary aim for the 2008 UWA REV team is to build two different types of licensable, road-legal electric vehicles; a compact commuter and performance road vehicle. The commuter vehicle is to be built using a 2008 Hyundai "*GETZ*" whilst the performance vehicle will use a 2002 series II Lotus "ELISE". The selected vehicles will be the platforms from which to start the conversions to that of full electric vehicles.

The specific aims for this project are to investigate, specify and select a suitable method of providing power steering and air conditioning (Cooling) for the commuter vehicle, and a traction motor for the performance vehicle. Each of the three aspects has its own unique function and requires a separate analysis, objective and criteria, and therefore will require individual assessment and review of current technologies available. The project intends to highlight the problems associated with each aspect and to provide viable solutions.

CHAPTER 2: LITERATURE REVIEW

Abstract: *This chapter is a review of current research in technologies relating to the design of power steering, air-conditioning and traction motors for electric vehicles. The aim being to assess the current state of the art in these fields.*

2.1 Review of Power Steering Systems

The Power Assisted Steering (PAS) system is one that aids the driver to control the vehicle. Assistance is provided to the driver by supplying additional force to the steering mechanism, in the correct amount and direction. Predominantly, Hydraulic Power Assisted Steering (HPAS) has been main stream; however there are also Electro Hydraulic Power Assisted Steering (EHPAS) and Electric Power Assisted Steering (EPAS) systems now beginning to emerge.

Power assisted steering has not always been present on vehicles, although in recent years the majority of manufacturers include PAS as standard equipment. Many vehicles could be operated without power assisted steering, however it does give the driver improved control. This is particularly advantageous when the vehicle is moving at slow speed, if the driver’s strength is minimal or if evasive manoeuvres are required to avoid an accident. In addition, if the driver can be aided and lessen the effects of fatigue due to over exertion from steering effort, thereby maintaining a safe level of operation.

Each type of Power Assistance has their advantages and disadvantages for use in the application. The HPAS uses a mechanical drive from the IC engine to provide its drive whereas the EHPAS has an electric motor to drive the hydraulic pump. The hydraulic systems are similar whereby both have hydraulic circuits to create the assistance. A high pressure fluid is pumped to an orifice valve located in the steering system. The amount of opening on the orifice valve determines the amount of assistance provided. The greater the resistance between the tyres and the steering effort determines the degree of opening of the valve and thus the amount of assistance provided (HMC, 2003). HPAS has been the main system employed in the automotive industry for many decades. EHPAS has advantages of intermittent operation, only activating when required. This saves energy and reduces emissions, over the HPAS which is always on and therefore always pumping. The EHPAS is modular in design and can be retrofitted to existing vehicles with minimal redesign effort.

In the automotive industry there is a recent trend away from the HPAS and towards EPAS system, mainly for efficiency improvements and helping to meet strict emissions targets. The electrical energy is converted in to mechanical force by an electric motor or electromagnetic flux which moves a pinion gear attached to the steering rack to provide the assistance. The emerging EPAS technology has several types; single and double pinion primarily for rack and pinion as explained in (Parmar and Hung, 2004). The EPAS system uses an electromagnetic field or electric servo motor to directly or indirectly rotate the steering shaft or rack, thus providing the assistance. The ability of the electric motor to operate only on demand reduces its overall energy consumption, as compared to conventional hydraulic systems that are always running.

All steering systems, both assisted and non-assisted, aim to provide the driver with control of the vehicle and are essential to its operation. The key issues remain safety, reliability and efficiency. The safety is of particular importance to the function of a steering system due to this being an essential primary control of a motor vehicle. To diminish the chances of failure, a survey of the Failure Modes and Effective Analysis (FMEA) is performed. FMEA is commonly used as a tool by the aerospace and automotive industry to avoid or reduce the likelihood of failure, which could result in unsafe operation or accident.

As discussed in “Requirements management in practice: findings from an empirical study in the automotive industry” (Lars et al., 2006) there is a balance between cost and performance. This is a known difficulty to the automotive manufacturer, as this also applies to the safety feature products installed in motor vehicles. It is of importance to give the most safety possible within the budget; there is a price associated with the level of safety provided and this ultimately dictates the type and quality of components installed in the vehicle.

2.2 Review of Air-Conditioning

The air conditioning (AC) system as used in motor vehicles is designed to keep the occupants at a comfortable temperature. If a motor vehicle is left outside during the daytime, particularly when ambient temperatures are high, the cabin accumulates heat and stores it in its mass. This potentially results in an uncomfortable environment for the occupants and can affect driver performance and awareness, as described in "Cooling and Ventilation of the Renewable Energy Vehicle (REV)" (Chan, 2006). Hence, providing air-conditioning systems in motor vehicles is a beneficial addition because it enhances driver safety by lessening fatigue. Additionally the AC system can be used to dehumidify the air and remove the moisture layer built up on the inside of the front windscreen, which is common in winter. The typical circuit shown if Fig.3

The systems commonly installed in motor vehicles use the heat from the IC engine to warm the cabin and have a separate vapour compression refrigeration system to cool. The cooling system takes warm air from either inside the cabin and recirculates it, or from outside and passes it through an evaporator. The evaporator is the part of the cooling system circuit that exchanges heat from the warm air and transfers it to the refrigerant. The evaporator is housed inside the ducting system within the cabin itself as shown in the Hyundai service manual (HMC, 2003). The heat extracted from the cabin to the refrigerant via the evaporator then travels to the condenser, where it is lost to the environment. The cool air is then circulated about the cabin, which removes heat from the thermal mass.

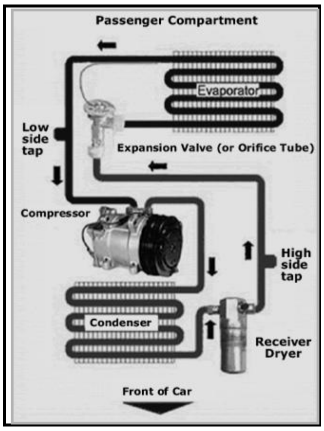

FIGURE 3: TYPICAL AUTOMOTIVE A/C SYSTEM CONFIGURATION, (CHILLYWILLYS.ORG, 2008)

The primary purpose for including AC systems in motor vehicles is to cool the occupants, not necessarily the whole cabin. Ideally, to cool the occupants only would require substantially less energy than to cool the whole cabin which has much greater thermal mass. This has prompted detailed investigations by a variety of researchers, such as that conducted in “3-D numerical and experimental analysis for airflow within a passenger compartment” (Chien et al., 2008). Here, Chien models the actual temperature variations within the cabin using computational fluid dynamics as shown in Figure 4. The purpose of the modelling was to determine how cool-air particles flow within the cabin. Chien found maximum cooling to occur near the head. This information can be used to improve the efficiency of the AC system, by cooling only where it gives maximum benefit to the occupants.

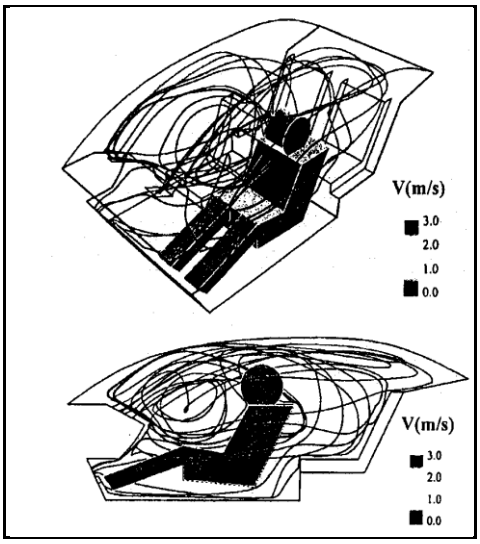

FIGURE 4: THREE DIMENSIONAL PARTICLE TRACK (VELOCITY), (CHIEN ET AL., 2008)

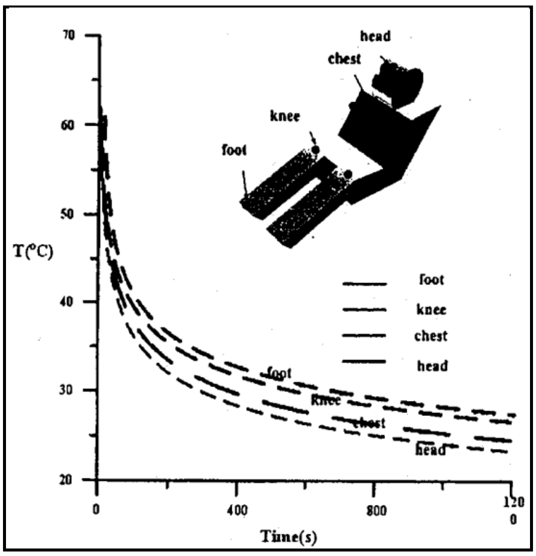

FIGURE 5: THE AIR TRANSIENT TEMPERATURE NEAR THE PASSENGER, (CHIEN ET AL., 2008)

The Vapour Compression Refrigeration system incorporates 5 main components:

- Compressor,
- Evaporator,
- Condenser,
- Expansion valve, and
- Refrigerant.

The refrigerant flows around the circuit and undergoes changes in pressure and temperature, which result in it alternating between liquid and vapour phases. The performance of the whole system is dependent upon the type of refrigerant and compressor used. Of these two key components, the refrigerant has a greater bearing on the overall performance of the system. The type of refrigerant affects the ability of the system to cool for a given amount of energy input. The refrigerant also dictates the size and type of compressor that can be employed. Table 1 below highlights some characteristics for three refrigerants; R-134a (Hydro Fluoro Carbon), HFO-1234yf (Hydro Fluoro Olefin) and the natural refrigerant R-744 (Carbon Dioxide). All three refrigerants shown in this table have a similar comfort scale, but the energy needed varies between them. The HFO and R-744 require more energy (~70%) compared to the R-134a.

Refrigerant	Fuel Consumption L/100km	Comfort scale summer (1-10)	GWP
R-134a	0.48	8.6	1300
HFO-1234yf	0.81	8.3	4
R-744 (CO2)	0.82	8.1	1

TABLE 1: REFRIGERANT COMPARISON, (MARA ET AL., 2007, WEISSLER, 2008)

Refrigerants

The refrigerant is the working fluid that enables the refrigeration process to take place. The type of refrigerant dictates the mechanical components used in the system. For example, different refrigerants need to operate at different pressures and therefore require a specific type of compressor to drive the process. The system pressure will determine the dimension and material properties of the connecting pipe-work and associated seals. There is a wide range of refrigerants available with varying performance characteristics and of particular interest is the Global Warming Potential (GWP). The GWP is a number relative to carbon dioxide that the refrigerant will have when compared to carbon dioxide over a 100 years.

With heightened awareness of the environmental impact of the refrigerant when released into the atmosphere, the GWP is now an important factor. The R-134a is currently the most common refrigerant used in the automotive industry due to its good performance and low ozone depleting potential; however its GWP is 1300. Because of its high GWP, this refrigerant is due to be phased out in Europe by January 1st 2011 when a GWP limit of 150 will be enforced (Weissler, 2008). The refrigerants which have a low or zero GWP such as ammonia, and their viability as replacements to current assets, show some real benefits in terms of low environmental impact, as discussed in "POTENTIAL OF LOW GWP ALTERNATIVES IN REFRIGERATION"(Sicars, 1999)

Having acknowledged the need to find a suitable replacement to current refrigerants, research is being undertaken to find alternatives that have good performance whilst still being friendly to the environment as discussed in "New Environment-friendly refrigerant" (Xiaoyu, 1999). There are several candidates that meet the criteria; however they have a noticeable drop in efficiency. Table 1shows two potential candidates compared to the existing R-134a and their energy consumption in L/100km. This testing was performed under the European drive cycle with IC engines.

Research conducted to date has found the natural refrigerant R-744, has excellent potential with its comparable cooling comfort scale and low GWP of one. The negative of this gas is it has to operate at extremely high pressures – up to eight times the pressure of R-134a. A comparison of the operating performance of alternative refrigerants was investigated in "Carbon Dioxide As An Alternative refrigerant for Automotive Air Conditioning"(Mathur, 2000) and "A comparison of the operating performance of alternative refrigerants" (Halimic et al., 2003).

2.3 Review of Traction Motor

The traction motor is a device which converts electrical energy into mechanical energy. When electricity is passed through a conductor an electromagnetic field is created. This electromagnetic field is then used to drive a shaft for the purposes of obtaining rotary motion, as explained in Physics for Engineers and Scientists (Tipler, 1999).

There is a need to provide the means of creating motion without combustion or emission. The electric motor can provide this. The electric motor can be used to provide motion by converting the electrical energy into a force capable of moving physical objects. Such as the gears in a transmission, the wheels on a vehicle or the propeller on an aeroplane.

Electrical energy (Current) is transmitted in one of two forms; Alternating (AC) or Direct (DC). This intern defines the two main types of electric motor AC and DC. Electric motors fall under one of three categories, AC, DC or Synchronous (combination of AC and DC).

Before proceeding, it is important to differentiate between sprung and unsprung mass. Unsprung mass is that which is in direct contact with the road surface (i.e. the wheel) - This effectively is undamped. Sprung mass on the other hand, is the mass which connects to the unsprung mass via a damping system (typically springs and shock absorbers). Figure 6 pictorially shows the difference between the two.

