DESIGN AND DEVELOPMENT OF POWER TRAIN

AND ITS COOLING SYSTEM

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Mechanical Engineering

By

MUHAMMAD SHARJEEL ASHIR
SYED AHMAD KAMAL
ASAD AFZAL

JUNE 2023

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

SYED AHMAD KAMAL	286434
ASAD AFZAL	283398
SHARJEEL ASHIR	294828

Titled: "DESIGN AND DEVELOPMENT OF POWER TRAIN AND ITS COOLING SYSTEM" be accepted in partial fulfillment of the requirements for the award of BACHELORS OF MECHNICAL ENGINEERING degree with grade ___

Supervisor: Dr. Rehan Zahid (Assistant Professor) SMME	____________ Dated:
Committee Member: Dr. Jawad Aslam (Associate Professor) SMME	____________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	____________ Dated:

____________________ (Head of Department)

__________ (Date)

COUNTERSIGNED

Dated: ______________

______________________ (Dean / Principal)

ABSTRACT

This abstract describes the participation of Team Alif in the Formula Student International competition, which is open to college teams from around the world. The competition allows students to showcase their engineering skills and develop innovative solutions to achieve the best vehicle performance. To comply with the FSUK rule book, the Team Alif electric vehicle was designed with weight reduction as a primary consideration, as weight is a critical factor in the competition. The vehicle's design has been adjusted to reduce total mass, with special emphasis paid to the heaviest and most impactful system. Team Alif aspires to attain optimal vehicle performance and stand out by sticking to these design concepts. The aim is to design a functional powertrain for the Formula Student EV. This includes the FEA analysis of the drivetrain and its components along with CFD analysis of the cooling system. The goal is to manufacture and assemble the powertrain and integrate it with other sub-systems of the EV

ACKNOWLEDGMENTS

We would like to express our deep appreciation and gratitude to Doctor Jawad Aslam and Doctor Rehan Zahid for acting as supervisors and their invaluable guidance, which was a catalyst for this project.

We are extremely thankful to Doctor Mian Ashfaq for funding this project to help us represent Pakistan at Formula Student competition. Manufacturing of Team Alif Electric car could not have been possible without his unwavering support and encouragement.

And finally, we would like to appreciate all Alif team members whose hard work, dedication and expertise made this project a success and we are truly grateful for their contribution.

ORIGINALITY REPORT

Thesis

ORIGINALITY REPORT

11%	8%	3%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	doczz.net Internet Source	1%
2	Gwangmin Park, Seonghun Lee, Sungho Jin, Sangshin Kwak. "Integrated modeling and analysis of dynamics for electric vehicle powertrains", Expert Systems with Applications, 2014 Publication	1%
3	Submitted to Higher Education Commission Pakistan Student Paper	1%
4	dspace.mit.edu Internet Source	1%
5	inba.info Internet Source	1%
6	jsae.jp Internet Source	1%
7	Jia Ying Yong, Vigna K. Ramachandaramurthy, Kang Miao Tan, N. Mithulananthan. "A review on the state-of-the-art technologies of electric	<1%

	vehicle, its impacts and prospects", Renewable and Sustainable Energy Reviews, 2015 Publication	
8	Handbook of Driver Assistance Systems, 2016. Publication	<1 %
9	M Palanivendhan, S Kiran, D Boopathi, Dhruv Dhingra, R Madhuritha. "Electric Power Train design for FSAE Electric Car and Study of that Performance Parameters", IOP Conference Series: Materials Science and Engineering, 2020 Publication	<1 %
10	www.researchgate.net Internet Source	<1 %
11	Submitted to South Bank University Student Paper	<1 %
12	greatnorthamericanskiadventure.com Internet Source	<1 %
13	autodocbox.com Internet Source	<1 %
14	Submitted to Oxford Brookes University Student Paper	<1 %
15	core.ac.uk Internet Source	<1 %
	Submitted to Bridgwater & Taunton College	

16	Student Paper	<1%
17	Submitted to Malta College of Arts,Science and Technology Student Paper	<1%
18	Submitted to University of the West Indies Student Paper	<1%
19	Submitted to Runshaw College, Lancashire Student Paper	<1%
20	photo-ads-classified.com Internet Source	<1%
21	Submitted to Coventry University Student Paper	<1%
22	www.engineersgarage.com Internet Source	<1%
23	cwo.revistapasajes.com Internet Source	<1%
24	"Proceedings of SAE-China Congress 2016: Selected Papers", Springer Science and Business Media LLC, 2017 Publication	<1%
25	Submitted to De Montfort University Student Paper	<1%
26	jobs.prcstaffing.com Internet Source	<1%

27	Submitted to Loughborough University Student Paper		<1 %
28	Submitted to University of Ulster Student Paper		<1 %
29	mdpi.com Internet Source		<1 %
30	oferta.abcnc.pl Internet Source		<1 %
31	timesofindia.indiatimes.com Internet Source		<1 %
32	Submitted to King's College Student Paper		<1 %
33	Submitted to University of Western Sydney Student Paper		<1 %
34	www.monolithicpower.com Internet Source		<1 %
35	www.racknsell.com Internet Source		<1 %
36	Submitted to The Robert Gordon University Student Paper		<1 %
37	Submitted to University of Brighton Student Paper		<1 %
38	etheses.whiterose.ac.uk Internet Source		<1 %

39	Zhonghao Li, Da Wang, Qiao Kang. "The Development of Data Acquisition System of Formula SAE Race Car Based on CAN Bus Communication Interface and Closed-Loop Design of Racing Car", Wireless Communications and Mobile Computing, 2021 Publication	<1 %
40	mdpi-res.com Internet Source	<1 %
41	researchspace.ukzn.ac.za Internet Source	<1 %
42	rucforsk.ruc.dk Internet Source	<1 %
43	www.mdpi.com Internet Source	<1 %
44	tsubaki.com.au Internet Source	<1 %

Exclude quotes Off
Exclude bibliography On
Exclude matches Off

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The competition has a variety of events and a solid performance in each of the events guides the design specification for the powertrain. The rules limit the maximum power output of the electric vehicle to 80 kW, but a lower power output with reduced mass and cost can easily outplay a heavy , expensive 80 kW vehicle. Following events are included in FSUK:

Table 1 : Outline of Competition

Events		**Contents**
Vehicle Examination	**Technical Inspection**	Vehicle safety and conformance to design requirements as stipulated in the rules.
	Tilt	Checking that vehicle has no damage and no fluid losses when tilted at 45 degrees and no rollover at 60 degrees.
	Noise	Making sure the noise is under 110 dB /
	Rain Test	Checking an insulation state when water is sprayed at the car at any possible direction for 120 seconds.
	Cost and Manufacturing	The validity / competitive of the cost calculations and manufacturing processes are examined.

Static Events	**Design**	Appropriateness, reformation, engineering process and repairability of the vehicle are examined.
	Business Plan Presentation	Teams' ability to develop and deliver a comprehensive business model is examined.
	Lap Time Simulation	Use of driving software's (CarMaker) to get a baseline vehicle performance is tested.
Dynamic Events	**Acceleration**	The acceleration performance from 0 to 75 meters.
	Skid-pad	The vehicle's cornering performance is evaluated in steady state turns over a figure of eight course.
	Autocross	Vehicles are driven over the main course of 1.5 km comprised of combinations of straights, turns and chicanes.
	Endurance	Vehicles are driven over 22 km with each lap of 1 km

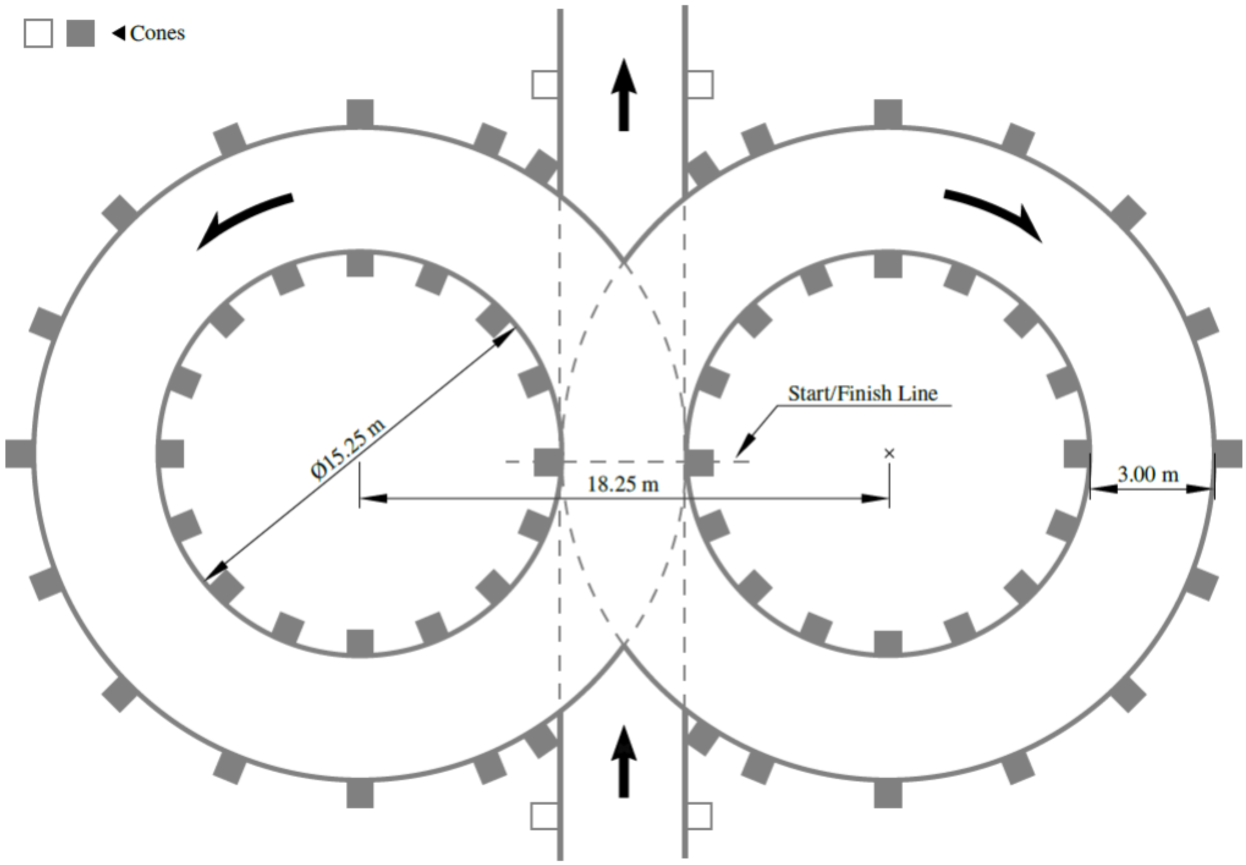

Figure 1 : Skid pad track layout

Relevant Rules and Design Constraints

As listed above, there are multiple events that our vehicle has to go good in and a multitude of rules that it must follow to qualify for the competition. Some of the major constraints regarding the transmission of the vehicle are:

- Maximum of 80 kW power output to be measured by Energy meter.
- Maximum System Voltage of 300 V.
- Supplying power to the motors such that the car is driven in reverse is prohibited.

- The commanded motor torque should be 0 Nm when mechanical brakes are actuated.
- The chain and the motor need to be guarded with specific materials and dimensions.
- The TS accumulator segment must not exceed 120 VDC, with maximum energy of 6 MJ and maximum weight of 12 Kg.
- The Accumulator should be removable from the vehicle.

Beside these rules, another significant constraint of design is that we must be able to manufacture all components in-house or have the ability to easily source the components. Thus, manufacturability is a factor that continuously drives the design decisions throughout the process.

At the competition, we must be able to pass the “rain test” and hence to need to design the tractive system in such a way that it can function even after being sprayed by water for two minutes straight. This will significantly impact motor selection and the transmission.

Formula student racing has been around for decades and has seen several significant improvements over the years. The current trend is the research of high-performance electric motor for best traction application. Permanent magnet synchronous motors have seen a rise in use in among the formula student vehicles. The transmission has also improved over the years, with most teams opting for an In Wheel type configuration to reduce mass and manufacturing complexity. This trend is accompanied by a rise in electronic control of motor and torque vectoring. Teams are increasingly relying on control systems to improve traction, especially at tight corners.

One of the most successful teams in the competition is University of Stuttgart's Green team which is powered by in-board 47kW synchronous motors, with a single reduction drive of 5.5:1. It indecently drives each of the rear wheel. It weights around 270 kg with driver and accelerates from 0 to 100 km/h in 3.3 seconds.

Figure 2 : Uni Stuttgart Green Team's Formula Electric Vehicle

Another successful team is from Royal Melbourne Institute of Technology, which uses a dual 30 kW brushless DC motor and a battery pack from Dow Kokam with a total capacity of 12.4 kWh (155 V , 80Ah).Their powertrain configuration for 2016 season was:

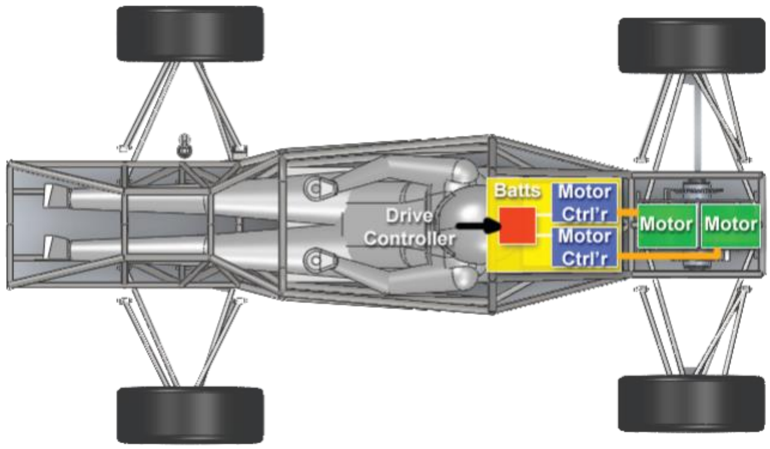

Figure 3 : RIMT's 2016 Powertrain

LITERATURE REVIEW

Growing concerns over global warming and climate change has created a surge in demand of electric vehicles which ultimately has driven the research in the field. We reviewed the design of some road-going commercial electric vehicles and also various the design of various different formula student teams as well.

Some of the studies published till date deal with the general aspects of design of electric vehicles. Many papers give a diverse classification of electric vehicles, on the basis of their design and performance parameters. They also analyze the impact these electric vehicles have on environment and electric infrastructure. For instance, Young et al. reviews the history of electric vehicles starting from the middle of the nineteenth century to the present day. They also carry out a classification of electric vehicles according to the powertrain configuration. Similarly, Richardson analyzes the potential impacts electric vehicles can have on the environment and electric grid. There have been various advances in the charging mechanism of the electric vehicles and battery technology in recent years that has led to development of electric vehicles with longer ranges and much quicker charging time. Finally, various papers regarding the economic impacts of electric vehicles were also studied and it all proved that electric vehicles are the future of transportation, and their development and innovation is critical for environment.

EVs are generally categorized on basis on hybridization ratio:

- Hybrid Electric Vehicles (HEV)
- Plug-in Hybrid Electric Vehicles (PHEV)
- Battery Electric Vehicles (BEV)

The aim of literature review was to study and analyze the transmission of BEVs, which are increasingly the most common type of electric vehicles and the objective of Formula student as well.

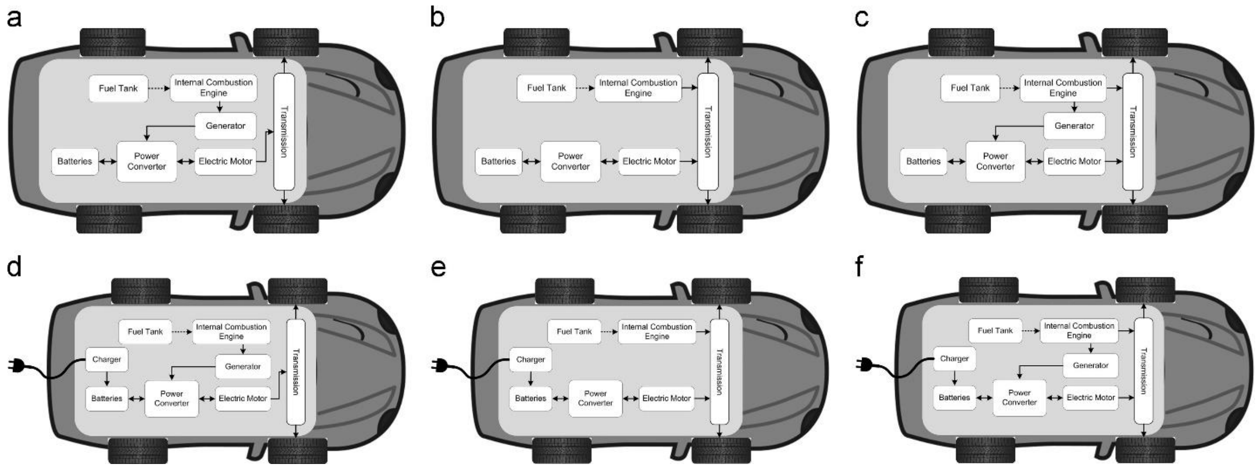

Figure 4: Power train configuration: (a) Series HEV , (b) Parallel HEV , (c) Series-Parallel HEV , (d) Series PHEV , (e) Parallel PHEV , (f) Series-Parallel PHEV

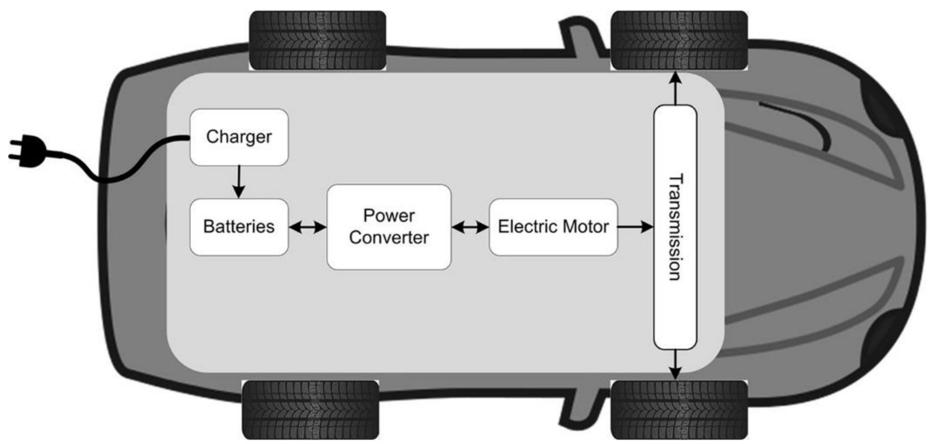

Figure 5 : Typical Powertrain configuration of BEV

Formula student has a decade long established competition and thus there are several professional and student papers available on the design and fabrication of formula student vehicles. Electric powertrain has come a long way in formula student and there are multiple options available withing the regulations of the competition. The basic purpose of a powertrain is to transmit the power from Batteries to motors and from motors to wheels in the best possible manner as to minimize the losses and maximize the overall performance of the vehicle.

Romani et al. explains that the powertrain in a vehicle consists of the power generating and delivery components that deliver the power to wheels. In an electric vehicle, the powertrain is powered by a battery pack. A motor is used that is typically connected to a single stage transmission. Control systems are used to perform functions such as AC/DC conversion, voltage amplification and traction control.

Depending on the number of motors available, design of chassis and required performance of the electric vehicle , EV powertrain are generally classified into six possible configurations:

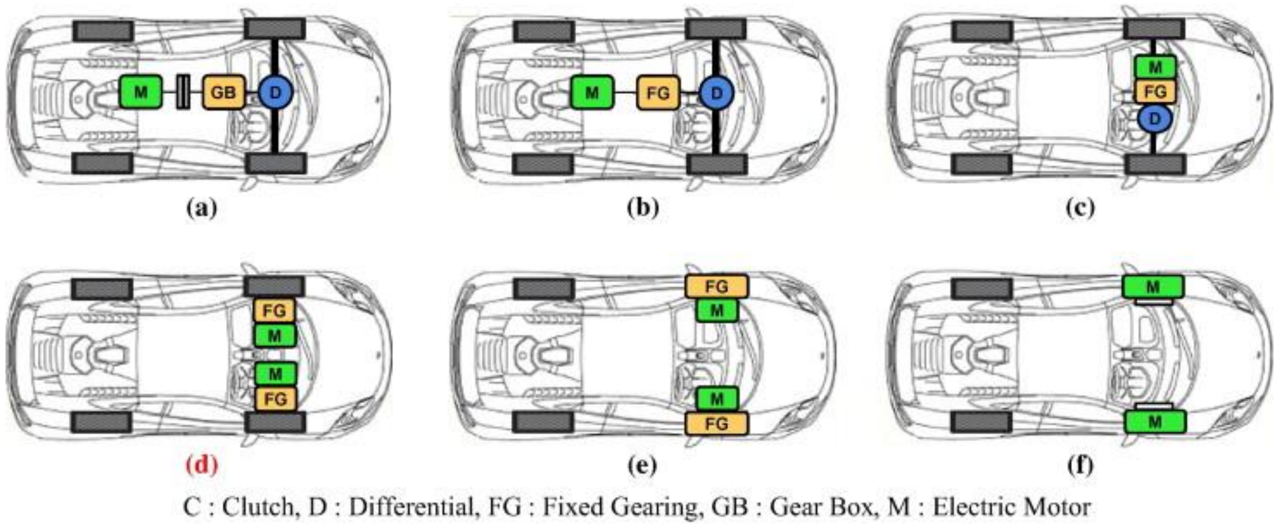

Figure 6 : Six types of EV configurations. One-motor based EV powertrains: (a) Conventional. (b) No transmission (RF). (c) No transmission (FF). Two-motor based EV powertrains: (d) No differential. (e) In-wheel with FG. (f) In-wheel without FG.

Table 2 : Categories of EV Power trains

One Motor Based Power train	**Two Motor based Powertrain**
a) Conventional Type It consists of a motor, clutch, gearbox and a differential. This is just same as an IC vehicle rear-engine-front wheel drive configuration	*d) No Differential Type* Two Electric motors connected to the wheel to delivery power directly without a differential through a fixed gearing.
b) No Transmission Rear-engine-front-Wheel Type	*e) In wheel type with fixed gearing*

It just has a fixed gear instead of a clutch and gearbox.	Similar to (d), except the motors are embedded in wheel for in wheel type.
c) No Transmission Front-engine-front-Wheel Type The motor, fixed gearing and differential are placed together in front.	*f) In Wheel type without fixed gear* No gearing is used and speed of wheel directly depends on the speed of motor.

Along with these types, there has been an increasingly used of four different in wheel motor to maximize the power and speed of the vehicle in sports and hyper cars. Use of wheel motors can simplify the mechanical transmission and remove the requirement of differentials at the cost of increased complexity of electrical components. The entire power train can be divided into electrical and mechanical power systems. The speed profiles obtained from the driver's command resulted from braked and accelerometer pedals are converted to speed command and torque command of electric motor. The motor gives a corresponding mechanical power, which travels through the mechanical power system to the wheels to give a traction force and a vertical force. According to Gwangmin:

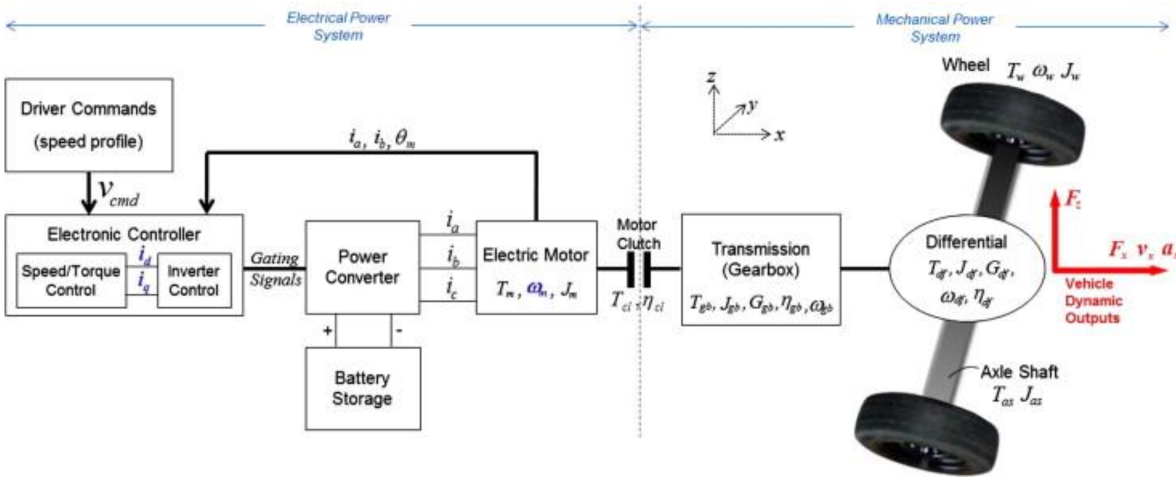

Figure 7 : Block diagram of conventional EV Power train

There can be different types of configurations of a power train, such as:

- Rear Wheel Drive
- Front Wheel Drive
- Four Wheel Drive

The details of these configurations and their pros and cons for a formula student car are discussed under:

Rear Wheel Drive:

High-performance sports cars, especially Formula 1 (F1) cars, frequently have rear-wheel drive (RWD) powertrains. A RWD system uses a driveshaft, transmission, and differential to send power from the engine to the rear wheels. Performance and handling are the two main benefits of RWD. Because the engine is mounted in the front of the vehicle, RWD vehicles typically have superior weight distribution, resulting in more stable handling. While the rear wheels oversee supplying power, the front wheels are in charge of steering, allowing for more precise control during high-speed cornering.

RWD vehicles typically perform better during acceleration because the weight of the vehi cle shifts to the rear wheels, which have more traction. This is especially important in F1, where every fraction of a second counts.

RWD also has the benefit of a straightforward drivetrain. An RWD system has fewer components, which can reduce weight and complexity, improve dependability, and make maintenance simpler. RWD, however, also has significant drawbacks. Less traction in low-grip conditions, such as in wet or snowy conditions, is one of the key downsides. While travelling off-road or up steep inclines, the weight distribution of a RWD vehicle may potentially be a disadvantage.

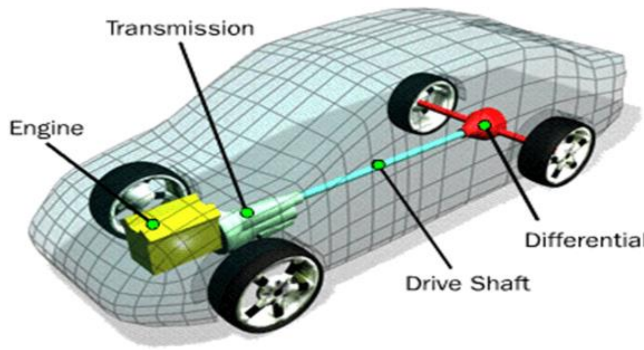

Figure 8: Rear Wheel Drive transmission

Rear-wheel drive is a common powertrain setup for high-performance sports automobiles, including F1 cars, to sum up. RWD has benefits in terms of performance, handling, and drivetrain simplicity, but it can also have certain disadvantages in low-grip conditions and specific driving circumstances. The goals and resources of the team designing the car, as well as the competition's rules and regulations, all influence the powertrain configuration choice.

Front Wheel Drive:

Front-wheel drive (FWD) is a configuration for a vehicle's drivetrain, where the engine's power is transmitted to the front wheels. In this setup, the front wheels provide both the traction and the steering, making FWD vehicles popular for their agility, efficiency, and lower cost.