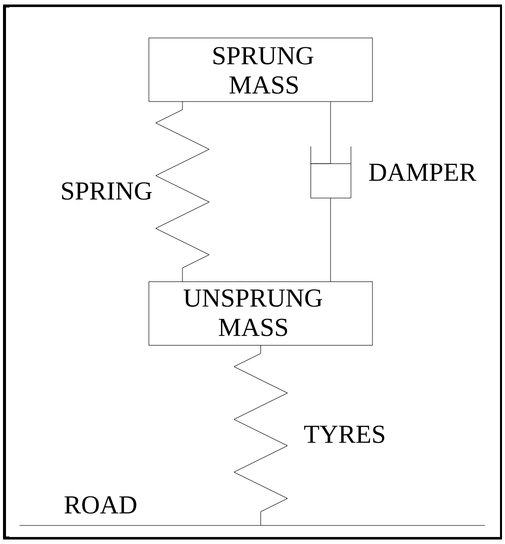

FIGURE 6: ONE D.O.F. MOTOR VEHICLE SPRUNG/UNSPRUNG MASS

There are several existing, as well as some new technologies that can be used as traction motor for a vehicle. Conventional thinking has been to mount the electric motor on to the vehicle's chassis making it part of the sprung mass. This means that the motor has to connect to the wheels via a transmission and series of drive shafts, much the same way as for IC engine powered vehicles.

Two key aspects of vehicle design that are critical are the sprung-to-unsprung mass ratio and the Polar Moment of Inertia (PMOI).

Sprung-to-unsprung mass ratio

It is desirable to have the highest possible sprung-to-unsprung mass ratio, and lowest unsprung mass to ensure the wheels stay in contact with the road surface particularly when navigating over rough terrain, as explained in "How to Make Your Car Handle" (Puhn, 1981).

Polar Moment of Inertia

The second key aspect is the PMOI, which is the relationship of mass and distance squared from a theoretical neutral axis. This affects a vehicles handling because it is a measure of its resistance to change in rotational motion.

Hence, when in motion, many variables affect a vehicle's handling dynamics (cornering, braking and accelerating behaviour). These fundamental principles are discussed in "Physics for Engineers and Scientists" (Tipler, 1999).

The current state of the art concept is to locate the traction motor directly on the wheel thus eliminating the need for transmissions and drive shafts. The theory behind employing wheel-mounted traction motors is all about reducing the friction losses in the transmission, and reducing the overall mass and number of parts that are in a vehicles construction. The wheel mounted traction motor achieves all of these goals. There are however consequences of mounting the electric motor in the wheel. This now increases the unsprung mass of the wheel which can have a detrimental effect on the handling performance of the vehicle.

Because wheel motors are such a relatively new technology there is very little published data on their use in vehicles and their behavioural effects on handling dynamics. The data that is currently available on wheel motors is predominantly about their electronic control, in particular the effects of wheel slip differential speed when cornering, as discussed in "Current distribution control of dual directly driven wheel motors for electric vehicles" (Yang and Lo, 2008). An aspect of wheel motor slip is when traversing inclined surfaces where the probability of slip increases. Figure 7 outlines the key forces acting upon a vehicle in such a situation, whilst Figure 8 shows an exploded view an Axial-Flux Brushless DC Wheel Motor.

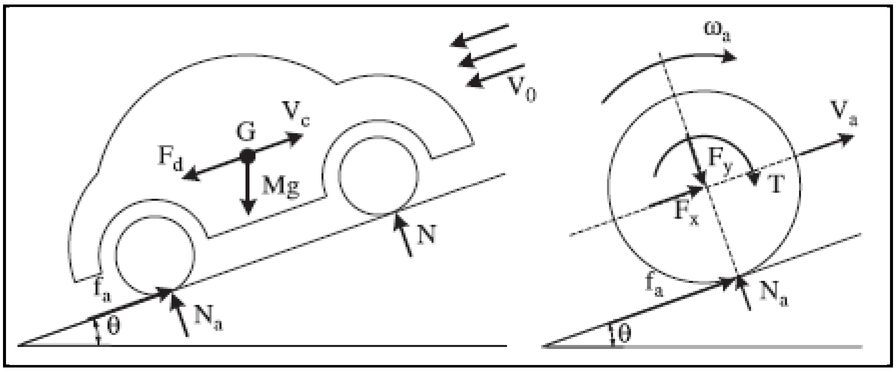

FIGURE 7: WHEEL MOTOR SLIP FOR AN INCLINED SLOPE (YANG AND LO, 2008)

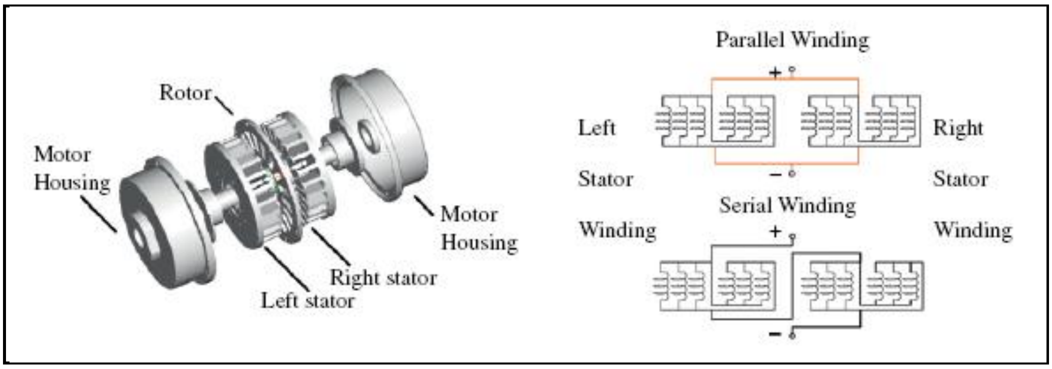

FIGURE 8: ELECTRIC WHEEL MOTOR CONFIGURATION(YANG AND LO, 2008)

A specific type of DC motor technology that can be used in either a sprung or unsprung format that is receiving considerable review is the Brushless Direct Current motor (BLDC). By using a BLDC motor efficiencies of over 90 Percent are obtainable. This does not represent a significant increase over a conventional AC induction or Brushed DC motors as they currently are 80~90 Percent. When the BLDC wheel motor is compared to current technology, they represent a significant step forward in terms of efficiency and simplicity.

CHAPTER 3: THEORY

Abstract: *This chapter is a discussion on the theoretical assets relating to the implementation of, and options available for the purposes of providing power assisted steering, air-conditioning and traction motor for an electric vehicle.*

3.1 Power Assisted Steering

All vehicles have some form of steering to enable them to be guided by their operators. Steering systems can be divided into two categories, either Manual (i.e. unassisted) or Power Assisted Steering (PAS). PAS systems come in several types; Hydraulic Power Assisted Steering (HPAS), Electro Hydraulic Power Assisted Steering (EHPAS) and Electric Power Assisted Steering (EPAS).

The HPAS system employs a hydraulic pump which is driven either directly off an IC engine or some external source. In the automotive industry, the hydraulic pump is typically driven via a pulley system off the main crankshaft of the vehicle's IC Engine. The hydraulic pump supplies high pressure fluid to a valve mechanism inside the steering assembly. The steering assembly can take one of two common forms, either rack and pinion or steering box types. Whichever is the case, the principle of operation is very similar. The hydraulic pump is continually supplying high pressure fluid to the high pressure side of the valve mechanism. When the operator applies effort to the steering wheel in a particular direction, the valve is exposed to a resistance force. The greater the resistance between the road and the vehicle's tyres, the more the valve opens and therefore allows more high pressure fluid through. This high pressure fluid acts on a piston thus provided assistance to turn the wheels in the same direction as the operator. This can be seen in Figure 9, where the top illustration shows the steering wheel in the neutral stationary position and no assistance provided. Then in the lower illustration, the steering wheel is rotating and the pressure in the line is directed to assist the front wheels to turn.

EHPAS uses the same hydraulic principles as the HPAS system except the pump is driven by an electric motor. Hence, this combination makes it an Electro-hydraulic system. The electric motor can either run continuously or it can be controlled to operate periodically as demanded.

The EPAS system uses electronics and electrics to assist the steering. Electrical energy is converted in to mechanical force by an electric motor or electromagnetic flux which moves a pinion gear attached to the steering rack or steering box, thus providing assistance. This system also requires electronics to control the degree of assistance given. An onboard computer receives information from a variety of speed and position sensors and outputs this information to the assistance motor. The computer adjusts the degree of assistance given depending upon the information it receives from those sensors.

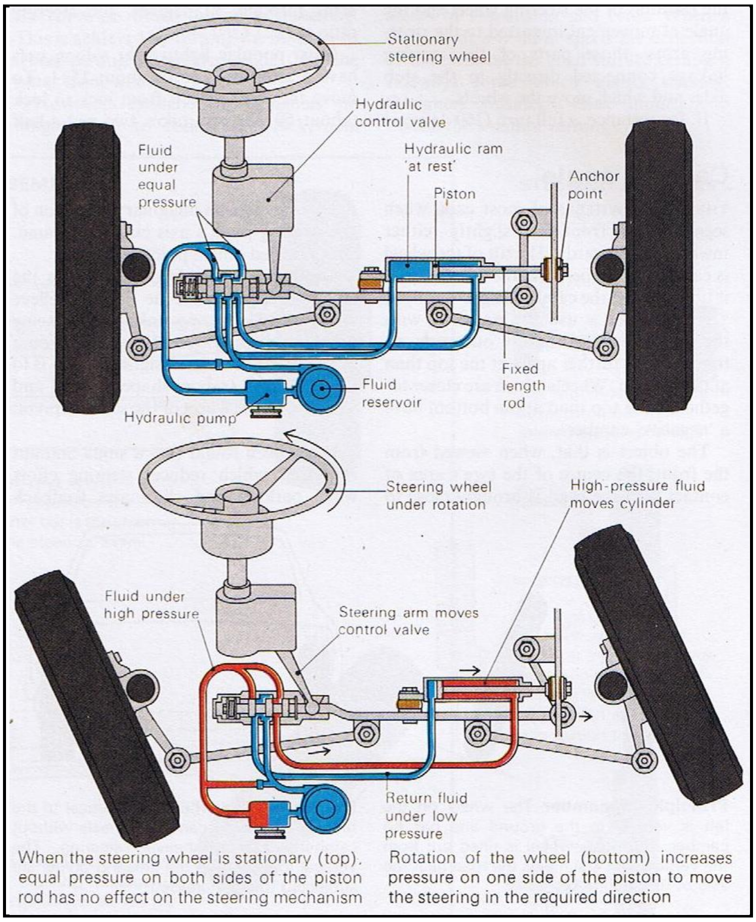

FIGURE 9: HPAS NEUTRAL AND ACTIVE HIGH PRESSURE(AA, 1973)

All three systems achieve their intended goal, which is to provide steering assistance to the driver. The HPAS system has been the automotive industry standard for several decades and has proven itself as a reliable means. It has also been found to give the driver appropriate levels of feedback and control. The EHPAS and EPAS systems are the newest technologies and therefore have not undergone the rigorous proving that the HPAS system has. Because the EHPAS system is all but identical in operation to the HPAS system, this too would give similar driver feedback and control, the only difference being the method of driving the hydraulic pump. The EPAS on the other hand, does not use hydraulics at all. The EPAS depends heavily on a complex electronic control system which relies on inputs from many sensors located on the vehicle.

3.2 Air conditioning

The air-conditioning system as employed in the automotive industry uses a thermal process. The terminology used to describe the specific type of air-conditioning system used in vehicles is the vapour-compression type. This system works by giving up heat from the vehicle cabin to a device which can absorb that heat. However, the system can be run in reverse to heat a space, thereby becoming a heat pump. This could be of particular interest to an Electric Vehicle because they do not have an IC engine as a source of heat.

The Vapour-Compression cycle requires 5 main components. The 5 components and their functions are given below:

1) Compressor: The compressor inputs work into the refrigerant to raise its pressure to that required by the system and to impart motion (flow rate). The compressor is normally located outside the vehicle's cabin somewhere in the engine compartment.
2) Condenser: Is a heat exchanger designed to extract heat from the refrigerant after its temperature has been increased by the compressor. Condenser must be located externally to the cabin because it is on the hot side of the circuit.
3) Expansion valve: Its primary purpose is to create a pressure drop. The expansion valve is positioned as close to the evaporator as possible but still outside of the cabin.

4) Evaporator: The evaporator is a heat exchanger coil enclosed inside ducting underneath the dashboard of the cabin. Its purpose is to transfer heat from the thermal mass of the cabin into the refrigerant.

5) Refrigerant: The refrigerant is the fluid which is pumped around the circuit. The refrigerant flows in a continuous loop from the compressor, to the condenser, to

the expansion valve, into the evaporator and then back to the compressor. During its journey around the circuit it undergoes changes in pressure and temperature, which result in it alternating between liquid and vapour phases. It absorbs and gives up heat continuously during the cycle.

The Figure 10 shows a typical layout of the arrangement for an automotive vapour-compression cycle air-conditioning system.