In a front-wheel drive vehicle, the engine and transmission are located transversely, with the transmission being mounted directly to the engine. The power from the engine is then transferred to the front wheels through the transmission's output shafts, which are connected to the front drive axles. These axles, in turn, transmit the power to the wheels via a set of CV joints.

One of the main advantages of FWD is that it can be implemented in smaller cars with limited space, as it eliminates the need for a bulky driveshaft and differential found in a rear-wheel-drive configuration. This makes FWD vehicles generally lighter and more fuel-efficient, as well as easier to maneuver in tight spaces.

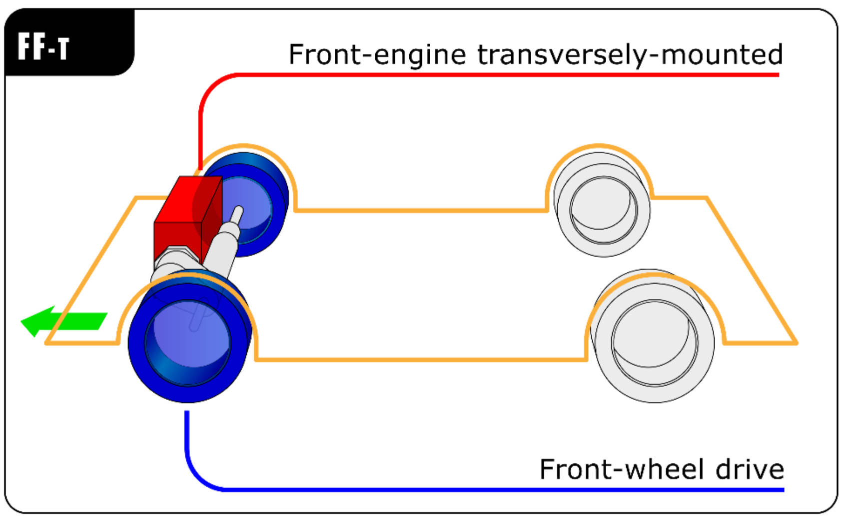

Figure 9: Front Wheel Drive Transmission

However, FWD vehicles may have a tendency to understeer, where the front tires lose grip, and the car wants to go straight even if the driver is trying to turn. This is due to the weight of the engine being over the front wheels, which can cause the tires to lose grip. To counter this, modern FWD vehicles often use electronic aids such as traction control and stability control to help maintain grip and stability.

Overall, FWD is a popular drivetrain configuration due to its efficiency, agility, and lower cost, making it a common choice for small and mid-sized vehicles, especially in urban environments.

Four Wheel Drive:

Four-wheel drive (4WD) is a configuration for a vehicle's drivetrain that allows power to be distributed to all four wheels, providing improved traction and off-road capability. In this setup, the engine's power is transmitted to all four wheels through a transfer case, which splits the power between the front and rear axles.

In a 4WD vehicle, the front and rear axles are connected by a drive shaft, which transmits power from the transfer case to the front and rear differentials. These differentials then distribute power to the individual wheels, allowing all four wheels to turn and providing better traction and stability on challenging terrain.

One of the main advantages of 4WD is its off-road capability, as it provides improved traction and control on loose, slippery or uneven terrain. This is particularly useful for driving in challenging environments such as mud, snow, or sand, where a two-wheel-drive vehicle would struggle to maintain traction.

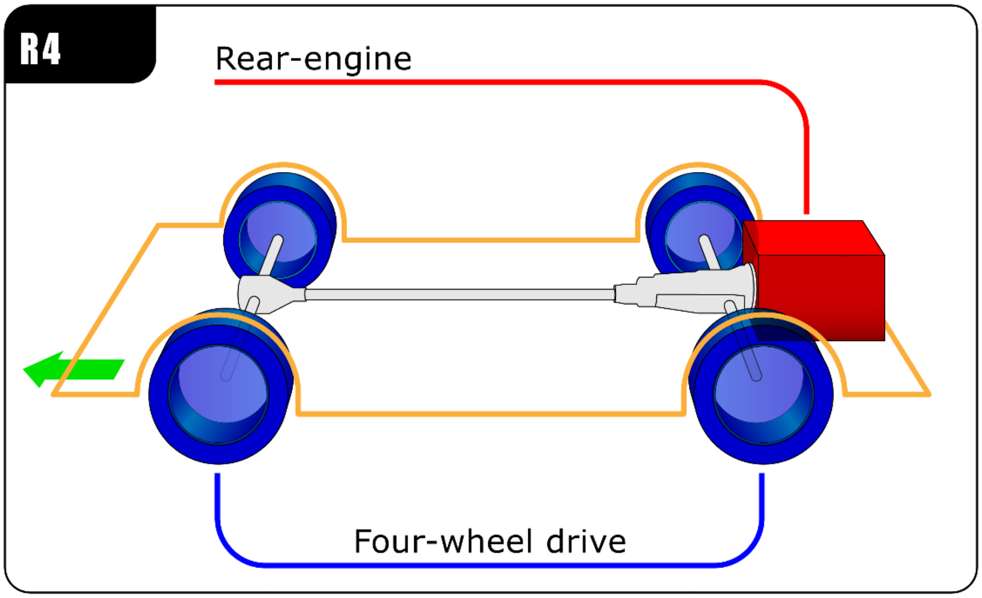

Figure 10: Four Wheel Drive Transmission

Another benefit of 4WD is its ability to tow heavy loads or navigate steep inclines. The additional traction provided by all four wheels makes it easier to pull heavy trailers or climb steep hills.

However, 4WD vehicles tend to be heavier and less fuel-efficient than their two-wheel-drive counterparts, as the added weight and complexity of the 4WD system requires more power to operate. Additionally, 4WD systems can be more expensive to maintain and repair due to their complexity.

Overall, 4WD is a popular drivetrain configuration for off-road vehicles and those that require heavy towing or high-performance capability. While it may be less fuel-efficient and more expensive to maintain, the improved traction and off-road capability make 4WD a valuable option for many drivers.

Bearings:

Bearings are mechanical components that facilitate rotational or linear movement between two parts. They are designed to support and reduce friction between moving parts, while also transferring loads from one part to another. Bearings are used in a wide range of applications, from automotive and aerospace to industrial machinery and household appliances.

There are several types of bearings, including:

- Ball Bearings: This is the most common type of bearing. It consists of a row of balls between two circular raceways, which support radial and axial loads.
- Roller Bearings: This type of bearing uses cylindrical, tapered, or spherical rollers instead of balls. They are suitable for handling heavier loads and are commonly used in machinery such as conveyor systems and gearboxes.
- Plain Bearings: Also known as bushings, plain bearings are made of a metal sleeve and a sliding surface. They are used for low-speed, high-load applications, such as in crankshafts and connecting rods.
- Thrust Bearings: Thrust bearings are designed to support axial loads, such as in gearbox applications or in car transmissions.

Overall, bearings play an essential role in many different industries, and choosing the right type of bearing for a particular application is critical for ensuring optimal performance and longevity.

Cooling of EV:

An electric vehicle (EV) needs to be cooled in order for its parts to function effectively and securely. The movement of energy through an EV's many parts, including the battery, motor, and power electronics, causes heat to be produced when it runs. Inadequate heat dissipation can result in decreased performance, early component failure, and potentially safety concerns.

An electric vehicle's cooling system typically combines liquid and air cooling. Components that produce a lot of heat, such the battery and power electronics, are cooled by liquid. The heat is transferred to a radiator via the liquid cooling system, which circulates a coolant fluid through pipes or channels inside the components.

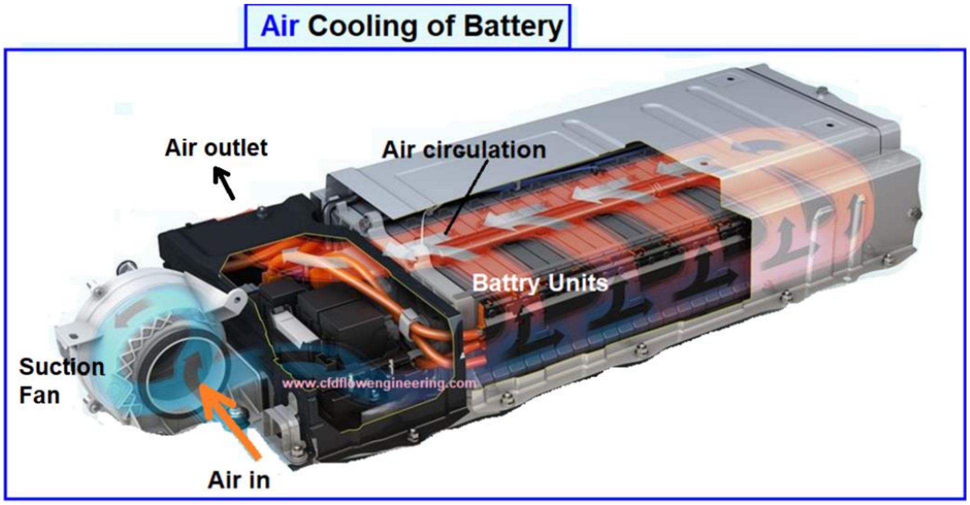

Figure 11: Air cooling of a commercial EV

Air conditioning is used to keep components like the motor and brakes cool. A fan draws air through the components and then discharges it back into the environment. A heat exchanger can be utilized in some circumstances to transfer heat from the air-cooling system to the liquid cooling system, increasing overall efficiency.

An EV's cooling system is normally managed by an electronic control unit (ECU), which monitors component temperature and modifies the cooling system accordingly. For example, if the temperature of the battery increases above a given threshold, the ECU can raise the flow rate of the coolant to bring it back down. Appropriate cooling is critical to an electric vehicle's performance, safety, and lifetime.

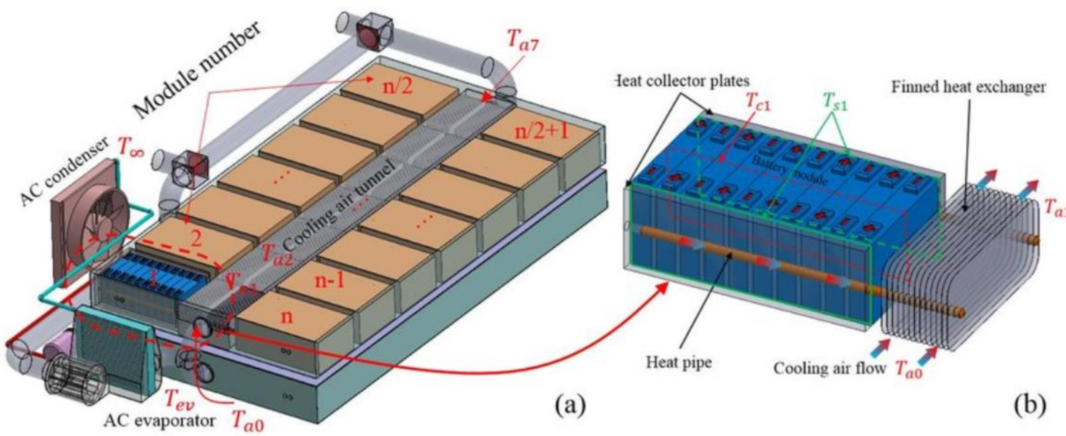

Figure 12: Water cooling schematic for EV

Selection of Air Cooling:

Air cooling is one method of cooling the components of an electric car (EV). Air cooling is commonly utilized to cool components like the motor and brakes, which produce less heat than the battery and power electronics.

Air is pulled through the components by a fan and then discharged back into the environment in air cooling. Because it does not require a coolant fluid, pump, or radiator, this technique of cooling is less sophisticated and less expensive than liquid cooling. Unfortunately, air cooling may not be sufficient to cool heat-generating components such as the battery and power electronics.

The option to use air cooling or another cooling method for 6 kW motors in an electric vehicle (EV) is influenced by a number of factors, including the unique application, environment, design constraints, and economic concerns. In general, air cooling may be enough for cooling 6 kW motors in some EV applications, particularly if the motors are working at low to moderate power levels and the ambient temperature is within a tolerable range. When compared to liquid cooling, air cooling is a simpler and less expensive solution because it does not require additional components such as a coolant fluid, pump, or radiator.

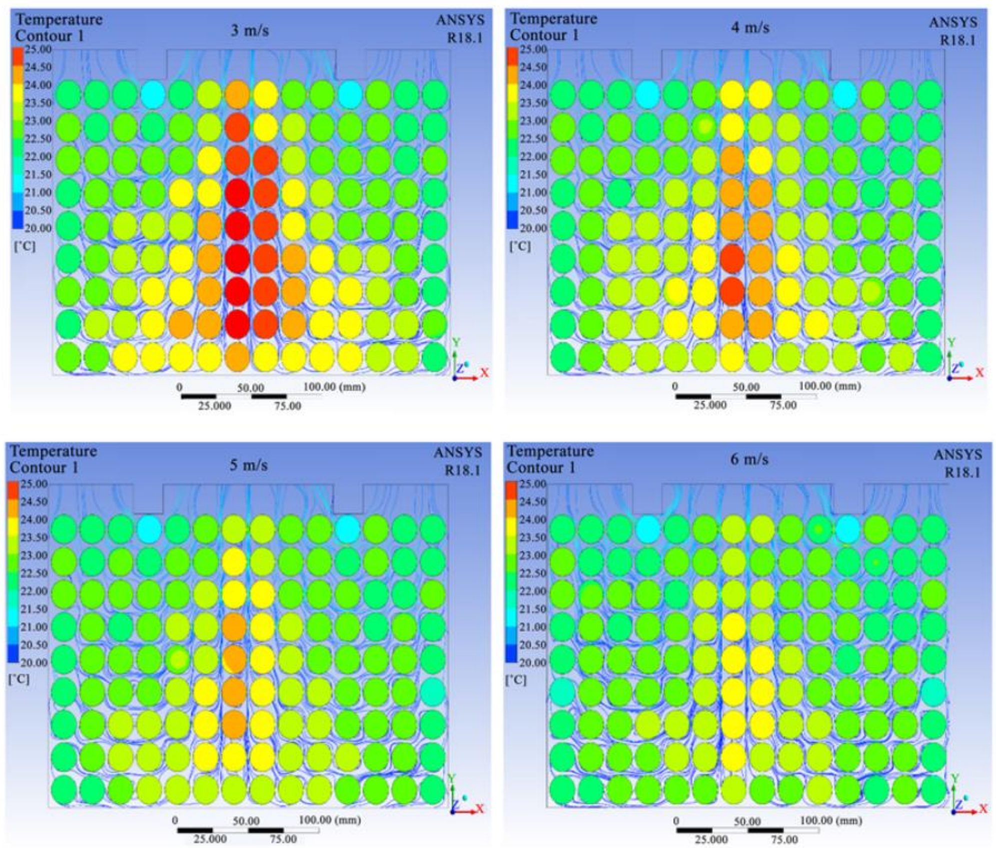

Figure 13: Air cooling simulation

Air cooling may be a realistic and cost-effective option for 6 kW motors operating at 48 volts. Lower operating voltages, such as 48 volts, often have a lower power density than higher voltage motors, resulting in less heat created per unit volume of the motor. This increases the effectiveness of air cooling in dispersing heat generated by the motor. Also, because the voltage is lower, the current flowing through the motor is larger, which can help to improve the effectiveness of air cooling.

Figure 14: Practical uses of Sidepods in vehicles

Several EV manufacturers employ ducts or vents to direct airflow into specific sections of the components, such as the engine or brake rotor, to improve air cooling effectiveness. Heat exchangers can also increase air cooling efficiency by transferring heat from the air-cooling system to the liquid cooling system.

While air cooling is a less expensive and simpler cooling solution than liquid cooling, it has significant disadvantages. Air conditioning is less effective at cooling components that produce a lot of heat, and it is also less effective in hot and humid settings. Also, air cooling can be noisy and cause air resistance, which can reduce the vehicle's overall efficiency. The cooling system of EV is crucial consideration for the design and performance, and careful design making is essential for cooling method being utilized.

Sidepods are a popular feature in many electric cars (EVs) and are intended to increase the vehicle's aerodynamics. Sidepods are often found on the vehicle's flanks and are designed to guide air around the vehicle, reducing drag and enhancing overall efficiency.

Sidepods can also be used to house cooling system components such as radiators or heat exchangers. By incorporating the cooling system into the sidepods, the overall design of the vehicle can be streamlined, and the vehicle's weight decreased. In addition to increasing aerodynamics and cooling, sidepods can give more space for other vehicle components like as the battery or power electronics.

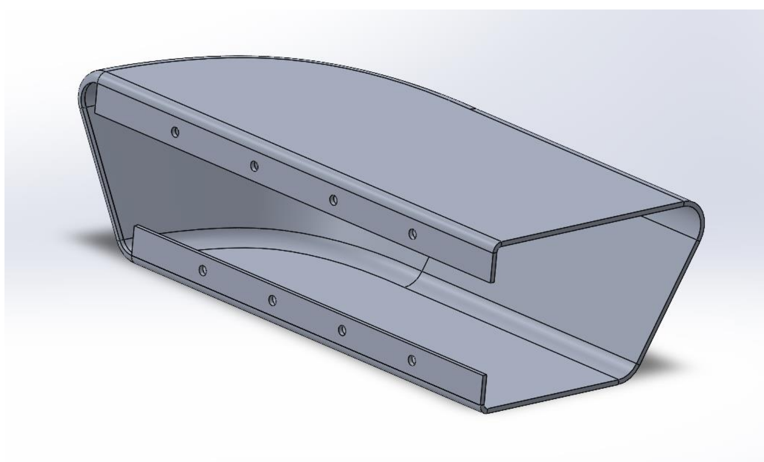

Figure 15: Sidepod designed for the EV.

Yet, there are several drawbacks to using sidepods. Sidepods can add weight to the vehicle, as well as enhance its total size and cost. Furthermore, the positioning of components within the sidepods can make maintenance or repairs more complex. Ultimately, as part of the overall vehicle design, the use of sidepods in an EV should be carefully examined. While they can give substantial benefits in terms of aerodynamics, cooling, and space optimization, they should be assessed in conjunction with other design factors such as weight, cost, and accessibility.

The size of the sidepods necessary to cool 6 kW motors will be determined by numerous factors, including the EV's design, operating conditions, and cooling system used. In general, sidepods with a surface area of 0.5 to 1.0 square meters may be suitable for cooling a 6-kW motor. However, this is an approximate approximation, and the final size and shape of the sidepods will be determined by the EV's use and design. To undertake more comprehensive calculations and analysis, it is advised that you speak with professionals in the subject or utilize specialized software.

Selection of Motors:

In place of an internal combustion engine, electric vehicles (EVs) employ one or more electric motors to power the wheels. The following are the various types of motors that can be used in an EV:

AC Induction Motor: This type of motor is based on electromagnetic induction principles. It is designed simply, with no permanent magnets in the rotor. Instead, the rotor is made up of short-circuited copper or aluminum bars. The AC induction motor is relatively cheap to produce and efficient at high speeds. It does, however, have significant drawbacks, such as decreased efficiency at low speeds and a limited torque range.

Permanent Magnet Synchronous Motor (PMSM): A magnetic field is generated by permanent magnets in the rotor of this type of motor. The magnetic field of the stator interacts with the magnetic field of the rotor to produce torque, which powers the wheels.

Switched Reluctance Motor (SRM): The SRM is a simple motor that does not use permanent magnets. Torque is generated by the rotor's reluctance to align with the magnetic field of the stator. The SRM is relatively cheap to produce, has a high-power density, and is extremely efficient at low speeds. Yet, it has some limitations, including high acoustic noise and vibration levels.

Brushless DC Motor (BLDC): Similar to the PMSM, the BLDC motor lacks a commutator. It employs a series of electromagnets in the stator to generate a spinning magnetic field that interacts with the rotor's permanent magnets. The BLDC motor is highly efficient, has a high power-density, and has a wide torque range. It is, nevertheless, more expensive to construct than an AC induction motor.

DC Series Wound Motor: This motor has a simple design that does not use permanent magnets. It has a high torque at low speeds, making it appropriate for heavy-duty applications. It is less efficient than other types of motors, however, and has certain reliability difficulties.

METHODOLOGY

Once the motors were selected, the next step was to select the configuration in which they would be connected to the wheel. Following aspects were considered in selection of the power train configuration:

- Ease of manufacturability.
- Having a robust design, which passes all the static and dynamic events successfully.
- Parts could be assembled in house or can be easily procured in Pakistan.
- Minimum Mass of the system.
- Minimum Un- sprung mass to allow better maneuverability.
- The power train should remain within the size and cost limits of the project.

Unsprang weight Considerations.

One of the most important decision the team had to make early on was to decide whether to go for an in-wheel motor configuration or place motors somewhere in center of the vehicle and transfer the power to wheel through a transmission. In this aspect, the team considered the unspring mass and cost as two of the major deciding factors.

“unsprang “refers to the mass of any part between road and suspension. This means that unsprang is the total weight of all the components unsupported by the vehicle’s suspension. The inertia of the unsprang mass causes the response of the wheel to lag, leading to poorer response time. This can also cause lose contact with road and hence lose traction. Hence, lower the unsprang mass , the faster the suspension can react.

The conventional type of powertrain with both motors in the center, delivering power through a transmission to wheel , offered a smaller unsprang mass which reduced the requirements for suspension and allowed better maneuverability. It also involved relatively simpler control system design. Considering these advantages, the team decided to go with conventional powertrain over a in wheel (Hub type) configuration.

Powertrain Layout

Once it was decided to have the motors placed within the body of the vehicle, it was time to select the layout of the powertrain. The motors selected provided a consistent torque over a broad range of RPMs and can deliver power instantly by having high torque at 0 RPM or low revs. The efficiency of electric motors is also high in broad rev range. Thus, EVs do not need to change gears and work great with a fixed gear ration. FSUK rules prevented any vehicle to move in reverse, so only one fixed forward gear is required.

Three different designs were considered:

1. Two Motors with chain drive configuration
2. Two motors with planetary gearbox
3. Single motor with chain drive configuration

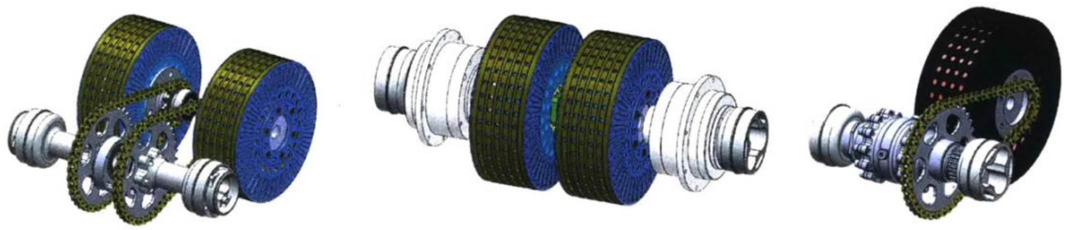

Figure 16 : Two motors with chain drive configuration (left), Two motors with planetary gearbox (center), single motor with drive chain configuration (right)

The team had two motors with each capable of providing up to 4 kW of power, so it was important to use both the motors. For simplicity and efficiency, a single Sprocket and chain mechanism was selected to transmit power from the combine axle of motors to rear axle.

There are many important parameters that determine different aspects of the powertrain of formula 1 electric cars such as Motors. Some of the main parameters are as under:

Weight of the Car:

The weight of a Formula 1 car plays a crucial role in determining its performance and handling. Teams are constantly striving to reduce the weight of their cars to improve their acceleration and top speed, as lighter cars are generally faster and more agile on the track.

A lighter car can accelerate faster because there is less mass to move, allowing for a quicker response to driver input. Additionally, a lighter car can reach higher top speeds, as there is less aerodynamic drag to overcome. This is because a lighter car requires less power to move through the air, allowing it to maintain higher speeds for longer periods.

Weight also affects the handling and balance of the car, as a heavier car is generally less agile and less responsive to changes in direction. A heavier car may also suffer from more understeer or oversteer, which can make it more challenging to control during high-speed maneuvers.

Overall, the weight of a Formula 1 car is a critical factor in determining its performance, with teams constantly seeking ways to reduce weight while maintaining strength and safety. By minimizing weight, teams can optimize their car's acceleration, top speed, and handling, giving them an edge over their competitors on the track.

The estimated weight of our car is around ***300 kgs****.*

Center of Mass

The center of mass of a car is an essential factor in determining its handling, stability, and overall performance. In general, a car's center of mass should be as low and as central as possible to achieve the best possible performance and handling.

The center of mass affects a car's handling by influencing its balance and stability. If the center of mass is too high, the car will be more prone to tipping over during high-speed maneuvers or sudden changes in direction. On the other hand, if the center of mass is too low, the car may have less ground clearance, making it more challenging to navigate over uneven terrain.

A car's center of mass also affects its stability. If the center of mass is too far forward or too far back, the car may experience understeer or oversteer, respectively. Understeer is when the car tends to move straight ahead instead of turning when the driver turns the steering wheel, while oversteer is when the rear of the car slides out in a turn.

Additionally, a car's center of mass affects its braking and acceleration performance. A lower center of mass means that the car can more effectively transfer weight between the front and rear wheels, allowing for better traction during acceleration and braking.

Overall, the center of mass is a critical factor in determining a car's handling, stability, and performance. By optimizing the center of mass to be low and central, engineers can achieve better balance, stability, and control over the car, resulting in improved lap times and a more competitive car on the track.

The Center of Mass of our car is around ***67% of the wheelbase from the front wheels*** *of the car.*

Maximum Traction Force Available:

The maximum traction force of a car is the maximum amount of force that can be applied to the ground without causing the wheels to slip. This force is essential for accelerating, braking, and turning the car, and its magnitude depends on several factors, including the weight and center of mass of the car.

As a general rule, the maximum traction force of a car is directly proportional to its weight. A heavier car can apply more force to the ground without slipping, as it has more mass to transfer to the wheels. This means that a heavier car can accelerate, brake, and turn more effectively than a lighter car, all other things being equal.

However, the location of the car's center of mass also plays a critical role in determining its maximum traction force. If the center of mass is too high, the car may experience a higher tendency to tip over, reducing the maximum traction force available during cornering. If the center of mass is too far forward or too far back, the car may experience understeer or oversteer, respectively, which can also reduce maximum traction force.

Therefore, the weight and center of mass of a car are crucial factors in determining its maximum traction force. By optimizing these factors, engineers can achieve the best possible balance, stability, and control over the car, allowing it to achieve maximum traction force and better lap times on the track.

The Traction force can be calculated by using the formulas given below:

$$F_{tRW} = \mu w$$

Were,

F_{tRW} = Traction Force of rear wheel drive

μ = Coefficient of Friction between tires and the road

(Here we have taken it to be 0.9 as it is the normal coefficient of friction between simple tires and the road)

w = Weight of the car on the rear wheels

*The Traction force from the above formula comes out to be **1734.6 N.***

To find the maximum force of traction there is also another parameter which comes into play. Whenever a car starts accelerating, a force due to the height of the center of mass from the ground also acts on the rear wheels which adds to the force of the traction force. This force can be calculated by the formula given as,

$$Wx = \frac{W \times a \times h}{t}$$

Where,

Wx = Longitudinal load transfer

W = Weight

A = lateral Acceleration

h = height of the COM

t = length of wheel track

*The longitudinal load transfer comes out to be **400.1 N.***

So, the Maximum traction force available can be given as,

$$F_{tmax} = F_{tRW} + W_x$$

The Maximum traction force comes out to be ***2134.9 N****.*

Targeted Acceleration:

As we have found the maximum force of traction, we know the limit which we cannot exceed so that our tires do not slip if provided more force than available to the tires. The next step is to find the force we need to reach our desired acceleration at the start of the motion. This acceleration can be set according to the rules or safety limits of the competition. If we are using a fixed gear ratio, our maximum speed also depends upon the acceleration or the torque we are using as the power is the multiple of Speed and torque.

$$Power = Torque \; x \; Angular \; Speed$$

Keeping in mind all these requirements we chose our *desired acceleration to be* **6 m/s²**.