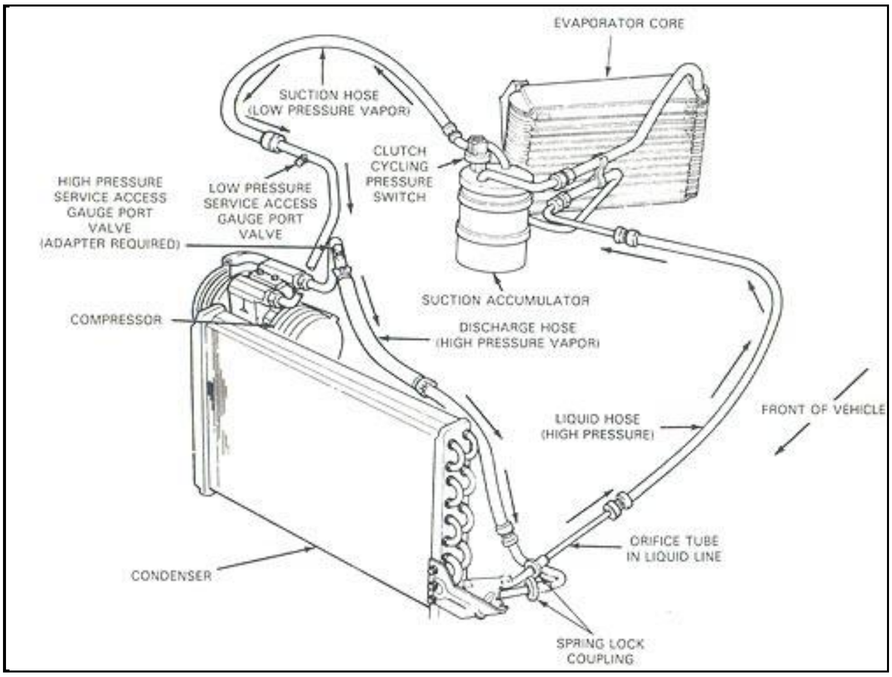

FIGURE 10: COMPLETE AIR-CONDITIONG CIRCUIT DIAGRAM,(EDMUNDS, 2008)

All five components are essential to make the system work; however the compressor and the refrigerant determine the overall system performance. Also, the compressor and refrigerant normally have to be designed to operate together. The compressor must operate at the pressure required by the refrigerant to achieve maximum level of performance. The ability of a compressor to convert input energy, into output cooling power is known as the coefficient of performance (COP). This is one of the values by which all compressors are judged and the higher the COP the better the compressor is at performing its function.

Thus far, the principles of operation of the Vapour-Compression refrigerated Air- Conditioning system have been described. The purpose of the AC system is to provide a comfortable environment for the occupants in the cabin. The amount of cooling power is inversely proportional to the amount of time needed to cool the thermal mass (i.e. the cabin). The results from Chien's research as described in "3-D numerical and experimental analysis for airflow within a passenger compartment" (Chien et al., 2008) are shown in Figure 11. The graph illustrates that it would take an average of 20 minutes to reduce the cabin temperature from 50^0C to 25^0C.

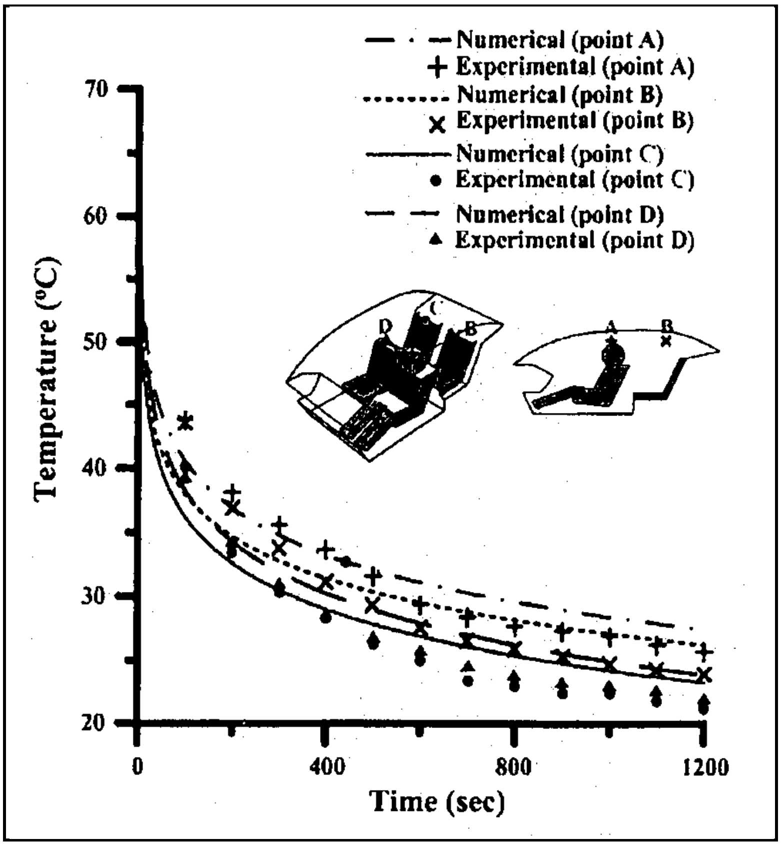

FIGURE 11: TEMPERATURE VS TIME PLOT OF EXPERIMENTAL & NUMERICAL DATA

The amount of energy that is required to cool down the cabin to a comfortable level can be as much as 4kW input energy. This is not a significant problem for of a fuel powered vehicle, as the engine works a little harder to supply the required energy. It does this by burning a little more fuel. It is estimated that AC use contributes to an additional 5~10% of a vehicles fuel consumption. This is an issue for electric vehicles as any additional load on the energy has a direct bearing on the range.

3.3 Traction motor

A traction motor is a specific type of electric motor. It is the term given to describe an electric motor that will be used to propel a vehicle. The traction motor is a device which converts electrical energy into mechanical energy by using the electricity to generate a magnetic field. This mechanical energy can then be used to drive a shaft and therefore the vehicle.

Electric motors are available in two forms; Alternating (AC) or Direct (DC).When specifically looking at electric motors and their suitability for application in Electric Vehicles, both AC and DC can be used. Each type is noticeably different in their setup. The typical energy source for Electric Vehicles is a DC battery array, which consists of a cluster of batteries housed within the vehicle.

To operate an AC motor from a DC source requires the use of an inverter. The inverter is an electronic device which converts DC into AC. The AC motors are capable of regenerative braking. This is where the motor is used in reverse, to charge the battery. Whilst braking part of the energy to slow it down can be used to rotate the electric motor. The regenerative braking can increase the charge level in the batteries, which can increase the achievable range. The use of regenerative braking can also reduce the wear on mechanical brake components; such as disc pads and brake rotors.

The DC motor of which there are two types Brushed and Brushless. The brushed DC motor has brushes that make contact with a commutator, which rotates inside a permanent magnet. The brushed DC motor does not have the ability to provide regenerative braking, but are low cost. The Brushless DC motor commonly referred to as BLDC has some significant differences in comparison to the bushed DC motor. The permanent magnets rotate and the armature remains stationary. This eliminates the need for an armature but does pose the problem of power distribution, formerly done by the commutator. An electronic controller performs this task, with the input from a rotary position sensor. The BLDC motor offer regenerative braking, without brushes to erode away from friction, and greater levels of efficiency, the BLDC motor is the current state of the art in electric motors.

3.3.1 MOTOR LOCATION

The location of the motor is very important to the overall vehicle design. There are physical dynamic handling issues that arise depending on where the motor is positioned on the vehicle. There are two are two fundamentally different locations that a traction motor be placed; attached to the chassis or directly on the wheel. The motor that is attached directly to the wheel is called unsprung, due to the rotating mass of the wheel being in direct contact with the ground without a spring. When the motor is attached to the chassis this is called sprung as there is at least one spring between it and the ground.

The ability of a vehicle to absorb shocks and maintain the contact between the wheels and the road surface is important. The wheel to road contact is a function of several important variables, of which some are; tyres, suspension geometry, unsprung and sprung masses. The tyres and suspension is outside the scope of this report so will not be discussed. The sprung mass and unsprung mass and the ratio between them are very important. The vehicles ability to perform dynamic manoeuvres and the shocks transferred through the wheels to the body are affected by these masses. This is discussed further 3.3.2 ~3.3.4. The basic layout and interaction between the road, tyres, unsprung mass, suspension spring/damper and sprung mass is shown in Figure 12 .

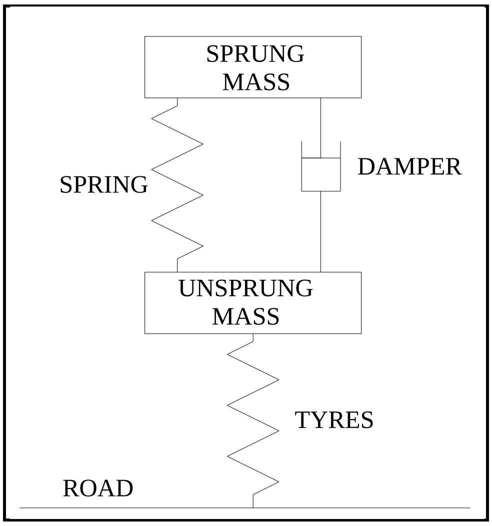

FIGURE 12: MOTOR VEHICLE SPRUNG/UNSPRUNG MASS

Amore realistic example is shown in Figure 13 where the amount of mass attributable to each component is based on how much movement it undergoes during full motion of the suspensions travel.

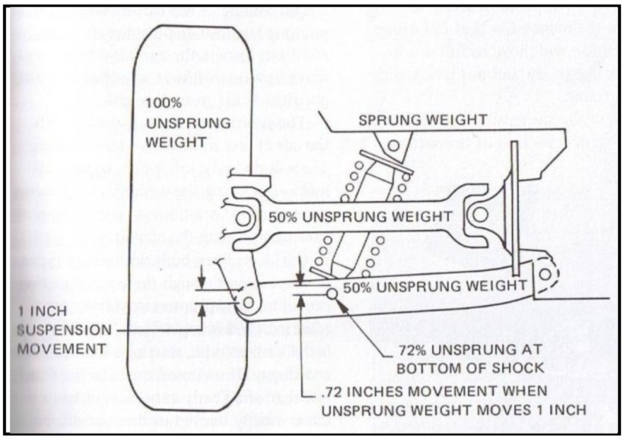

FIGURE 13: SPRUNG AND UNSPRUNG % BY MOTION (PUHN, 1981)

3.3.2 TRACTION MOTOR (SPRUNG)

The sprung motor is similar to the layout found in most existing IC engine vehicles. The mass of the motor rests on the vehicles springs. The drive is transmitted to the wheels via the transmission, differential and driveshaft's. There is a loss of efficiency, due to overcoming the friction, in the mechanical gears and axles. The location of the motors mass has a significant effect on its PMOI, Centre of Gravity (COG) and the wheels ability to absorb shocks. It is desirable to have a low PMOI and COG and unsprung mass.

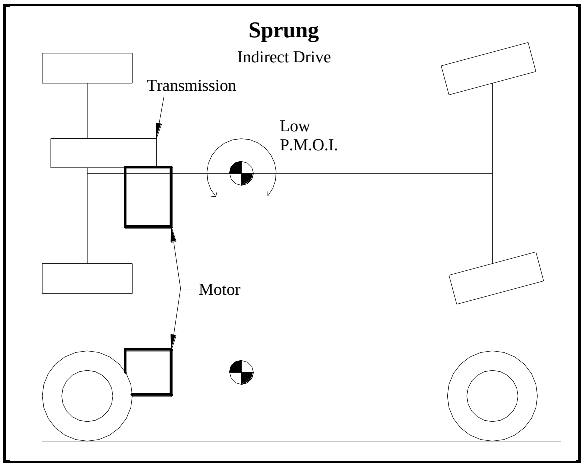

FIGURE 14: SPRUNG MOTOR PMOI AND COG

3.3.3 TRACTION MOTOR (UNSPRUNG)

This type of motor is located inside the wheel rim and directly drives the wheel. This is does away with the need for a transmission and driveshaft's and a differential. It has benefits of weight saving and reduction in drive train fictional losses.

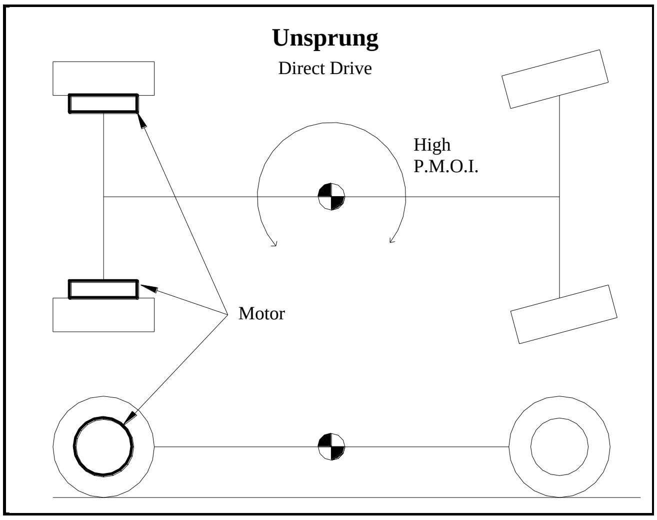

FIGURE 15: UNSPRUNG MOTOR PMOI AND COG

3.3.4 TRACTION MOTOR COMPARSON

The unsprung wheel motor appears to offer a degradation of the vehicles handling abilities when compared the sprung motor. This due to the additional mass attached to the wheel having a large effect on the vehicles dynamics. These are explained and shown below.