Now, by using Newton's 2nd equation of motion:

$$F = m \times a$$

Here,

F is the force provided by the motors to the tires.

M is the mass of the car

A is the desired acceleration of the car.

$$F = 300 \times 6$$

$$F = 1800\ N$$

By putting in values we get the force required to achieve the acceleration to be ***1800 N.***

Required Torque:

As we have calculated the force required at the tires to achieve the desired acceleration we can calculate the torque required at the tires by using the radius of the tire.

$$Torque = Force \times Radius$$

The radius of the tire is decided by the suspension team according to the requirements, The radius of the selected tires is ***0.2667 m.***

$$T = 1800 \times 0.2667$$

$$T = 432.05\ Nm$$

The torque comes out to be ***432.05 N.m.***

Gear Ratio:

The gear ratio can be found by using the torque provided by the motors to the torque required at the rear wheels. As we know from the data sheet of the motors, each motor provides 180 Nm of torque which makes 360 Nm in total and our desired torque at the rear wheels is 432.05 Nm. So, by using the formula for the gear ratio,

$$Gear\ Ratio = \frac{Torque\ Provided}{Torque\ Required}$$

So, *the gear ratio comes out to be* ***1:1.174***.

Maximum Speed:

The maximum speed achievable can be found out by using the maximum rpm of the motor from its data sheet and the gear ratio.

$$Angular\ speed\ of\ motors = G.R\ \times Angular\ Speed\ at\ the\ tires$$

Angular Speed at the tires comes out to be 766 rpm.

By using the radius of the tires we can get the velocity of the car.

$$v = r\ \times \omega$$

$$v = 0.2667\ \times 80.21$$

$$v = 21.39\ m/s$$

$$\boldsymbol{v = 77\ \ km/h}$$

So, the maximum attainable speed of the car comes out to be ***77 km/h.***

Rear-wheel drive is the preferred drivetrain configuration for Formula 1 cars due to several advantages it offers in terms of performance and handling.

Firstly, rear-wheel drive provides better traction and acceleration compared to front-wheel drive or all-wheel drive configurations. This is because the weight of the car shifts to the rear wheels under acceleration, which increases the amount of force being applied to the tires, improving grip and reducing wheel spin. This results in faster acceleration and higher speeds, which is essential for Formula 1 racing.

Secondly, rear-wheel drive provides better balance and handling characteristics, particularly when entering and exiting corners. Since the front wheels are not responsible for both steering and power delivery, the rear wheels are free to concentrate solely on providing traction, which improves handling and stability during cornering. Additionally, since the weight of the engine is located over the rear wheels, this provides better balance and stability, further improving handling and allowing drivers to take corners at higher speeds.

Thirdly, rear-wheel drive allows for better weight distribution and aerodynamics, which are important factors in Formula 1 racing. Since the engine and transmission are located at the rear of the car, this allows for a more balanced weight distribution, which improves handling and reduces understeer. Additionally, the front of the car can be designed with less aerodynamic downforce, which reduces drag and improves top speed.

Finally, rear-wheel drive offers greater flexibility in terms of suspension design, which can be fine-tuned to provide the best possible balance between handling and grip.

In summary, rear-wheel drive is preferred in Formula 1 racing due to its superior acceleration, handling, balance, aerodynamics, and suspension design capabilities. These advantages allow drivers to push their cars to the limit and achieve faster lap times, which is critical in this highly competitive sport.

Motors Configuration:

We procured two DC Brushless motors which are basically hub motors. There are two main ways these motors can be included in the vehicle. One being the motors used directly in the wheels and the other being the two motors used in the mid of the car attached together through a shaft to a transmission system.

Mid Train Configuration:

The first approach can be to use the motors being used in the mid terrain. There are several advantages of using the motors in the mid train which are as follow:

One of the primary benefits of using mid-mounted motors is improved weight distribution. Placing the motors in the middle of the car helps to distribute the weight more evenly between the front and rear axles, which can improve traction, stability, and handling. This is particularly important in high-performance cars that require precise handling and cornering.

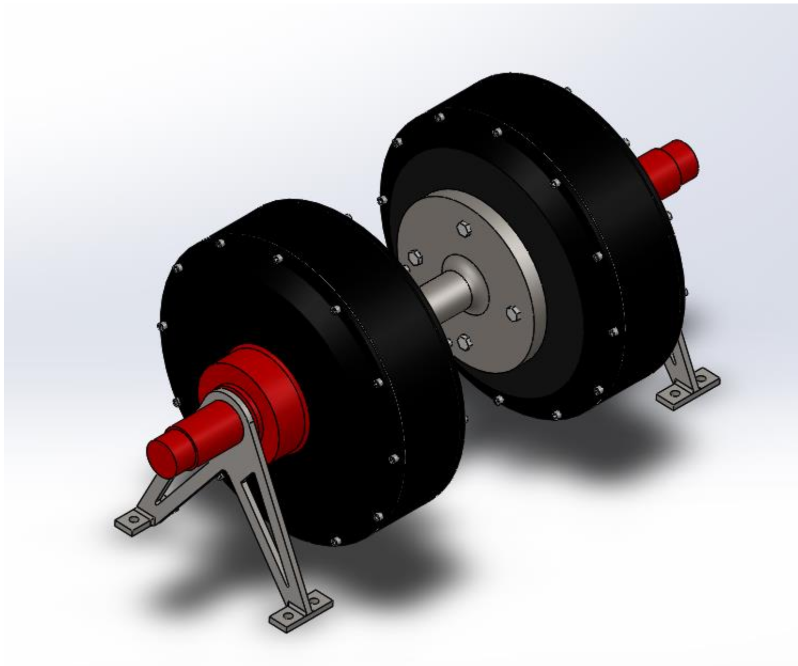

Figure 17: Two motors attached together via a shaft.

Additionally, by placing the motors in the middle of the car, they can also be positioned closer to the car's center of gravity, which can further improve handling and stability.

Finally, using mid-mounted motors can also help to reduce unsprang weight, which is the weight of the suspension and wheels that is not supported by the car's springs. This can improve the car's responsiveness to changes in road conditions, as well as its overall ride quality.

Shaft Design:

The shaft between the two motors bears the torque and some of the weight of the motors as well. This shaft can be made by using the formula,

$$T = \tau \times \frac{\pi}{16} \times d^3$$

Here,

T is the torque on the shaft.

τ is the maximum torsional stress.

d is the minimum diameter of the shaft

$$360000\ (Nmm) = 200\ \left(\frac{N}{mm2}\right) \times \frac{\pi}{16} \times d^3$$

$$d\ = 20.1\ mm$$

By putting the values in the formula for stainless steel we get the value of the ***minimum diameter to be 20.1 mm.***

For the rear axle shaft as the torque there was more than the shaft attached between the motors. We do the same calculations for that shaft.

$$432000\ (Nmm) = 200\ \left(\frac{N}{mm2}\right) \times \frac{\pi}{16} \times d^3$$

$$d\ = 22.24\ mm$$

Selection of Chain and Sprockets

Chain and sprocket were selected on basis on desired gear ratio and service condition by following a step-by-step procedure outlined by ANSI:

- **Step 1: Determining Service Factor**

In most situations, the nominal horsepower is usually known. However, the peak horsepower that is sustained by the chain may be much larger than the nominal horsepower depending on power source and type of equipment used. The service factor allows a way to estimate the maximum horsepower that the chain may be exposed to. There is a standard table from ANSI that gives the service factor on the basis of power source and type of equipment driven. Since, in this case the power source is an electric motor and a small car is driven, thus:

$$\text{Service factor} = 1.3$$

- **Step 2: Calculating the design horsepower.**

The nominal horsepower is multiplied by the service factor to get the design horsepower:

$$\textit{Design Horsepower} = \textit{Input Horsepower} \times \textit{Service Factor}$$

$$\textit{Design Horsepower} = 9 \times 1.3 = 11.7$$

- **Step 3: Making a preliminary chain selection.**

There may be several possible chains for design power. Generally, however, the smallest pitch, single strand chain conveys the power in most economical way. Referring to the abridged Horsepower Ratting and looking for 11.7 design Horsepower, at 900 RPM (of smaller sprocket). It falls within the area for ***#50 chain***. This is the smallest single strand chain which will transmit the required power. The type 50 chains have a pitch of 0.625 inches. Correspondingly the Small Sprocket should have 17 teeth minimum and 0.625-inch pitch. To allow robustness, the number of teeth of smaller sprocket is selected at 23.

- **Step 4: Selecting the large Sprocket.**

Now that the chain and the smaller sprocket has been selected using the ANSI horsepower rating, the number of teeth of the large sprocket can be determined by multiplying the number of teeth of small sprocket by required speed ratio. We set the number of teeth on the smaller sprocket as 23 * (Though a 17 teeth sprocket can do the job too), and the desired speed ratio is.

$$Desired\ Ratio = \frac{Input\ RPM}{Output\ \ RPM} = \frac{900}{766} = 1.1749$$

$$Number\ of\ teeths\ on\ Large\ Sprocket = Small\ Sprocket\ \ No\ .of\ teeths\ \ \times Desired\ Ratio$$

$$Number\ of\ teeths\ on\ Large\ Sprocket = 23 \times 1.1749$$

$$\boldsymbol{Number\ of\ teeths\ on\ Large\ Sprocket = 27}$$

- **Step 5: Calculating Chain Length**

Since the driver and the driven sprocket are of different sizes, the ANSI formula can be used to find out the required length of the chain:

Let,

N = Number of teeth on Larger Sprocket = 27

n = Number of teeth on Smaller Sprocket = 23

C = Center distance between the shafts ***in pitches*** (multiple of 0.625 inch)

Since we know the circular pitch and the number of teeth for both sprockets, we can find the pitch diameter of both the sprockets by the following formula :

$$d = \frac{pN}{\pi}$$

So, for Smaller Sprocket:

$$d\_s = \frac{0.625 * 23}{\pi} = 4.5757 \; inches$$

And for larger Sprocket:

$$d\_l = \frac{0.625 * 27}{\pi} = 5.3714 \; inches$$

The minimum distance between the two shafts (center of the two sprockets) should be enough to avoid interference. Hence the minimum distance between the two shafts would be.

$$\frac{d_s + d_l}{2} = \frac{4.5757 + 5.3714}{2} = 4.973589 \; inches$$

That is approximately 8 pitches.

However, 20 pitches are desired to avoid chain wrapping and potential drive damage.

So, let's take C = 20.

The chain length is given by:

$$L = 2C + \frac{N + n}{2} + \frac{.1013\ (N - n)^2}{4C}$$

Where, L is total chain length in pitches.

$$L = 2(20) + \frac{27 + 23}{2} + \frac{.1013\ (27 - 23)^2}{4(20)} = 65.02026$$

So, we need a chain of length of **66 pitches** (41.25 inches).

Once the chain and sprockets were designed and selected, the team made a CAD Model of them and performed FEA to ensure that they are safe :

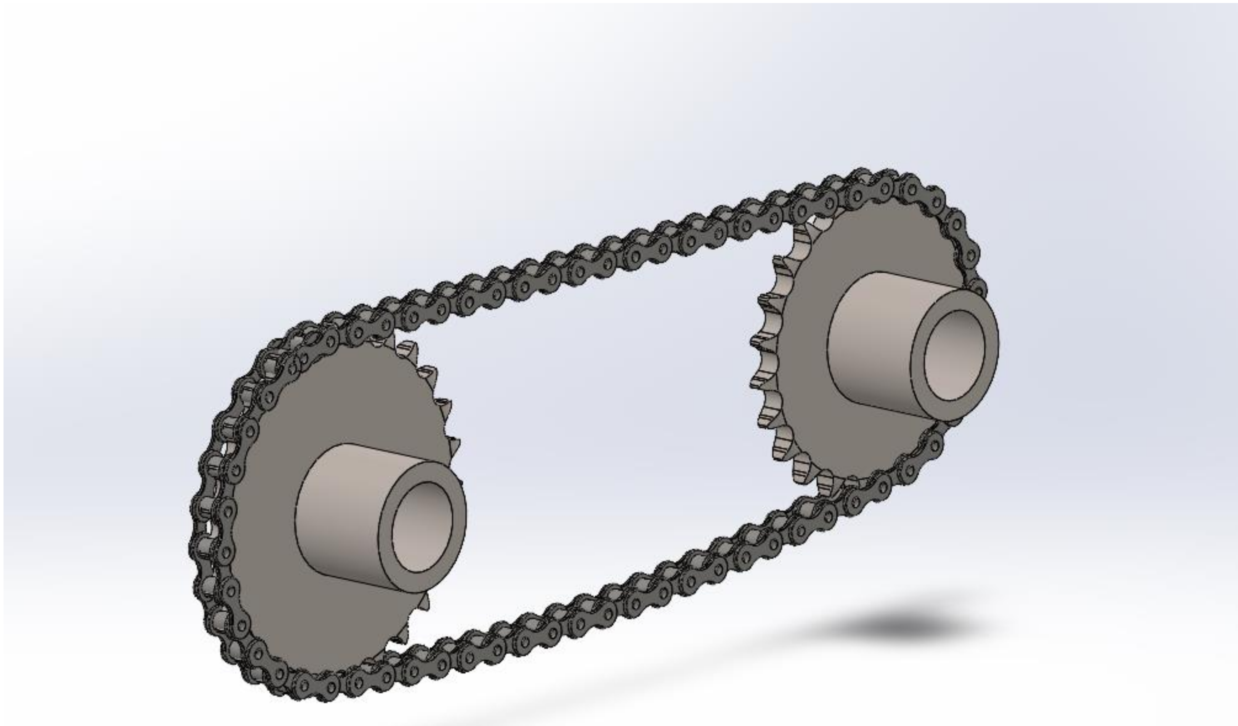

Figure 18 : CAD Model of Sprocket and Chain mechanism

Rear Axle Mounts:

The rear axle of the car when mounted with the chassis of the car needs some flexibility to absorb the jerks so that the chain and sprocket system does not fail. Whenever there are road bumps jerks occur which can tighten the chain as the axle moves from its location and if it is fixed with the chassis with a rigid support the chain can fail due to high stresses.

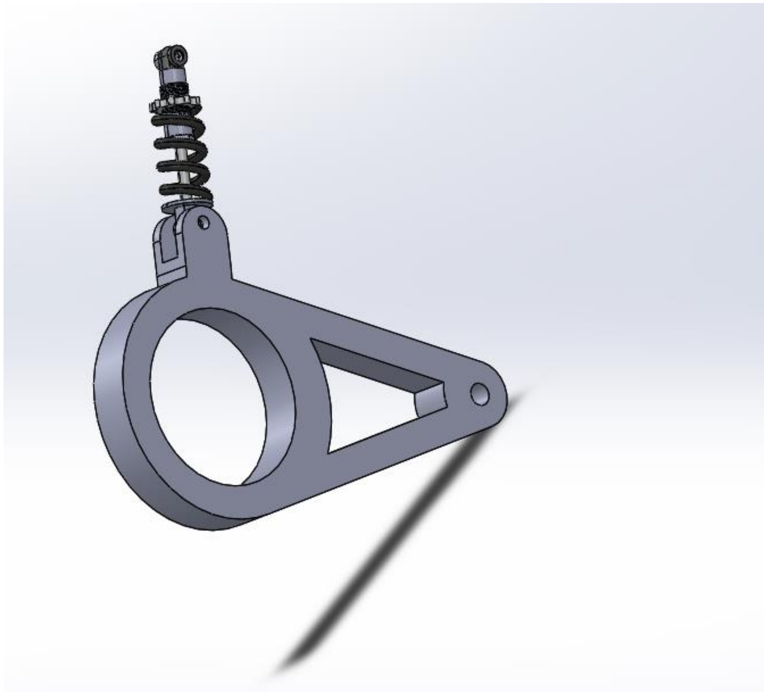

Figure 19: Rear Axle Mount

To prevent this from happening we use mounts with springs attached to them which act as shock absorbers for the rear axle.

This provides some room for the axle to move if there are any jerks and hence saves the chain from tightening to an extreme extent that it fails.

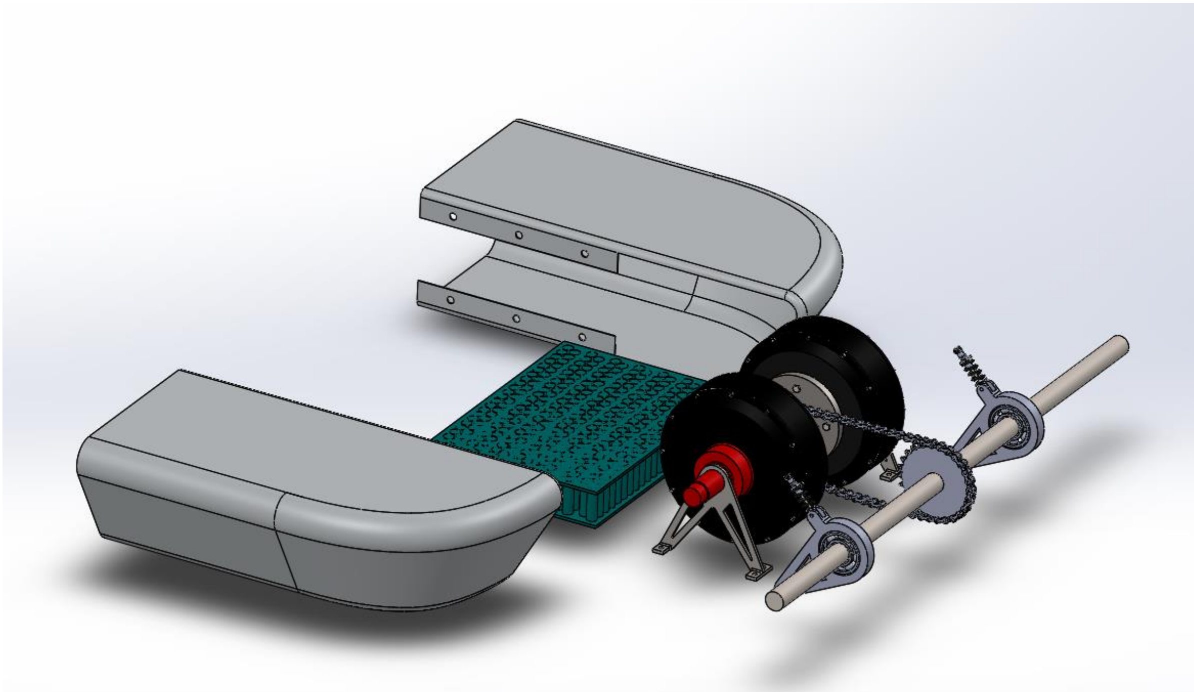

Figure 20: CAD Model

BLDC Motor:

A BLDC motor is a type of synchronous electric motor that employs a permanent magnet rotor and a win dinged stator. A control circuit energizes the windings by switching the current direction in the windings to create a revolving magnetic field that interacts with the permanent magnets in the rotor, delivering torque and power to the wheels. The control circuit is often a microcontroller-based system that adjusts the speed and torque of the motor based on input from the driver or other sensors.

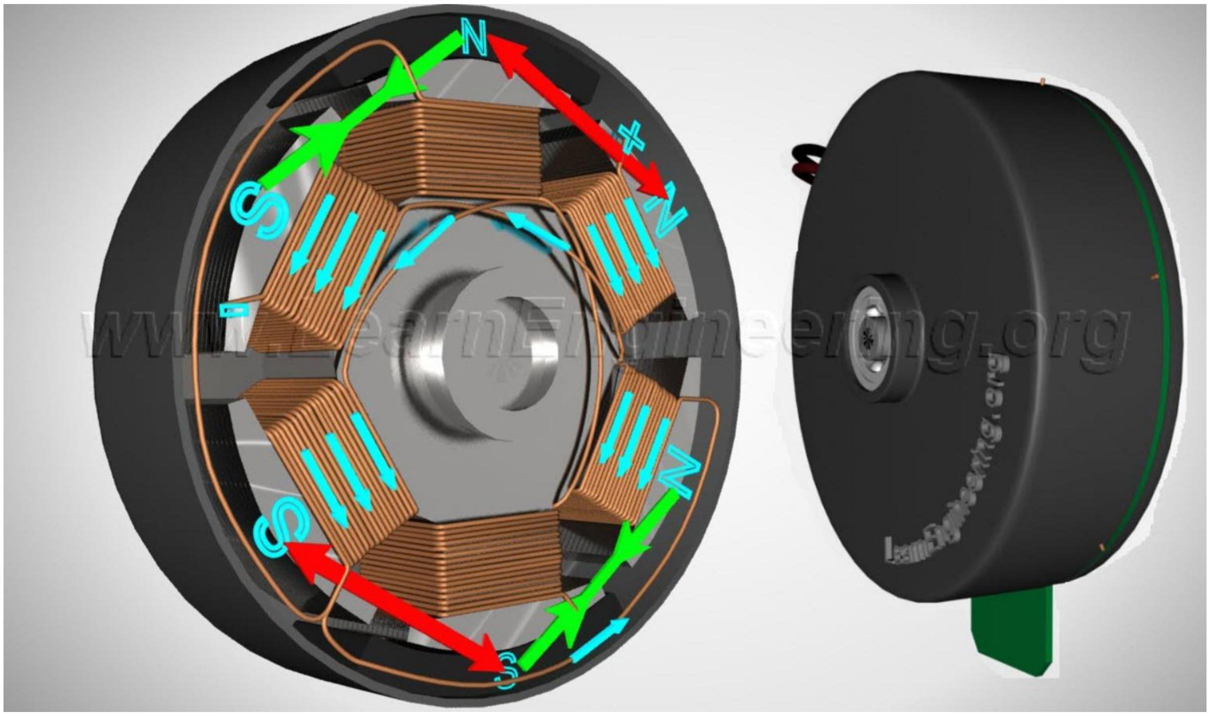

Figure 21: BLDC motor internal view

The great efficiency of BLDC motors is one of their primary advantages. There are no brushes to create friction and wear out over time because they lack a commutator. There are no brushes to create friction and wear out over time because they lack a commutator. This means that BLDC motors outlast other types of motors and require less maintenance. BLDC motors are also highly responsive and can deliver smooth, precise acceleration and deceleration since the control circuit can precisely regulate the motor's speed and torque.

In conclusion, because of their great efficiency, high power density, and precise control, BLDC motors are a preferred choice for electric cars. While they cost more to produce than other types of motors, their extended lifespan and low maintenance requirements make them a cost-effective alternative over the life of the vehicle.

Figure 22: Use of BLDC motor as Hub motor

The selection of BLDC motor model is selected via the Power and Torque requirements, generally higher power and torque leads to enhanced performance, but leading to higher cost. The voltage and current requirements of the motor should be compatible with EV battery pack and motor controller. The motor is generally limited to voltage and current of battery and controller. The size and weight are significant as light motor leads to more compact and efficient EV, but heavier motor may provide higher performance at cost range. The cooling and cost are yet another factor which can be utilized to select the model of the motor.

Ball Bearing:

Firstly, ball bearings are designed to handle both radial and axial loads, which makes them ideal for supporting the weight of a car while also allowing it to turn and change directions. This is important for the axle of a car, which must support the weight of the vehicle while also allowing the wheels to rotate freely.

Secondly, ball bearings have a low coefficient of friction, which means they produce less resistance to movement and reduce the amount of energy needed to rotate the wheels. This translates into better fuel efficiency and smoother handling for the driver.

Thirdly, ball bearings are generally durable and long-lasting, which makes them suitable for the demanding conditions of automotive applications. They are designed to withstand high speeds, heavy loads, and the wear and tear of regular use.

Finally, ball bearings are relatively easy to install and maintain. They are widely available, and replacements can be easily found when needed. Additionally, they require minimal maintenance and lubrication to keep them functioning properly, which makes them a cost-effective solution for automotive applications.

Figure 23: 6207 Deep Groove Ball Bearing

Overall, the use of ball bearings in the axle of a car provides a reliable and efficient solution for supporting the weight of the vehicle while also allowing it to move smoothly and efficiently.

The model of the bearing used in the car is ***Deep groove Ball Bearing 6207***

The specifications of the Deep groove ball bearing are as follows:

Internal Diameter: 35 mm

Outer Diameter: 72 mm

Width: 17 mm

Accumulator:

There are various battery kinds that can be utilized in electric vehicles (EVs). Lithium-ion batteries are the most popular type of battery used in EVs. They are lightweight, have a high energy density, and can be charged reasonably quickly. They're also commonly seen in consumer gadgets. Before lithium-ion batteries became more popular, nickel-metal hydride (NiMH) batteries were extensively utilized in hybrid electric vehicles (HEVs).

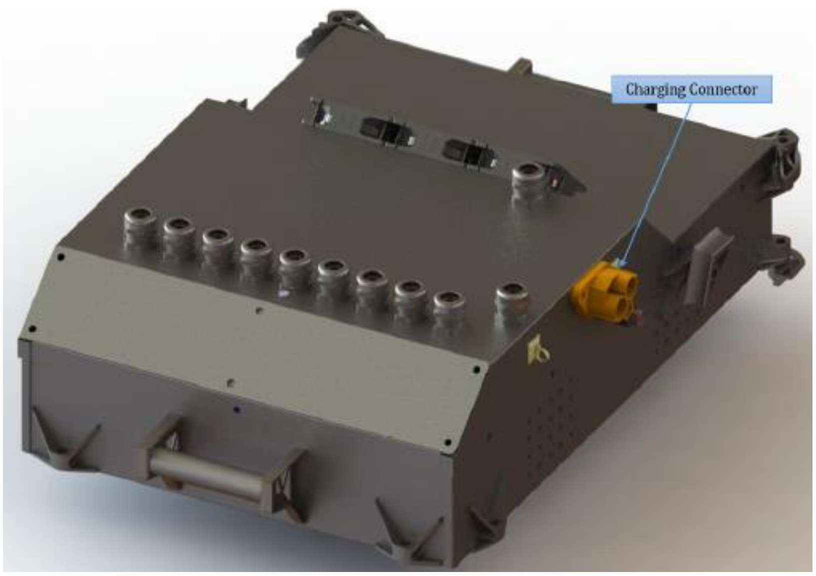

Figure 24: Accumulator casing of Formula EV

They are less expensive than lithium-ion batteries, but they have a lower energy density and are heavier. Solid-state batteries are still in the development stage, although they are viewed as a viable EV technology. Instead of a liquid electrolyte, they utilize a solid electrolyte that makes them safer and potentially more efficient than lithium-ion batteries.

Traditional lead-acid batteries have lesser energy density, and their usage in an EV would result in occupying too much space as well as adding too much weight in the EV but they are inexpensive and can be utilized for testing purposes of the motor.

18650 Cells:

The designation "18650" refers to rechargeable lithium-ion batteries that are cylindrical in shape and measure 18mm in diameter and 65mm in length. They are commonly utilized in a wide range of products, such as laptops, power tools, electric vehicles, and even in some high-performance flashlights.

18650 cells have a nominal voltage of 3.6-3.7 volts and a common capacity of roughly 2,000-3,500 milliampere-hours (mAh), while some larger capacity cells can reach up to 4,000-5,000 mAh. They are distinguished by their high energy density, which enables them to store a large amount of energy in a small space.

One of the benefits of using 18650 batteries is that they can be recharged hundreds of times before their performance begins to degrade. They also have a low self-discharge rate, which means they may keep their charge for extended periods of time when not in use.