Polar Moment of Inertia

The PMOI, which is the relationship of mass and distance squared from a theoretical neutral axis. This affects a vehicles handling because it is a measure of its resistance to change in rotational motion. A vehicle with a large PMOI does not respond readily to a change in direction, this reduces it handling ability.

Unsprung mass

The lower the unsprung mass the greater is the road following ability of the wheel. The wheel has a greater tendency to follow the bumps and dips in the roads surface. The heavier wheel as shown on the lower right in Figure 16, the heavier wheel travels across the top of the dip, and is deflected up by the bump. The opposite is true for a low unsprung mass vehicle; the wheel follows both the dip and the bump.

Sprung-to-unsprung mass ratio

It is desirable to have the highest possible sprung-to-unsprung mass ratio. When the vehicle is in motion the wheels are rolling over the road surface. The bumps in the road surface will cause the wheel to deflect. The energy the wheel has is proportional to its mass and velocity.

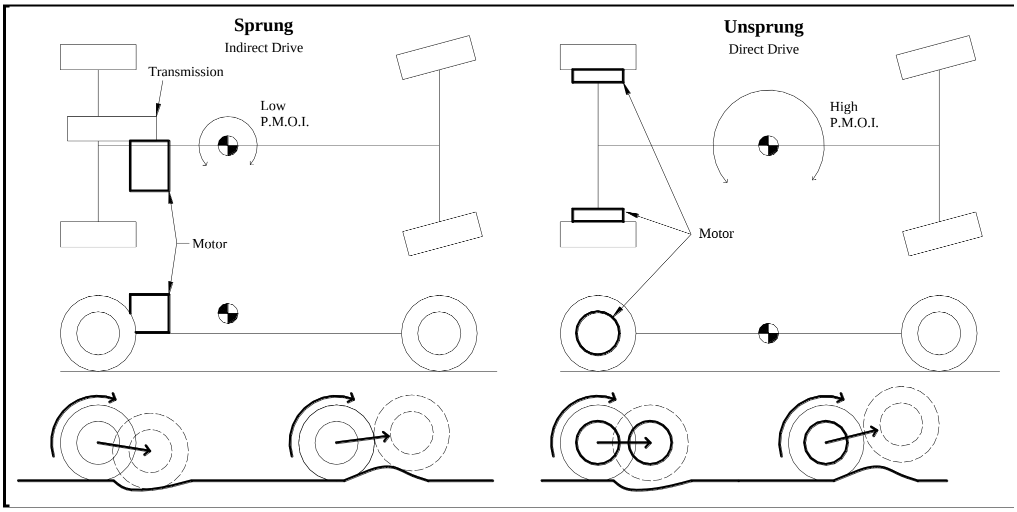

FIGURE 16: FBD SPRUNG UNSPRUNG MOTOR LOCATIONS

CHAPTER 4: DESIGN CONSIDERATIONS

Abstract: *This chapter outlines the design requirements and the considerations involved in the design of power assisted steering, air-conditioning and traction motor for an electric vehicle.*

4.1 Power Assisted Steering

To provide the vehicle with PAS there are several factors that need consideration: This should be done in a considered manner, whereby all the aspects relating to the steering a given due thought. Especially the safety of operating, a motor vehicle with a modified steering system, and not degrade any of the vehicles existing safety devices. In addition it must be efficient, within budget, integrate with minimal modification.

- Safety
- Efficiency
- Financial limitations
- Integration

Safety

The provision of PAS will require the modification of the existing vehicle and the removal of some components. As safety is of a major concern it is the aim of this project to specify a method of performing these tasks. With a minimal intrusion into the safety equipment as such as the steering wheel mounted airbag. The final design of the PAS should not be disadvantaged by the modification or removal of existing safety devices.

Efficiency

The lower the energy consumed the less drain will be on the vehicles limited energy resources. Keeping the energy consumption low; increase the vehicles range. There is a limit of 500watts set as the target efficiency. The PAS should aim to use less than this amount.

Budget

The budget for the purchase of the required components is set with a limit of $1000.

Integration

The design must be compatible with the existing system, and not create more problems than it solves. Such as extensive modifications to the existing system

4.2 Air conditioning

To provide the vehicle with a comfortable cabin environment for the occupants, there are several factors that need consideration and research:

- The cooling capacity and efficiency of the original system
- The amount of energy available from the battery source
- The amount of cooling power required
- A survey of the most efficient systems
- Integration in to the vehicle
- A review of alternatives
- Compressors

The original AC system specifications for cooling power sourced from the (HMC, 2003) is that the system provides 5.0kW of cooling power. The efficiency of the system is a function of the refrigerant and the compressor. The refrigerant dictates the operational characteristics of the system, such as pressure and temperature. The compressor drives the process. The measure of efficiency with which the compressor and refrigerant work together is known as the Coefficient of Performance (COP). The COP is the amount of input energy versus output, the higher the value the better is the system efficiency. The original compressor when operating with the **R134a** refrigerant gave a maximum COP=2.

The amount of energy available was initial set to be 1kW. The 1kW value is set as it would not significantly reduce the battery power level and therefore the range.

The amount of cooling power required is largely influence by the incoming energy from the sun and therefore the temperature of the environment. The environmental temperature and thus the heat load vary throughout the year. The sun supplies 1367kW/m^2 (peak), of which 1kW/m^2 is direct solar radiation. The vehicle has a surface area of 3m^2 exposed to this solar radiation. This contributes 3kW to the heat load on the vehicle. The passengers also add to the heat load, which is 114W for light work. If the vehicle has 5 adults in it then they contribute 570 W to the heat load. This is a total of 3.57kW of total heat load on the vehicle.

A search of the most efficient AC system was performed, the systems with the highest COP= 3.9 are those using R410a and Rotary compressors, the product data sheet shown in the appendix D (Toshiba-Aislu, 2008).

The provision of AC must fit the vehicle with minimal modifications to the existing infrastructure.

Compressors

This refrigerated AC can be provided by two different methods. The use of an electric motor; to drive the original belt driven compressor. The replacement with a combined motor and compressor in one package. The use of a separate electric motor to drive the electric motor to rotate the original compressor would require minimal modification to implement. However this would limit the system efficiency as the COP=2. It can be done within the prescribed budget.

An example of the piston type compressor is shown below. There are several pistons that reciprocate to impart energy to the fluid, this is the type currently fitted to the vehicle.

FIGURE 17: PISTON COMPRESSOR(SANDEN, 2008)

The alternative is to replace the existing compressor only. With a combined motor and compressor; which has the benefits of greater levels of COP, but with major modification to the existing vehicle and significant cost? There are some modern compressors that operate at COP approaching 4; the utilisation of this system in the EV would be a significant step forward in terms of efficiency. The AC systems' using this technology is designed for commercial and domestic applications. There is a difficulty with the adapting them for use in an electric vehicle, for the compatibility issues with voltage supply.

The efficiency with which the compressor can convert electrical energy in to mechanical is the main goal in their selection. There are several types of compressor; that can perform the function in a variety of ways, piston, rotary and scroll.

An example of very efficient compressor is the brushless DC inverter compressor, with rotary vanes using R-410a (shown below). This yields a significant increase in efficiency over the original piston type using R-134acompressor.

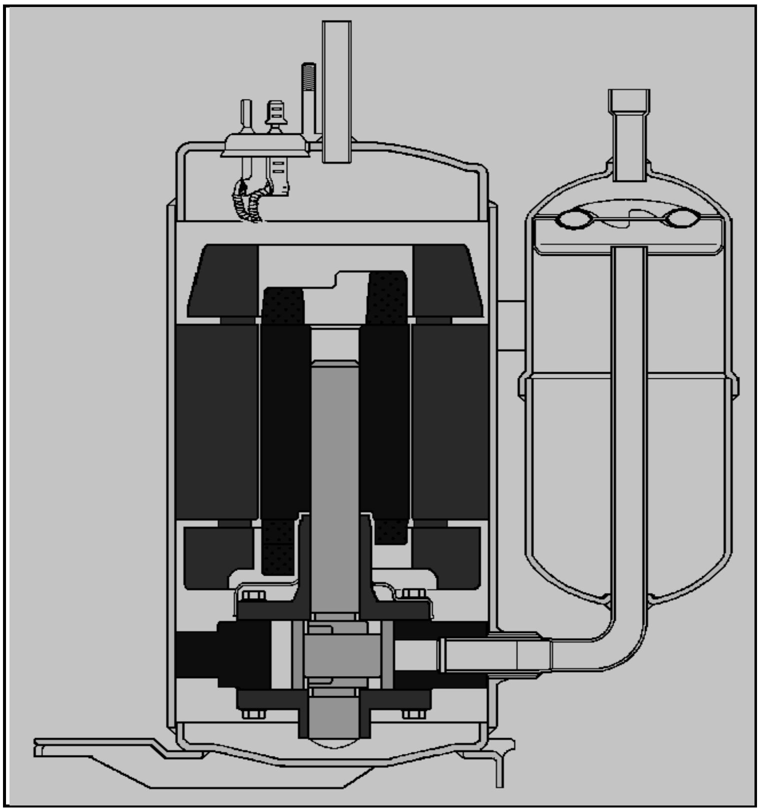

FIGURE 18: SECTION VIEW OF A ROTARY COMPRESSOR(MATSUSHITA-ELECTRIC-JAPAN, 2008)

The compressor shown above has the added benefits of a compact and modular design. The lower mass, than the existing unit. The ability to vary its output whilst maintaining a high level of efficiency (COP).

4.3 Traction motor

To provide the vehicle with traction motor there are several important considerations that need consideration and research:

- Specifications (Power /Torque etc...)
- Motor Location (type unsprung/sprung)
- Motor choice
- Financial constraints
- Controller

The provision of traction or primary drive motor requires the consideration of many aspects of the vehicle to yield a suitable solution. There are many different options available to provide the traction motor and determining the best outcome will require the assessment of each based on a selection criteria.(Cross, 2000)

Specifications

The starting point for this was to gather the published specifications/information from the vehicles original manufacturer. This was initially set as the goals with which should be met. The table below shows the IC engine vehicles performance specifications.

Lotus *Elise* 2002 series 2	
Vehicle mass	756kg
Power Max	91kW
Torque Max	168Nm
Power to weight	0.12kW/kg
Speed (Top)	200 kph
0-100 kph time	5.7s
Weight distribution F:R	38:62
Range	600km

TABLE 2: LOTUS ELISE PERFORMANCE SPCCIFICATIONS

Motor Location (type)

There are essentially two locations for the motor as discussed earlier; the location of the motor is probably the one of the most important decisions. The type of motor available and their performance characteristics, relate to feasibility of matching the set objectives. Which is to match the performance levels of the original vehicle as shown in Table 2: Lotus Elise performance spccifications table 3. Firstly the wheel motors are only available in limited performance levels from a few manufacturers therefore the choice is restricted.

The example shown in the Figure 19 has the following specifications: The optimal rpm to achieve maximum power is 4000rpm this gives a maximum power of 78.4kW and max torque of 195Nm is in the range 0 to 3800rpm

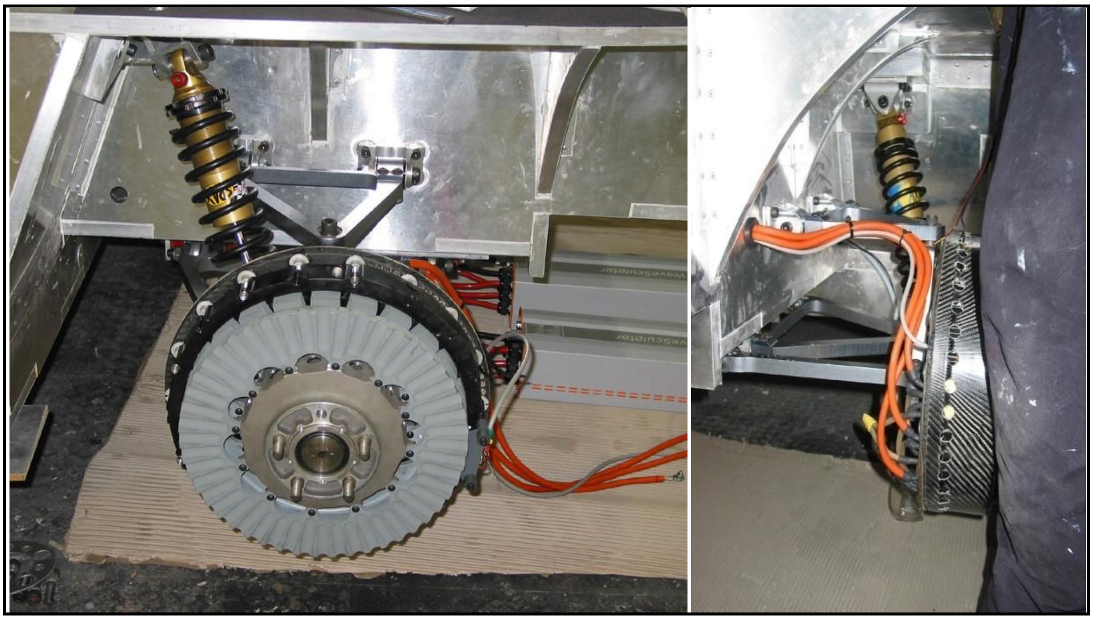

Figure 19: Wheel motor (HybridAuto.PTY.LTD, 2006)

The conventional sprung motor is available in many sizes and types, shown in the table below are three different motor and their comparison to the original IC engine vehicle.