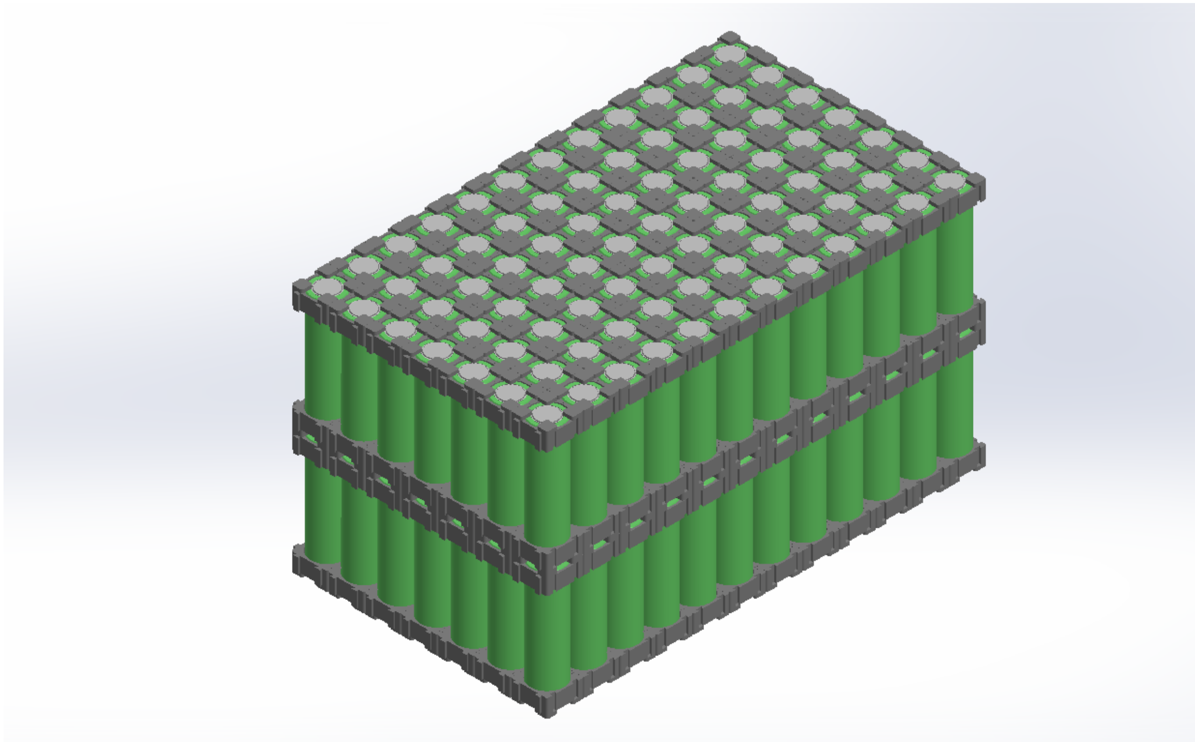

Figure 25: Accumulator battery with 18650 cells

However, 18650 cells, like any other lithium-ion battery, can be deadly if mistreated or improperly charged. If they are punctured, crushed, or exposed to high temperatures, they can overheat and even explode. To avoid mishaps, it is critical to use the proper charger and handle them with care. Overall, 18650 cells are a popular choice for a wide range of applications due to its high energy density, rechargeability, and long lifespan.

CHAPTER 4: RESULTS AND DISCUSSIONS

Optimization of Sprockets

Weight reduction is an essential to ensure maximum performance of the vehicle. To do so a design optimization was carried out to remove material in such a way that it does not affect performance and safety of sprocket. The optimized shape and its von misses stress plot is as follows:

Figure 26 : Optimized Shape and Von misses stresses in sprocket

Motor Mounts

Another part of interest in the analysis phase were the motor mounts. They should be strong enough to hold the motor firmly and bear the braking forces. However, they should also be light weigh to minimize overall weight of the suspension. The mounts should also be stiff to prevent any unwanted vibrations near motor. The initial design of mounts was as follows.

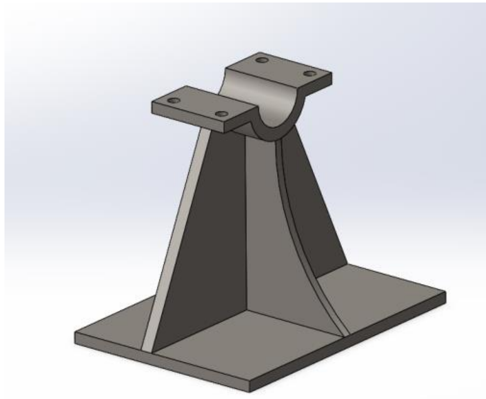

Figure 27: Initial Mount Design

A design optimization was carried out to remove the material without effecting the strength and performance of the mount and the final design was as follows :

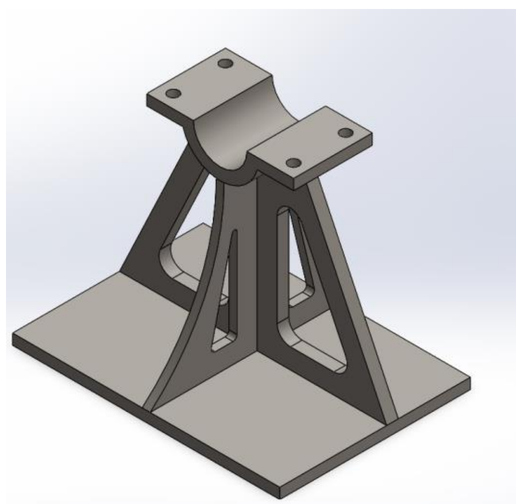

Figure 28: Optimized Shape

Fatigue Analysis:

We also know that as the shaft will go under cyclic load it can also undergo fatigue analysis, so Fatigue analysis has to be done on a Finite element analysis software. The software which we use is ***Ansys.*** Torque was applied on the shaft and to find the factor of safety we used 10^6 cycles as reference. The result of the simulation is as follows

Definition			
Type	Life	Damage	Safety Factor
Identifier			
Suppressed	No		
Design Life		1.e+009 cycles	
Results			
Minimum	1.e+006 cycles		1.6784
Minimum Occurs On	Rear axle shaft\Solid1		Rear axle shaft\Solid1
Maximum		1000.	
Maximum Occurs On		Rear axle shaft\Solid1	

Figure 29: Fatigue Analysis of Shaft

These results were obtained when we used a shaft of 35 mm with the torque value given. So, the shaft diameter we have chosen for our design is ***35 mm***. ***Factor of safety for the shaft is 1.678.***

Sidepods Simulations:

The Computational Fluid Dynamics (CFD) analysis was performed on the sidepods of the car, with the goal to improve the aerodynamics performance of the sidepods, along with the constraint of maintaining a certain frontal area to enable the proper heat transfer from the battery. The sidepods along with their use for the air cooling also help to increase the overall speed and handling of the vehicle. The streamlines were utilized to understand the flow pattern by the sidepods on the surface with velocity being 0 ms^{-1}.

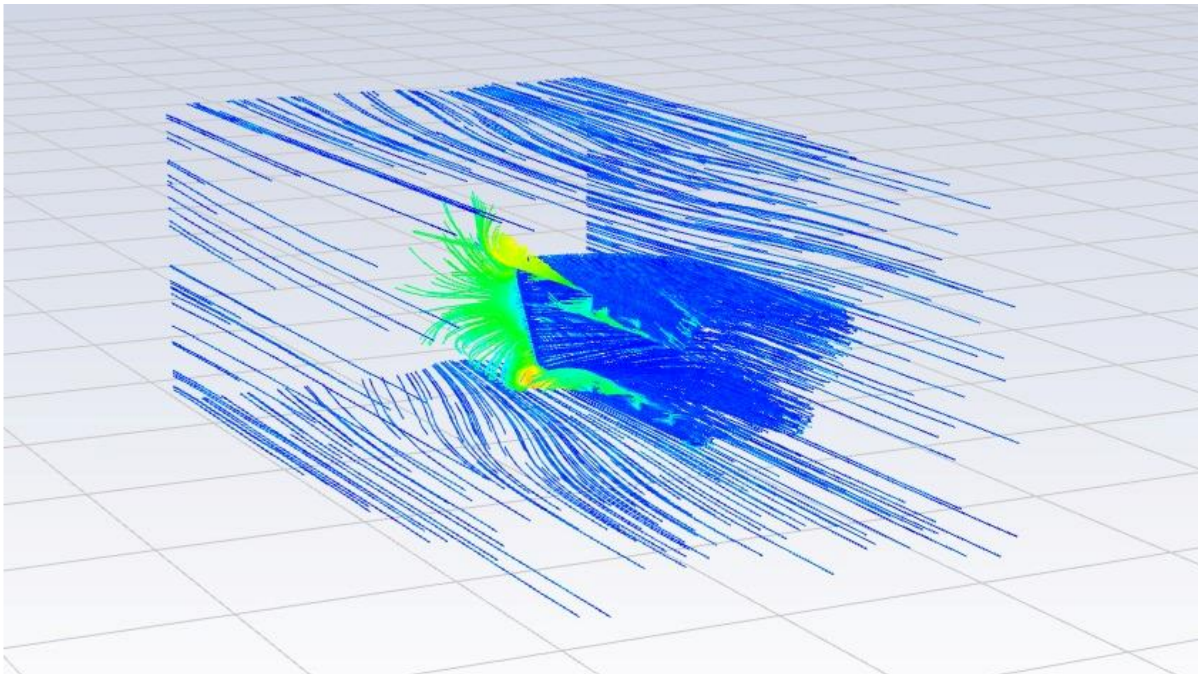

Figure 30: Sidepods CFD simulation

The Finite Element Analysis (FEA) was performed on the sidepods of the car, with the goal to prove the structural stability. The material used is Aluminum 5150 grade. The air flow weight and the structural weight of the material is used which are bolted to the frame/ chassis of the EV. The maximum von Mises stress of 10.9 MPa ensures that the sidepods are structurally stable and would not impact the bolts.

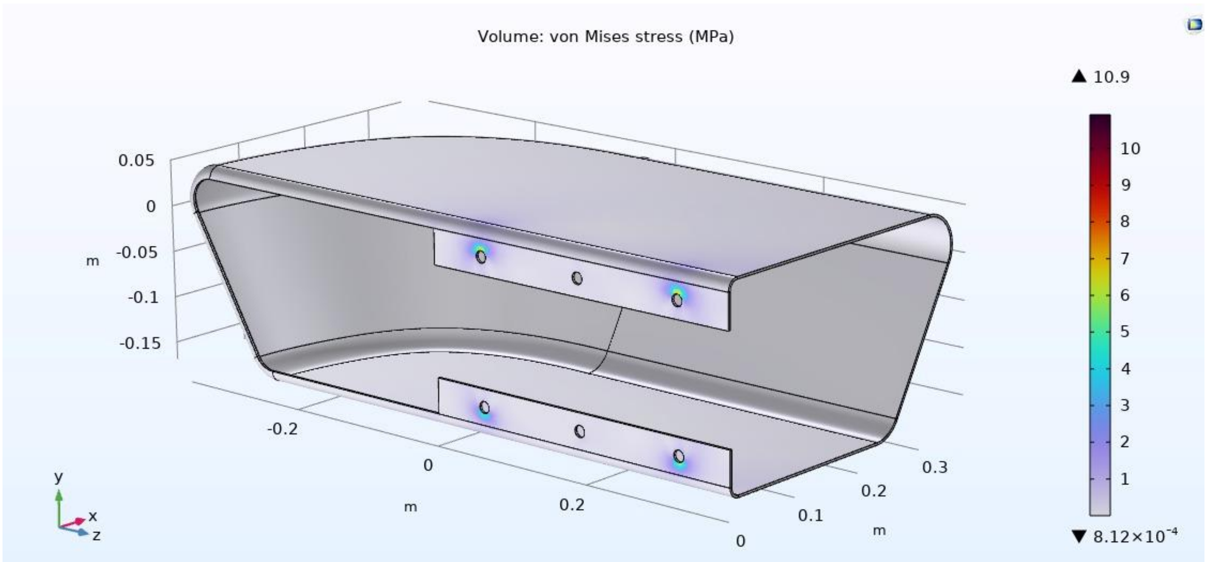

Figure 31: FEA Analysis of Sidepods

Battery simulation is the practice of modelling the behaviour of a battery in a certain application or use case. It involves utilizing computer models and simulation software to forecast the performance of a battery under various situations, such as temperature, discharge rate, charging rate, and capacity.

Battery Simulation

Battery simulation can assist engineers and researchers in understanding how a battery will function in a certain system and optimizing system design to achieve optimal efficiency and dependability. It is feasible to anticipate the battery's lifetime, estimate its energy storage capacity, and examine the impact of various environmental conditions on its performance by simulating its behaviour. The battery simulation is performed for the 2*13s 22p which refers to 22* 3.6 V approximately 72V and 26 * 2.6 A approximately 70 A, with total power of about 3kWh delivering 6 kW of about half an hour.

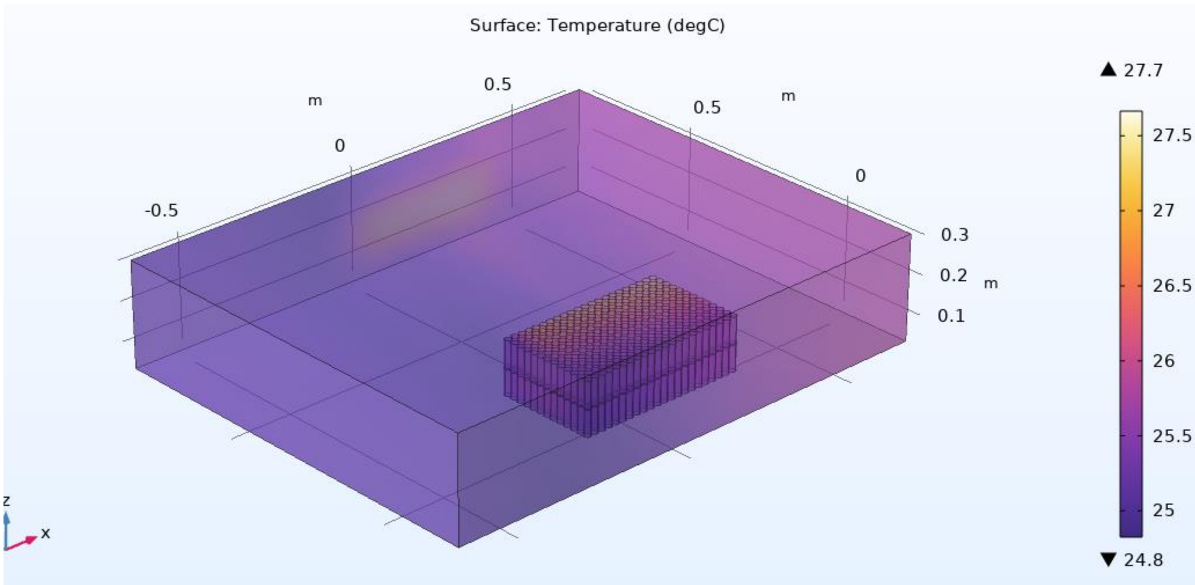

Figure 32: Battery CFD simulation as 15 ms^{-1}

Second Design Approach: In Wheel Motors (Hub Motor Design)

In recent years, electric vehicles have gained significant attention in the automotive industry, and Formula Student Electric (FSE) competitions are no exception. Designing an efficient and high-performance electric powertrain is crucial for success in these competitions. In this engineering description, we will discuss the in-wheel motor (hub motor) design as an alternative to the traditional chain transmission approach. The in-wheel motor design offers several advantages, including reduced manufacturing complexity, elimination of differentials and chain drives, and improved vehicle dynamics.