Motor Designation	Power(P) kW	Mass(M) kg	P/M kW/kg	Cost(C) $	C/kW $/kW
Brusa	100	53	1.887	25,000	250
MES	100	55	1.81	12,000	120
Azure Dynamics AC55	59	106	0.736	5000	64
Lotus(Original fuel engine)	91	150	0.6	-	-

TABLE 3: IC EGINE/EVMOTOR COMPARISON

An example of an indirect sprung motor is shown for illustration purposes with a corresponding performance curve of a typical AC induction motor.

FIGURE 20: METRIC MIND CORP.: (METRICMIND, 2008)

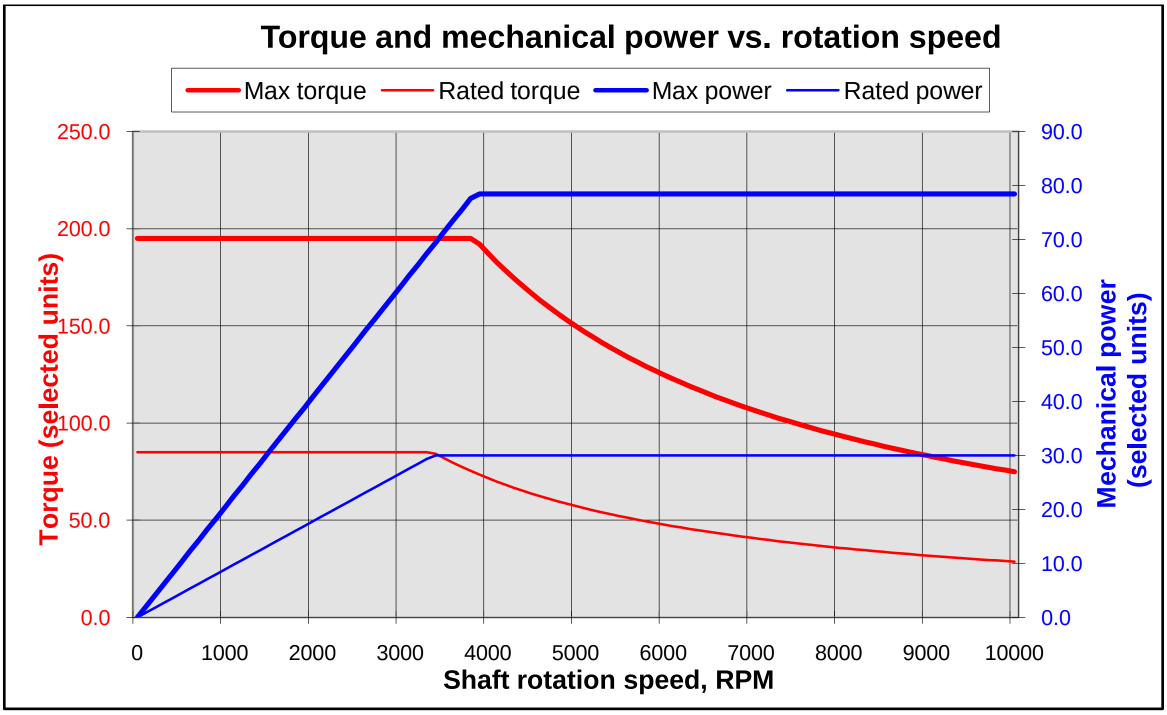

FIGURE 21: AC INDUCTION MOTOR PERFORMANCE CUVE (METRICMIND, 2008)

The demands, voltage current power are the three most important figures to look at when making a choice the voltage will dictate the max power achievable the max current draw is limited by the rate at which the motor can dissipate the I^2 current losses to heat either air or liquid cooled the greater the current flowing the more cooling is required and limitation apply to the amount of heat expelled with air cooled methods however the liquid cooling by passing a coolant through the casing can significantly reduce heat build up below that of air cooling.

The max power will give the max speed possible for the lotus EV due to aerodynamic drag and induced drag from physical shape and aerofoils on the vehicle the faster a vehicle moves through air the rate at which energy is consumed to push it through the air increase with the cube of velocity. So air resistances the largest obstacles to overcome which requires large amounts of power for a performance vehicle to achieve top speed. Possible the most difficult aim for an EV is that of a performance vehicle. Given the already heavy expensive and low energy density of a battery compared to a full tank of petrol the objective of building or constructing a performance EV is much more difficult.

Cost of the various options

The budget in most cases limits what’s achievable and it’s no different in this case the aim of building a performance vehicle that can exceed the original is not possible within the bounds of the limited budget, as such a compromise between cost and performance is sought to offer the most performance possible for the given funds.

Controller

The controller is the device that links the battery array to the main drive motor, this is an important part of the system as provides the means of converting DC into AC for use in AC alternating current motors it also provides a means of controlling the output of the main drive motor it can provide regenerative braking or limit the current flow to the motor to conserve battery life or an electronic link to sat nav or such like data to maintain a safe driving condition.

CHAPTER 5: PROPOSED DESIGN

Abstract: *This chapter outlines the proposed solutions for each of the three categories discussed in this report; the most suitable method is given in each case.*

5.1 Power steering

The method selected to provide power assisted steering, which can satisfy all the set criteria, for efficiency, safety and within budget is as follows. The recommendation is the conversion of the vehicle from an HPAS system to that of an EHPAS system. This will minimise the number of alterations required to the existing vehicle, especially the vehicles original safety systems of collapsible steering column and airbag.

The aim is to specify an electro hydraulic pump unit which can replace the existing mechanical hydraulic system. This required searching for suitable units that were available within budget, and there performance specifications matched.

It was also determined that commercially manufactured components have strict quality control requirements to meet, and that they are more accountable for the products they manufacture. This is opposed to a one off unit where the product quality is questionable.

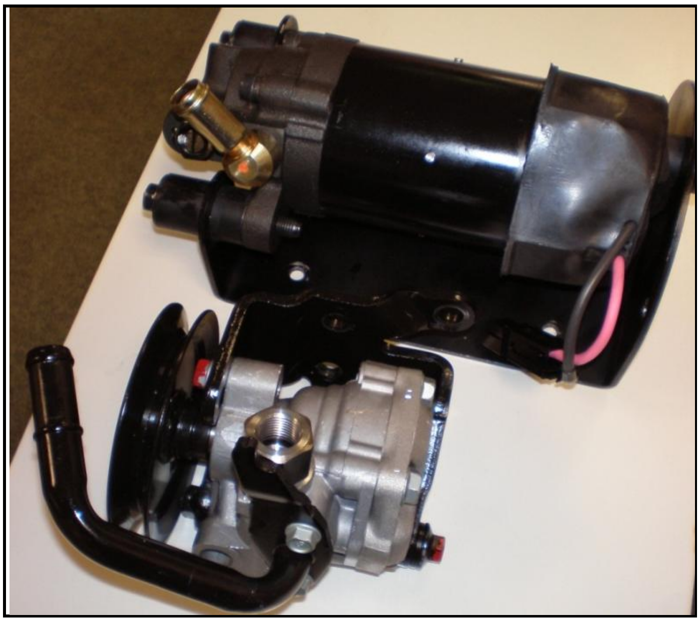

FIGURE 22: HPAS-LOWER, EHPAS-TOP

The Figure 22 shows the new electro hydraulic power steering unit next to the original mechanically driven hydraulic unit as originally fitted Hyundai/Kia Part Number: 57110-1C580.

Handling

There are several important reasons to use the EHPAS method; there is some evidence that suggests hydraulic system provides the driver with a greater level of control over Electronic systems. This is could be due to the level feedback to the driver. This is a criticism of all power assisted steering; they do not provide enough driver feedback. This reduces the driver ability to sense how the wheels and road surface are interacting. Possible the best method is to not have any PAS however this can increase fatigue

Energy Flow

The steering of a vehicle is an essential primary system, to minimise the chance power loss the circuit is kept simple. Shown in green is the 12V system. In the event the main battery supply ceases, then the 12V battery will maintain power levels to the EHPAS pump unit. The system is configured this away intentionally to prevent the loss of steering control. The wiring circuit is shown in appendix A.

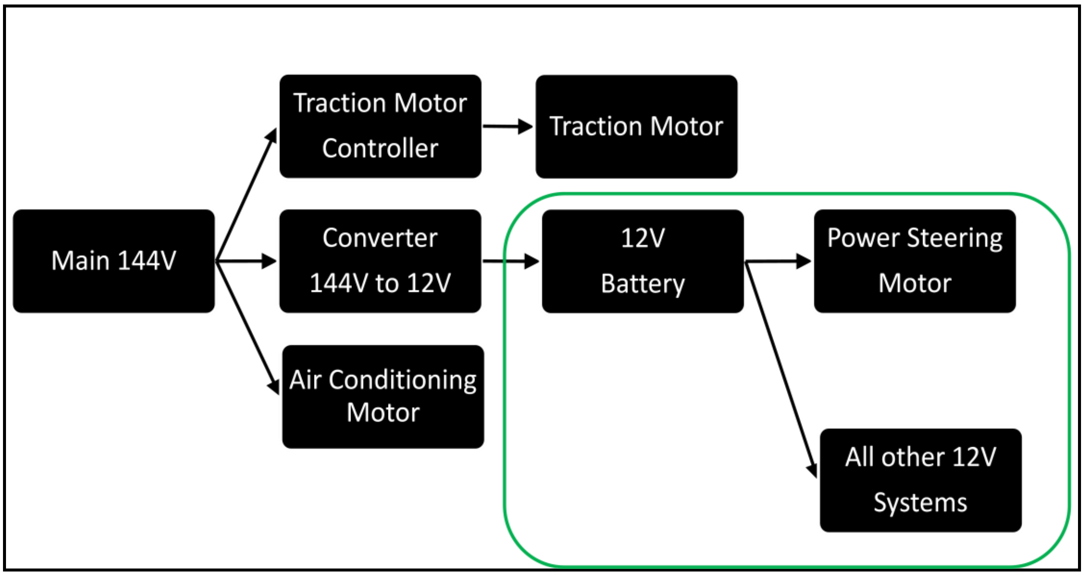

FIGURE 23: EHPAS ENERGY SUPPLY DIAGRAM

System layout

The major parts and there locations within the vehicle are shown below.

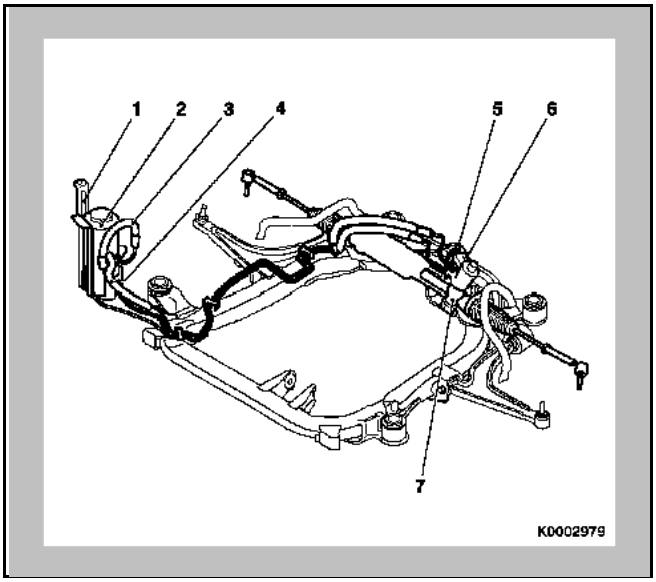

FIGURE 24: EHPAS SYSTEM CONFIGURATION (OPEL MOTORS CO.)

1-Return line,
2-EHPAS unit,
3-Supply line,
4-Steering gear,
5-Bracket,
6-Rotary valve,
7-Steering rack

The EHPAS is to be mounted securely with bracket as shown in the Figure 25 in the using the appropriate hardware.

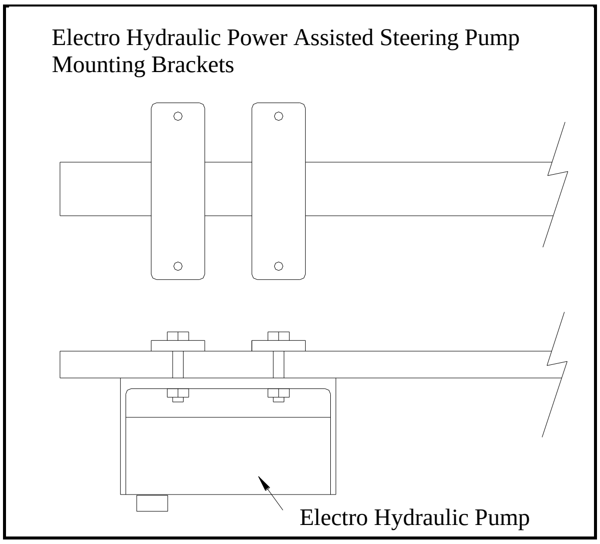

FIGURE 25: EHPAS MOUNTING BRACKET

5.2 Air-Conditioning

The proposed method for provision of AC to adequately cool the cabin to a comfortable temperature is as follows; the recommendation to retain the existing refrigerant and system, to provides an external electric motor to operate the original compressor.

The motor would operate the compressor at 1000rpm. This would then enable the compressor to operate at its maximum COP =2. The input power required would be 1.5kW and a cooling power of 2.85kW would be obtained. The input power is greater than the allocated amount of 1kW, however it can be used less to compensate. The cooling power of 2.85kW is less than the original vehicles specifications; however there is no heat load from the IC engine. Seen below is a similar piston type compressor as used in the "*GETZ*" is has a max COP of 1.9 at 1000rpm.

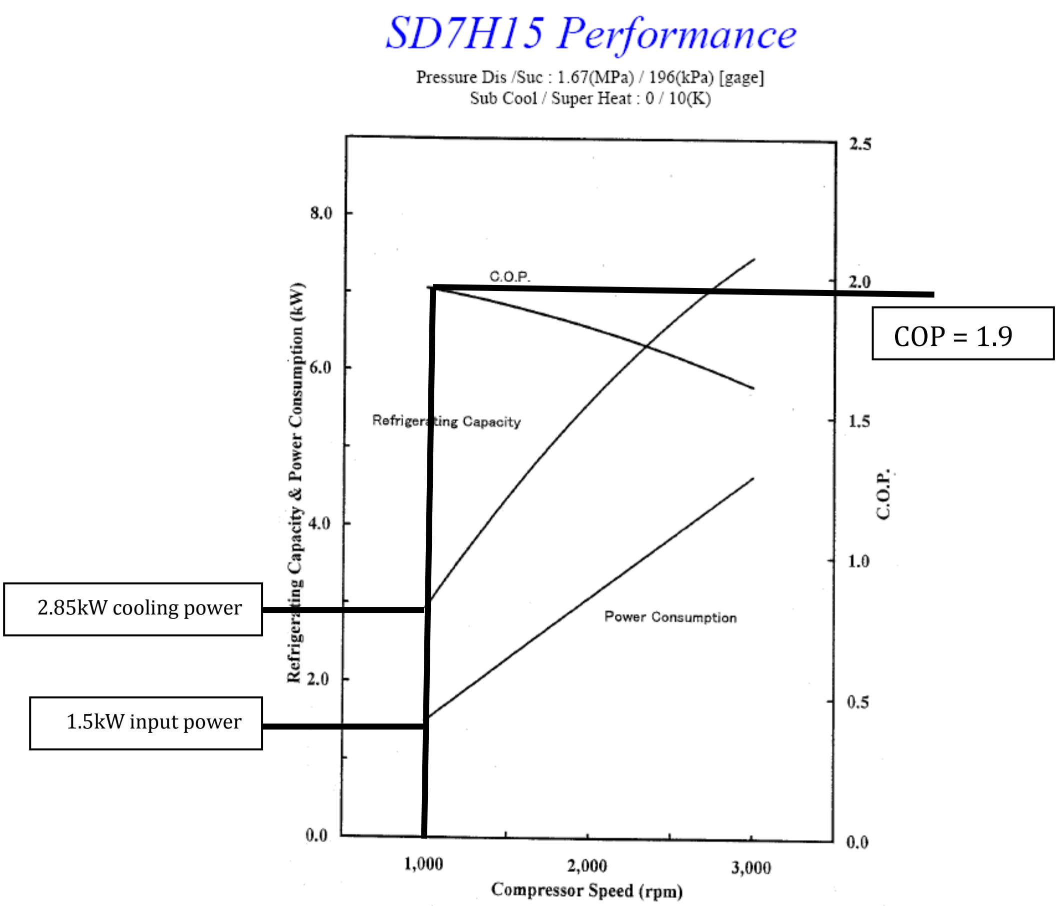

FIGURE 26: SD7H15 PERFORMANCE CURVE(SANDEN, 2008)

- COP=1.9
- Input power=1.5kW
- Cooling power= 2.85kW

5.3 Traction Motor

The choice of traction motor that's suitable use in a performance REV required an investigation all the aspects of its selection criteria. Firstly the type of motor either sprung or unsprung. Then on the performance criteria required.

- Unsprung
- Sprung

The **unsprung** motor is not included as a potential candidate to use as traction motor, for two main reasons. There is a high cost associated with their purchase. If two are used on the vehicle, then it requires the purchase of two electronic control devices. The dynamic handling of a vehicle fitted with them is unknown. There is sufficient evidence to suggest that they would perform significantly lower than conventional sprung motors (as discussed in chapter 3). The motors do offer levels of efficiency that are desirable; there use is unfeasible at this time for the purposes of traction motor. Shown in the figure below is a typical example of a direct drive wheel motor. It is claimed to have efficiencies above 90percent and relatively high torque 250Nm. The simplicity of installation is apparent as shown in Figure 27Figure 37 there are no axles or drive shafts. (Another example in Appendix H)

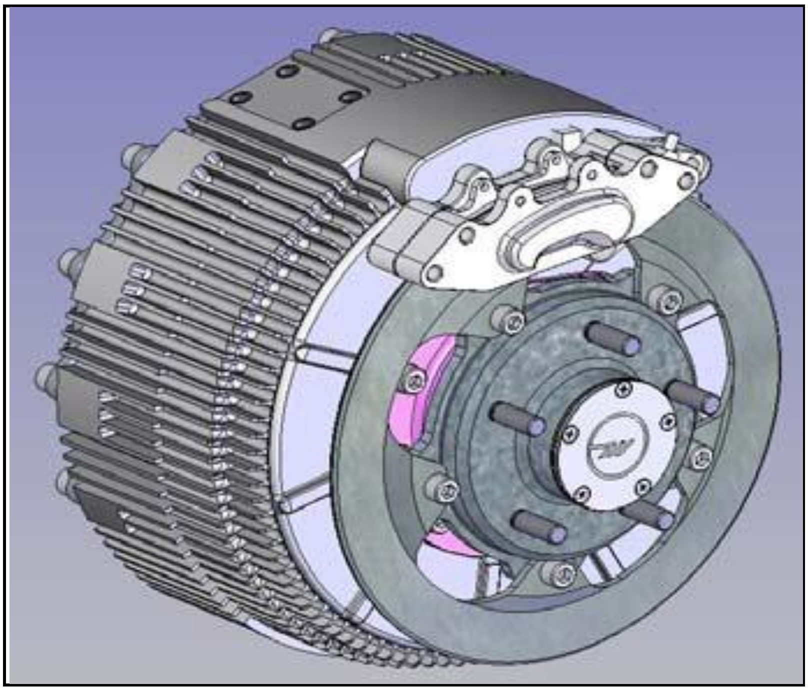

FIGURE 27: WHEEL MOTOR DIRECT DRIVE (WAVECRESTLABS, 2008)

The sprung motor is considered to be the prime candidate for use as traction motor for several important reasons. They offer the dynamic handling advantages over the direct drive wheel motor. They are readily available in various sizes and performance specifications. Integrating them in the vehicle is a simpler task. Shown below is an example of indirect drive traction motor.

FIGURE 28: AC55 AZURE DYNAMICS INDUCTION MOTOR

The ***AC55*** Induction motor from Azure Dynamics satisfies most of the performance requirements and is available within the financial restrictions. The motor has one area of deficiency the power output is lower than the IC engine vehicle. The original motor produced 91kW peak power the AC55 motor has a peak power of 59kW. There is however significantly more torque as shown in the table below. This may lead to gearbox or transmission issues if not controlled properly.

	Lotus MY2002 S2	**Lotus REV (AC55)**
Power	91kW @ 5500rpm	59@ 2000rpm
Torque	168Nm @ 3500rpm	280@ 2000rpm
Mass total kg	756	962kg (estimated)
Top speed	200km/h	*
0-100	5.6s	*
Transmission max Torque input (PG1)	240Nm	240Nm
Mass distribution F/R %	68/32	?/?
Motor mass kg	200	106
Main Battery Array Mass	-	300
Power to weight kW/kg	0.12	0.061

*** Yet to be determined**

TABLE 4: SPECIFICATION COMPARISON LOTUS AND REV LOTUS (AC55)

CHAPTER 6: STEERING SAFETY AND TESTING

The safety of the design is so critical that the EHPAS system should be analysed and preliminary testing carried out to ensure it operates as expected.

Failure Modes

The table shows a list of possible failure modes, and a proposed remedy. This table can then be used to prevent problems that are easily avoidable.

Fault	Likeliness	Remedy
Faulty motor (Burnt wiring)	L	Regular Maintenance
Brushes worn low	L	Regular Maintenance
Low Fluid level (Seal failure)	M	Regular inspection
Air pocket in system	L	Self bleeding
Pressure loss	M	Pressure gauge
Low battery voltage	M	Low voltage warning
Tripped Circuit Breaker(Overloaded)	L	Self resetting

L=Low, M=Medium, H=High

TABLE 5: FAILURE MODES AND REMEDIES

Testing

The electrical current draw versus time was plotted. This is done for two reasons to ensure the circuit breaker does not trip under normal operation, and that the energy use is within the set limits. The steering wheel was operated by turning it left and right whilst stationary, and the current draw measured. The wheel was rotated gradually (small bump on left) and abruptly (large peak on right). There is a noticeable increase in current draw when the steering wheel is rotated abruptly.

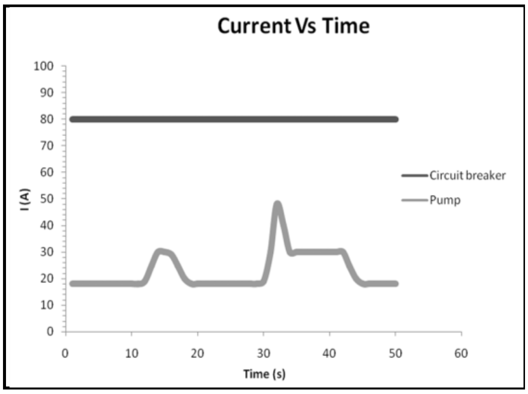

FIGURE 29: CURRENT VERSUS TIME

CHAPTER 7: CONCLUSIONS AND RECOMENDATIONS

Abstract: *This chapter offers the authors conclusions and recommendation for future work, for the three categories discussed in this report.*

Conclusions

This project investigated the options available for the most suitable candidate for Power Assisted Steering, Air Conditioning and Traction Motor for a Renewable energy Vehicle. The options available for each application were carefully considered, and for reasons of Safety Cost and Functionality the following recommendations can be submitted:

For the provision of Power Assisted Steering it is recommended to retain the existing Hydraulic Power Assisted Steering system. Replace the mechanically driven pump unit with an electric operated unit. This converts the system to an Electro Hydraulic Power Assisted Steering system. The EHPAS system was chosen for the following reasons:

- The EHPAS system has the ability to operate only on demand, to conserve energy.
- The vehicle's original safety systems such as air bags remain intact
- The existing infrastructure remains thus keeping costs down.
- Insufficient time to rebuild a new EPAS system

For the provision of Air Conditioning it is recommended to retain the entire system including refrigerant and compressor. To then provide a separate motor to operate the compressor, via a belt. This method was chosen for the following reasons:

- The high cost of replacing the entire system, including degassing/re-gassing
- Insufficient time to replace the entire system
- Mounting a 1.5kW, 144V DC most straight forward method
- Known performance of existing system

For the provision of Traction Motor it is recommended to use an air-cooled AC induction motor model AC55 (Azure Dynamics). To then integrate this into REV Lotus. The reasons his motor was chosen:

- Satisfies budget restrictions
- Meets some of the performance criteria
- Air cooled requires no additional cooling
- Handling characteristics (more predictable)
- Allows regenerative braking.

Recommendations

The investigation into a method of improving the EHPAS pumps efficiency. To devise and implement a method of control, which enables the pump to operate only on demand.

The capture of waste heat from the heat built up in electric motor and controllers, for the purpose of heating the occupant cabin. This reduces the electrical load placed on the batteries. A review into the feasibility; of a reverse cycle heat pump, to provide heating as well as cooling.

The further investigation into the use of wheel motor for the use as traction motors and their affects on dynamic handling.

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A Appendix: Power steering electrical schematic

The power steering pump is wired up as shown in the diagram below, this circuit is used as it is the simplest possible. The aim to try and avoid complications arising from complex wiring with numerous electrical plugs and long wire lengths which can create voltage drops, and reduce the pumping pressure. The safety of the system starts with the circuit breaker (C/B), the size (Amp) used is critical. Too low and it will trip whilst under normal operation undesirable, too high and it may not trip and cause overheating and start a fire. The size and type of circuit breaker used is 80A self resetting, this was found to be optimal as it provided adequate operational limits.

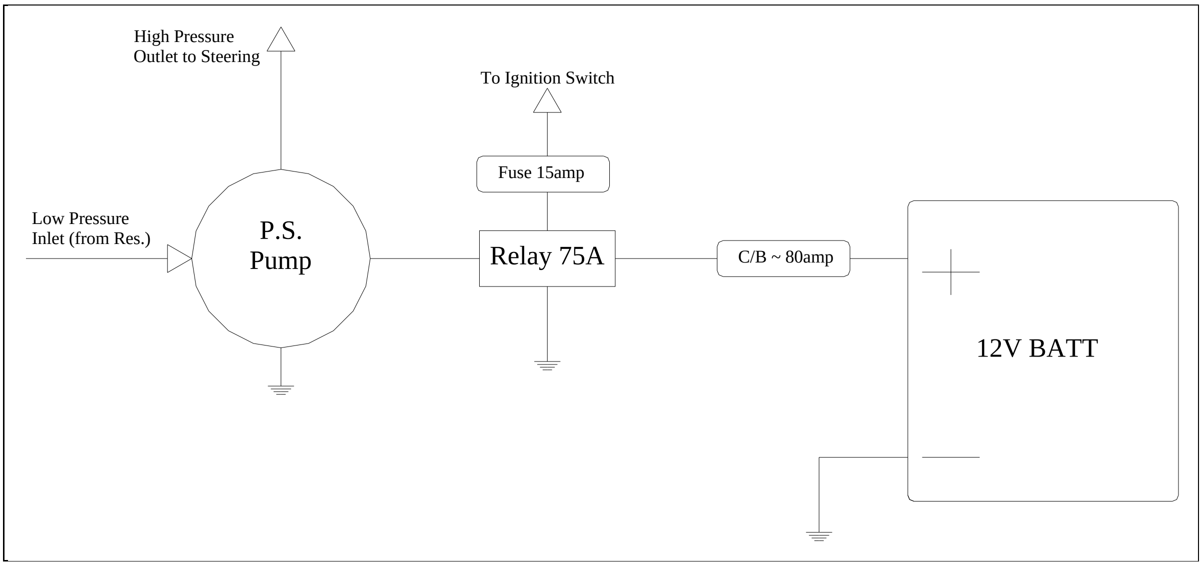


FIGURE 30: POWER STEERING-ELECTRICAL CIRCUIT

- New Pump: Mass 13lbs (including bracket)
- Original Pump: Mass 6lbs (including vee belt pulley)
- Hyundai/Kia Part Number: 57110-1C580

B Appendix: Air conditioning Refrigerant Performance

The tables below show some important characteristics of two refrigerants the natural refrigerant R-744 Carbon Dioxide and R134a (Hydro-Fluoro Carbon).

TABLE I: THERMOPHYSICAL PROPERTIES OF CO_2 R-134a AT 5/10/15 °C

REFRIGERANT	CO_2 (R-744)	R-134a
Saturation Pressure (MPa)	3.969/4.502/5.086	0.350/0.414/0.488
Latent Heat (kJ/kg)	214.6/196.8/176.2	194.8/190.9/186.7
Surface Tension (mN/m)	3.53/2.67/1.88	11.0/10.3/9.6
Liquid Density (kg/m3)	899.6/861.5/821.3	1277.1/1260.2/1242.8
Vapor Density (kg/m3)	114.8/135.3/161.0	17.1/20.2/23.7
Liquid Viscosity (uPa.s)	95.9/86.7/77.2	270.3/254.3/239.7
Vapor Viscosity (u Pa.s)	15.4/16.1/17.0	11.2/11.4/11.7
Liquid Specific Heat (kJ/kg K)	2.73/3.01/3.44	1.35/1.37/1.38
Vapor Specific Heat (kJ/kg K)	2.21/2.62/3.30	0.91/0.93/0.96

TABLE II: DESIGN DATA USED FOR THIS INVESTIGATION

VARIABLES	DATA
Evaporation Temperature	-17.8 to 4.4°C (0 to 40° F)
Cooling Load	5.3 kW (1.5 tons)
Condensing Temperature for Base Case (R-134a)	48.9°C (120° F)
Gas Cooler Pressure for CO_2 System	130 to 150 bars (1885.5 to 2175.6 psia)
Vapor State at Suction	Saturated Condition
Base Case	No Subcooling at Condenser Outlet
Compression	Isentropic

FIGURE 31: CARBON DIOXIDE AND R134A COMPARISON(MATHUR, 2000)

C Appendix: Air conditioning mounting Bracket Schematics

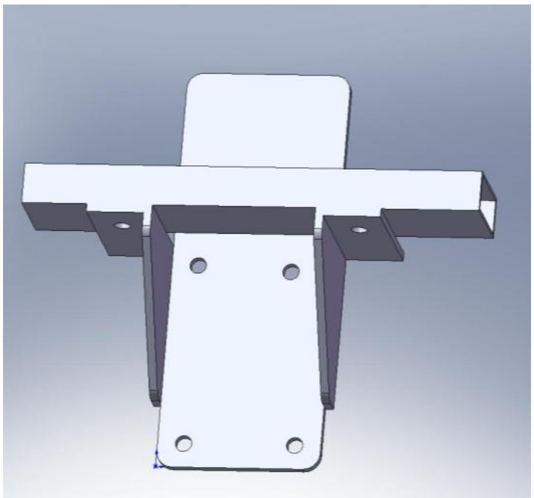


FIGURE 32: AIR-CONDITIOING COMPRESSOR BRACKET

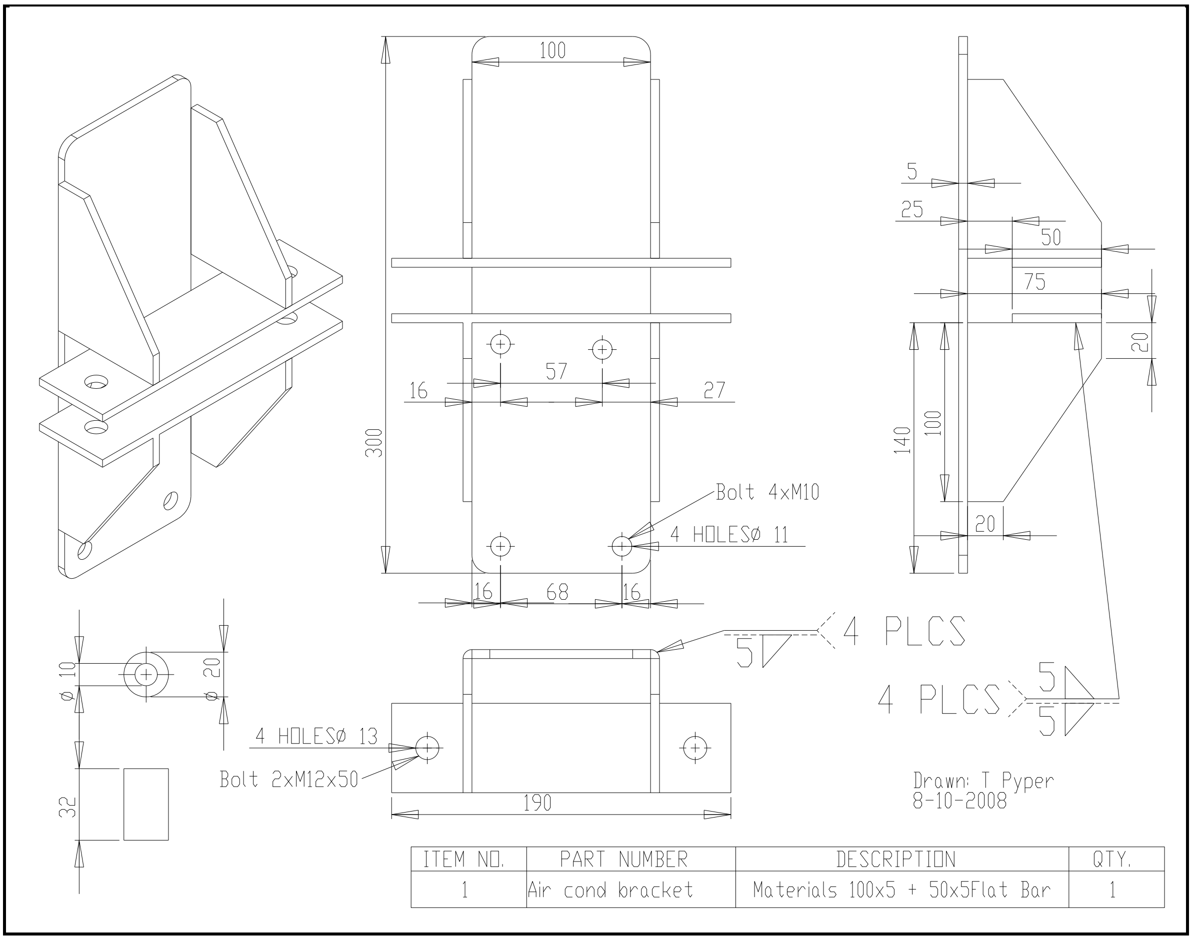


FIGURE 33: COMPRESSOR MOUNTING BRACKET

D Appendix: Air conditioning Compressor Data sheet

The technical data sheet below shows the specifications for

Standard models of AISLU inverter compressors

Model Name	Model Type	Displ.	Capacity (60rps/Hz)		Power	COP	EER	Current	Frequency Range	Oil	Refrig. Max	Wt.	Sizes Refer to Table 10
		(cm³/rev)	(W)	(Btu/HW)	(W)	(W/W)	(Btu/HW)	(A)	(Hz)	(Ml)	(Kg)	(Kg)	
DA89X1C-23FZ	R410A DC	8.9	2650	9037	680	3.90	13.3	4.7	18~120	370	0.9	9.9	NO.14
DA89X1C-20FZ3	R410A DC	8.9	2650	9037	705	3.76	12.8	4.8	18~130	370	0.9	9.9	NO.14
DA108X1C-20FZ3	R410A DC	10.8	3200	10912	855	3.74	12.8	5.2	18~120	480	1.2	10.3	NO.15
BA160X2C-20KU	R410A AC	16.0	4750	16198	1640	2.90	9.9	10.8	30~120	750	1.8	15.6	NO.19
DH108X1C-20FZ3	R22 DC	10.8	2240	7638	590	3.80	12.9	3.5	18~120	370	0.9	10.3	NO.13
DH130X1C-20FZD3	R22 DC	13.1	2695	9190	700	3.85	13.1	4.2	18~120	370	0.9	10.3	NO.13
BH108X1C-20FZ	R22 AC	10.8	2250	7673	725	3.10	10.6	5.3	30~120	370	0.9	10.7	NO.13
BH130X1C-20FZ	R22 AC	13.1	2700	9207	270	3.10	10.6	5.7	30~120	370	0.9	10.7	NO.13
BH160X2C-20FT	R22 AC	16.2	3420	11662	1100	3.11	10.6	7.1	30~120	480	1.2	14.0	NO.18
BH200X2CS-20KU	R22 AC	20.0	4245	14475	1360	3.12	10.6	9.2	30~120	750	1.8	16.0	NO.20
BH240X2CS-20KU	R22 AC	23.9	5120	17459	1640	3.12	10.6	11.7	30~120	750	1.8	16.0	NO.20
BG108X1C-20FZ	R407C AC	10.8	2340	7979	750	3.12	10.6	5.3	30~120	370	0.9	10.7	NO.13
BG130X1C-20FZ	R407C AC	13.1	2775	9463	890	3.12	10.6	5.7	30~120	370	0.9	10.7	NO.13
BG200X2CS-20KU	R407C AC	20.0	4365	14885	1410	3.10	10.6	9.2	30~120	750	1.8	16.0	NO.20
BG240X2CS-20KU	R407C AC	23.9	5265	17954	1700	3.10	10.6	11.7	30~120	750	1.8	16.0	NO.20

FIGURE 34: INVERTER COMPRESSOR SPECIFICATIONS (TOSHIBA-AISLU, 2008)

The model *DA89X1C-23FZ* would require an input power of 680Watts; this would result in an output cooling power output of 2650Watts. This unit is chosen as yields the highest possible coefficient of performance COP (W/W efficiency of input over output), which for this manufacturer is the best performer with a COP of 3.9 and the lowest mass of 9.9kg.

E Appendix: AC55 Traction motor Specifications

Specifications

Peak Torque	Nm	280
Continuous Torque* at Nominal Speed	Nm	140
Nominal Speed	Rpm	2000
Maximum Mechanical Speed	Rpm	8000
Maximum Current	A rms	250
Continuous Shaft Power* at 1500-2500 rpm	kW	25
At a voltage of	VDC	312
Peak Efficiency	%	87
Peak Shaft Power	kW	59
At a voltage of	VDC	312
Weight AC55	kg	106
Weight DMOC445	kg	14.7
Diameter AC55	mm	343
Length AC55	mm	447
Length DMOC445	mm	450
Width DMOC445	mm	228
Height DMOC445 (with fan)	mm	238
Minimum Recommended Nominal Battery Voltage	VDC	312
Maximum Nominal Battery Voltage	VDC	336
Minimum Operational Voltage	VDC	100
Maximum Operational Voltage	VDC	400
Maximum Voltage "On Charge"	VDC	450
Minimum/Maximum Operating Temperatures	˚C	-40 to 60

*At 25˚C

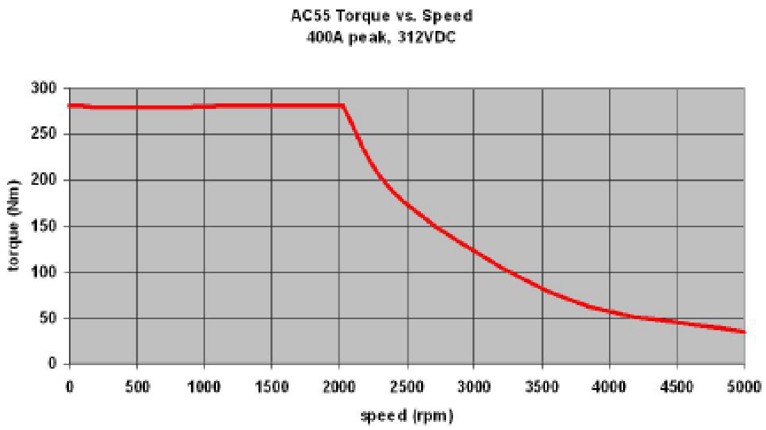
TABLE 6: AC55 SPECIFICATIONS

F Appendix: AC55 Traction motor Performance curves

Azure Dynamics Electric Drive Solutions

AC55 Motor with DMOC445 Controller

Torque-Speed Envelope



Power-Speed Envelope

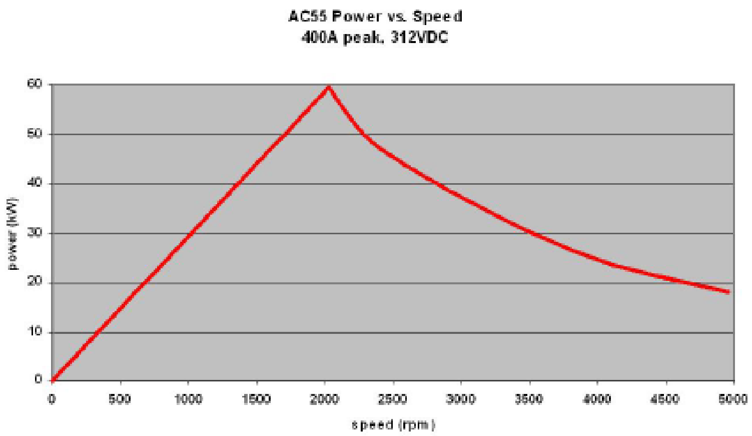


FIGURE 35: PERFORMANCE CURVE, POWER AND TORQUE

G Appendix: AC55 Traction motor dimensions

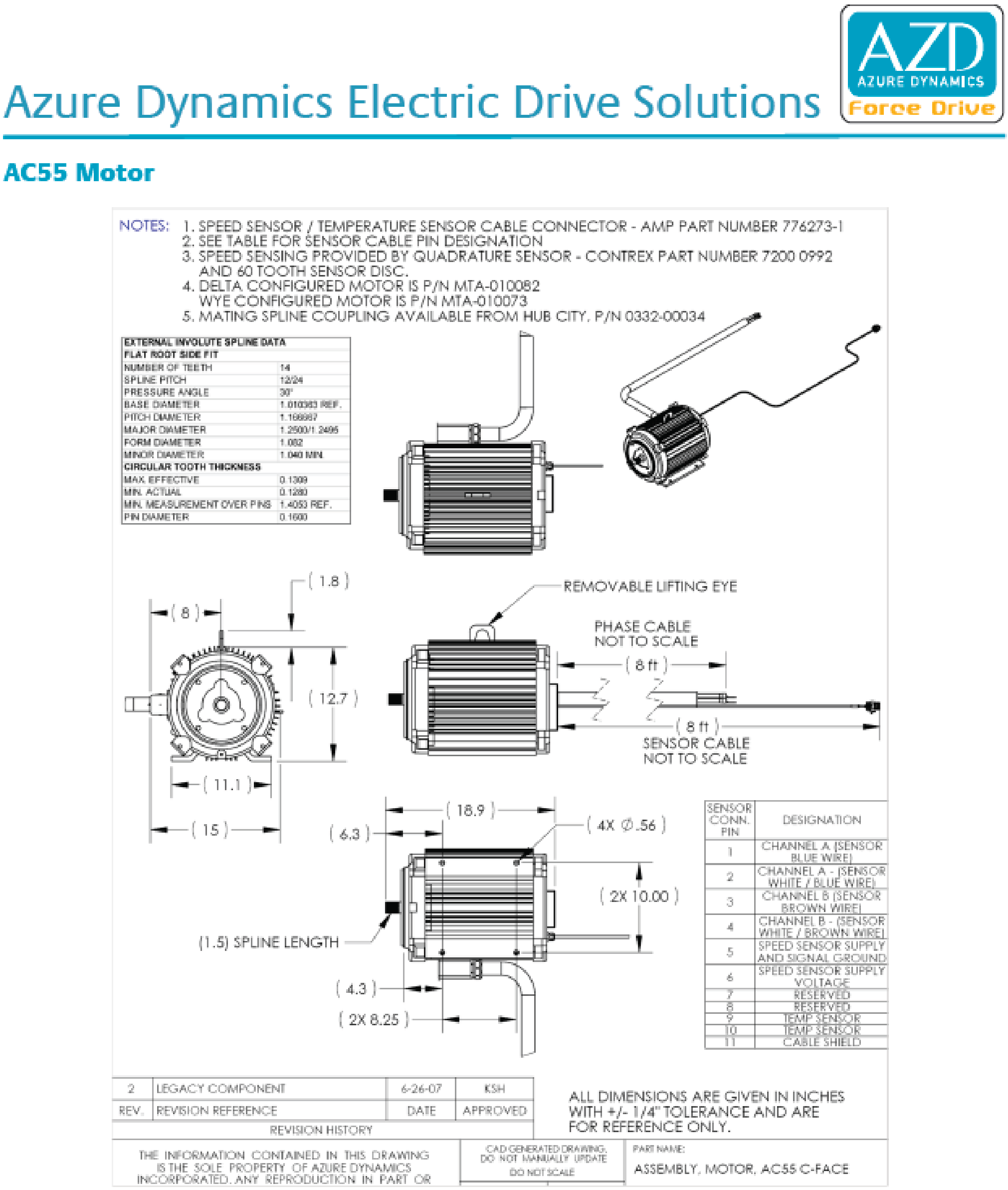


FIGURE 36: AC55 TRACTION MOTOR DIMENSIONS

H Appendix: Direct drive wheel motor

Ultra commuter motor specifications

Number of Phases	3
Number of Poles	24 poles, 2 stators
Peak air gap flux density	0.65T
Motor case outside diameter	391mm
Peak Torque	500Nm
Continuous Torque	250Nm
Magnet mass Active mass Total mass	8.9kg 18.3kg 24kg
Throughput cycle efficiency: Air Resources board No. 2 (ARB02) Urban dynamometer drive cycle (UDDS) High fuel economy test (HWFET)	 94.10% 92.60% 97.30%

TABLE 7: 3PHASE WHEEL MOTOR SPECIFICATIONS ADAPTED FROM (HYBRIDAUTO.PTY.LTD, 2006)

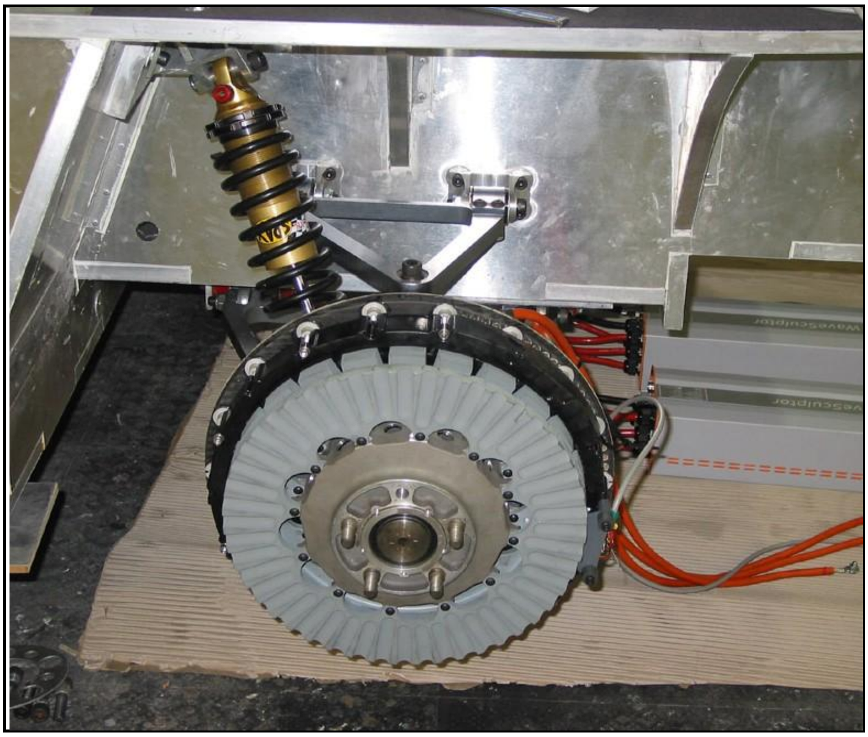


FIGURE 37: WHEEL MOTOR (HYBRIDAUTO.PTY.LTD, 2006)

I Appendix: Motor Power, Mass, Cost Table

The table shows a performance cost comparison of several vehicles. The performance REV has a greater cost and a lower power to weight than the commuter REV.

Vehicle	Power(P) kW	Mass(M) kg	P/M kW/kg	Cost(C) $	Cost/kW $/kW
Lotus (REV)	58	962*	0.061	60,000	769
Lotus (Original fuel engine)	91	756	0.12	80,000	879
GETZ (REV)	86	900	0.086	35,000	407
Tesla	185	950	0.19	100,000	540
Ferrari	250	1250	0.2	200,000	800

*Estimated

<u>Lotus Elise REV Specifications</u>

The car estimated to be 1000kg

Original car = 756kg

Mass engine (fuel) = 150kg (EST.)

Fuel = 40kg

Batts 100*2.5=250kg

Motor =110kg

Controller and brackets =30kg

Totals=756-100-30+250+110+30=1016

Nominal voltage 3.2v per batt

Continuous current 180Ah

J Appendix: System Layout Schematic

To help with the integration of all the major components a layout of the motor bay was produced. This gives a clear idea of the amount of space available to each device and the amount of room left for additional future additions. Shown in the Figure 38 the major components that go into an electric vehicle; motor, controller, throttle (electric potentiometer), etc... The design of these systems is very modular for this reason consumes more space and appears ad-hoc. This does enable each individual responsible for their task to not hinder or be hindered by another.

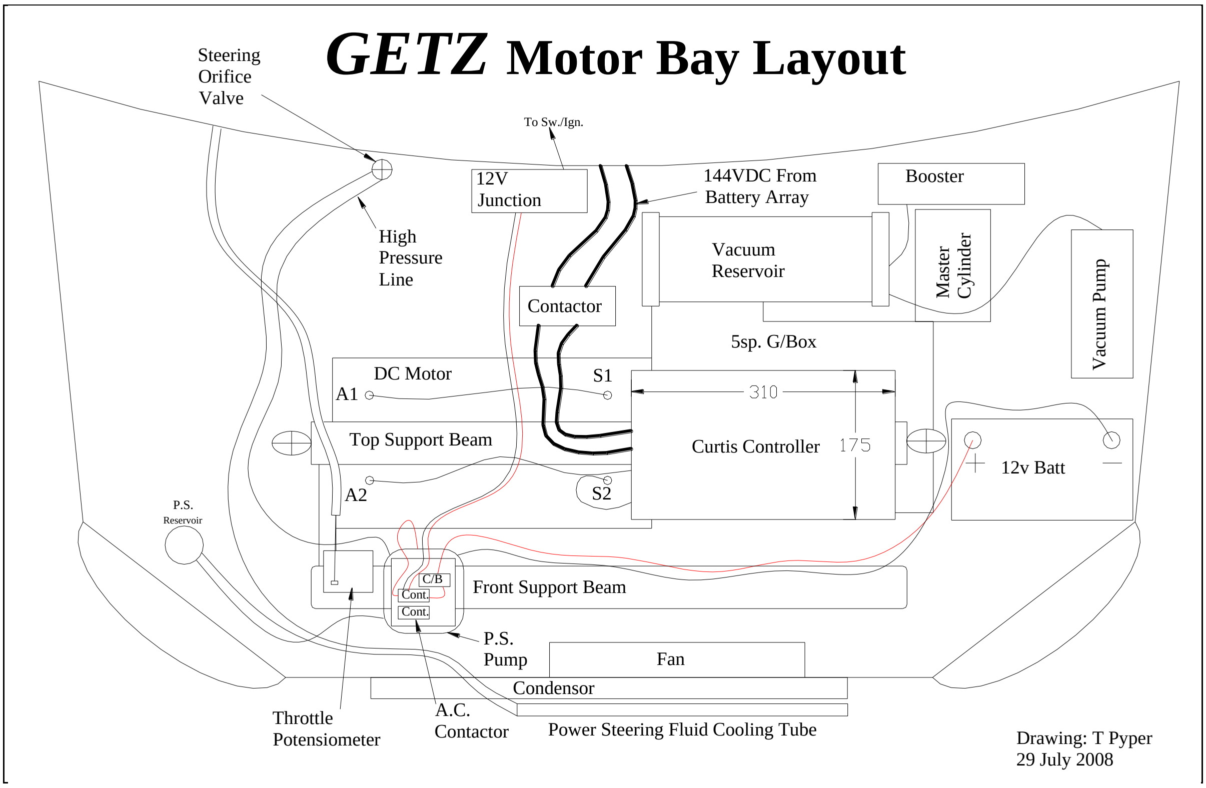


FIGURE 38: HYUNDAI "*GETZ*" MOTOR BAY LAYOUT