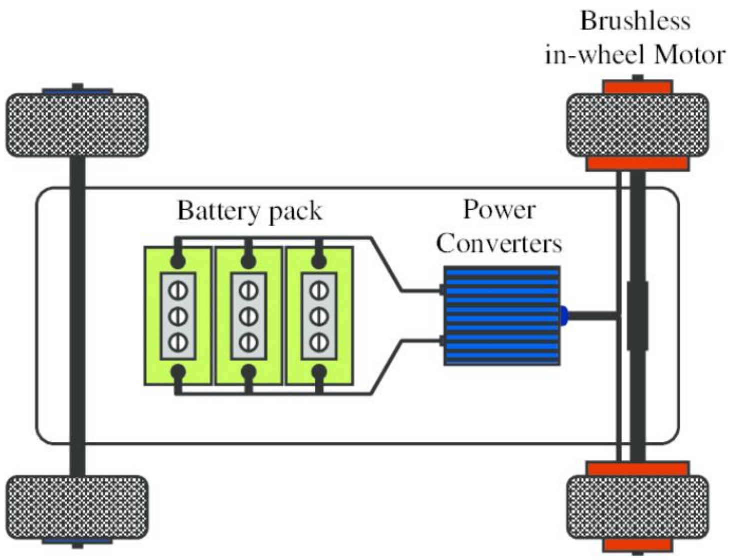

Figure 34: In Wheel Motor Design

DESIGN PRINCIPLES

1- Motor Type and Specifications

The selection of an appropriate motor type is crucial for the success of an in-wheel motor system. Brushless DC (BLDC) motors and permanent magnet synchronous motors (PMSMs) are popular choices due to their high-power density, efficiency, and reliability.

Key motor specifications to consider include:

- Power output: The motor must provide sufficient power to meet the performance requirements of the vehicle.
- Torque: High torque is essential for rapid acceleration and hill climbing capabilities.
- Efficiency: Higher efficiency motors can improve overall vehicle efficiency and extend driving range.
- Size and weight: Compact and lightweight motors are preferred to minimize unsprung mass and maintain vehicle handling characteristics.

2- Motor Integration and Packaging

The integration of motors into the wheel hubs requires careful consideration of packaging constraints and structural requirements. Key factors to consider include:

- Motor housing: The motor housing must be designed to withstand the forces and stresses experienced during vehicle operation. Lightweight materials such as aluminum or carbon fiber can be used to minimize unsprung mass.
- Cooling system: Efficient cooling is essential for maintaining motor performance and longevity. Liquid cooling systems with integrated coolant channels can be employed to manage heat dissipation.
- Electrical connections: Robust and reliable electrical connections are required to transmit power and control signals between the motor and the vehicle's control systems.

3- Suspension and Braking System Design

The integration of in-wheel motors necessitates modifications to the suspension and braking systems. Key design parameters to consider include: The suspension system must be designed to accommodate the added mass and forces generated by the in-wheel motors. This may involve adjustments to the suspension geometry, spring rates, and damping characteristics. Regenerative braking can be implemented to recover energy during deceleration, reducing the reliance on traditional friction brakes and improving overall efficiency. The integration of regenerative braking systems with conventional braking systems must be carefully managed to ensure seamless operation and driver control.

4- Vehicle Dynamics and Control

In-wheel motor systems offer the potential for advanced vehicle dynamics and control capabilities, such as torque vectoring and independent wheel control. By independently controlling the torque applied to each wheel, the vehicle can achieve improved traction, cornering performance, and stability. This requires the development of sophisticated control algorithms and vehicle dynamics models. In-wheel motor systems also enable independent control of each wheel's speed and direction, offering the potential for advanced maneuverability and vehicle stability control features.

Upon a thorough examination of the theoretical application of motor design, following performance parameters have been ascertained for the vehicle:

Table 3: Parameters for Approach 2

Parameter	Value	Units
Estimated Mass of the Vehicle	300	Kg
Maximum Torque of one motor	181	Nm
Maximum RPM	900	Rpm
Maximum Force of Traction	2134.9	N
Gear Ratio	1:1	
Maximum Velocity Achievable	110	Km/h
Acceleration	5.2	m/s^2

BENEFITS OF IN-WHEEL MOTOR DESIGN

1- Simplified Powertrain

One of the primary advantages of in-wheel motor design is the simplification of the powertrain. By eliminating the need for differentials and chain drives, the overall complexity of the system is reduced. This can lead to lower manufacturing costs, easier maintenance, and increased reliability.

2- Improved Efficiency

In-wheel motors offer direct torque transmission to the wheels, resulting in higher efficiency compared to traditional powertrain systems. The elimination of mechanical losses from gearboxes, differentials, and chain drives can lead to improved overall vehicle efficiency and extended driving range.

3- Enhanced Vehicle Performance

The direct torque control provided by in-wheel motors allows for precise torque vectoring, which can improve vehicle handling and stability. By independently controlling the torque applied to each wheel, the vehicle can achieve better traction and cornering performance. Additionally, the elimination of mechanical components can result in a lower center of gravity, further enhancing vehicle dynamics.

4- Design Flexibility

In-wheel motor design offers greater flexibility in vehicle layout and packaging. With motors integrated into the wheel hubs, designers have more freedom to optimize the placement of other components, such as batteries and cooling systems. This can lead to improved weight distribution and overall vehicle balance.

CHALLENGES AND CONSIDERATIONS

1- Increased Unsprung Mass

As mentioned earlier, the integration of motors into the wheel hubs can result in increased unsprung mass. This can negatively impact vehicle handling and ride quality. To address this issue, lightweight materials and optimized motor designs should be employed to minimize the added mass.

2- Thermal Management

Effective thermal management is crucial for maintaining the performance and longevity of in-wheel motors. The enclosed nature of the wheel hub can make heat dissipation more challenging, necessitating the use of efficient cooling systems and materials with high thermal conductivity.

3- Structural Integrity

The integration of motors into the wheel hubs can place additional stress on the suspension and wheel components. Engineers must ensure that the structural integrity of these components is maintained, considering the added mass and forces generated by the in-wheel motors.

SELECTED APPROACH:

After checking all the details and specifications of both the approaches discussed we concluded that Approach 1 was the best approach, but we were compelled to use Approach 2 due to different financial constraints attached to Approach 1. Some of the comparisons of both the approaches are as below.

Balance while taking a turn:

Approach 1 is better in this regard as the weight is centered and COM is in the middle of the car, while in approach two it is spread towards the outer edges, and we know that a car is more balanced if its weight is centered as:

1. **Stability**: By concentrating the weight in the middle of the vehicle, the center of gravity is lowered. By decreasing the possibility of tipping or rolling over during sudden spins or maneuvers, this increases stability. Since the weight is distributed more evenly with a lower center of gravity, the car is less likely to tip over.
2. **Handling and Control**: The car responds to driver inputs more predictably when the weight is centered. Because of the more symmetrical weight distribution, it is simpler to steer and maneuver. During cornering, braking, and accelerating, it is simpler to retain stability and control since the automobile is less prone to exhibit extreme oversteer or understeer.
3. **Traction:** To maximize traction between the tires and the road surface, a balanced weight distribution is important. A more evenly distributed weight allows each tire to apply pressure to the road more uniformly, improving grip and

lowering the risk of slipping or skidding. This increases the car's total traction and makes it easier for it to maintain control under different driving circumstances.

4. **Comfort:** The suspension system of the car can function more efficiently when weight is distributed uniformly. It makes the ride for the passengers smoother and more comfortable by distributing road impacts and bumps more evenly across all four wheels.

Speed and Acceleration:

In approach 1, we used a gear ratio of 1:1.174 but in approach 2 we are using a gear ratio of 1 (No Gear box) due to which our theoretical maximum speed comes out to be around 105 kmph but due to high speed we have lesser torque to work with. This results in lower force being applied to the car to move forward. According to the total torque supplied (362Nm) by the two of the motors we can have a maximum acceleration of 5 m/s^2.

Motors Synchronization:

In approach 1, we were synchronizing the motors via a shaft. This would have counted for any difference in the rpms of the two motors and a smooth equal flow of power would have been done to the wheels. In approach 2, as the motors are being directly used in the hubs the motors having small rpm difference would try to rotate the wheels at different speeds which can result in the car skidding or trying to rotate in a certain direction. The car would try to turn slightly in the direction of the wheel which has lower rpm.

Cost:

In approach 2, we are not using any transmission system to transmit the power from the batteries to the wheels, but we are directly fitting the motors in the hub of the wheels. This helps in saving a lot of cost of material, operations, and equipment. So, in comparison we can say that approach two is a lot more economical than approach 1. We saved following costs by selecting the approach 2 instead of approach 1:

1. Shaft and hubs joining the two motors.
2. Chain-Sprocket System
3. Limited Slip Differential
4. Rear Axle shaft
5. Shock absorbers and holders to maintain the tension in the chain at an optimal value.

With all these costs reduced we were able to complete our deliverables at a lower cost. Which is the main reason we choose the 2nd approach over 1st.

CHPATER 5: CONCLUSION

The Formula EV Powertrain project aimed to develop an efficient and powerful powertrain for Formula EV, initially using a dual motor configuration and later moving to a wheel hub configuration. Through extensive design, analysis, prototyping and testing, the project successfully achieved its goals and provided valuable insight into the performance and feasibility of the two configurations.

The original two-motor design showed satisfactory performance and energy efficiency. However, certain limitations were observed in terms of weight distribution and complexity. Integrating two electric motors required careful coordination and control, adding complexity and weight to the system. Nonetheless, the dual-motor set-up yielded promising results, demonstrating potential for improved acceleration, torque distribution and overall vehicle dynamics.

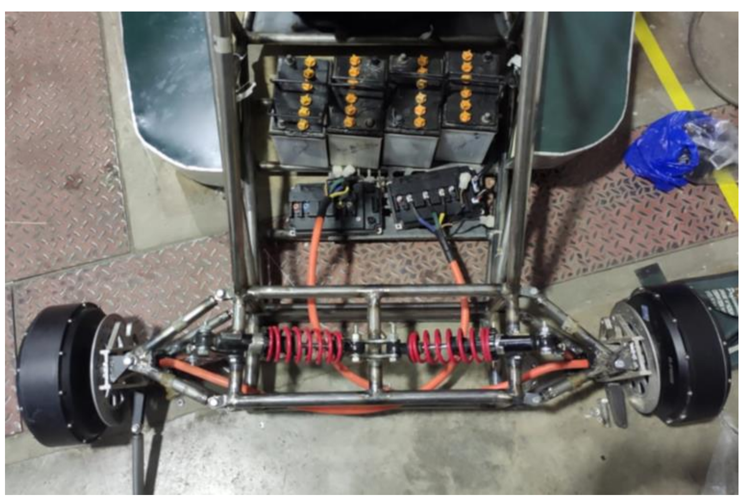

Figure 33: Final Powertrain Photo

The move to a wheel hub configuration turned out to be a key turning point in the project. Several advantages were realized by integrating individual electric motors directly into each wheel hub. The wheel hub design improves handling and maneuverability, reduces weight and improves energy efficiency through reduced gear losses. Eliminating complex mechanical components such as conventional powertrains and differential systems simplifies the powertrain and improves overall efficiency. In performance evaluations, the wheel hub configuration outperformed the dual motor configuration in terms of acceleration, cornering and overall vehicle dynamics. A direct motor-to-wheel connection provides instant torque response for improved traction and maneuverability. In addition, the lighter powertrain improves handling and allows for more precise control during high-speed cornering.

The findings and conclusions of this project will have a significant impact on future developments in the field of electric vehicle drive technology. The success of the wheel-hub configuration highlights its potential as a viable alternative to traditional dual-motor configurations. Further investigation and optimization are recommended to refine the wheel hub configuration, especially regarding control algorithms, thermal management strategies and structural integration. Focusing on these areas can lead to even greater performance gains, increased energy efficiency and improved overall vehicle performance.

Figure 34 : The Team Alif Car at Open House

The results of this project also highlight the widespread importance of electric vehicle propulsion technology. Advances in propulsion systems play a key role in achieving energy efficiency and reducing CO2 emissions as the demand for sustainable transportation increases. The Formula EV Powertrain project contributes to this ongoing effort by exploring innovative configurations and demonstrating the superior performance potential of electric vehicles. In summary, the Formula EV powertrain project successfully studied and compared dual motor and wheel hub configurations for Formula EV. The move to wheel hub construction has brought significant benefits in terms of performance, efficiency and driving dynamics. The results of this project will provide valuable insights and recommendations for future research and development in the field of electric vehicle powertrains and contribute to the further development of sustainable transportation solutions.

REFRENCES

[1] Yong, J.Y.; Ramachandaramurthy, V.K.; Tan, K.M.; Mithulananthan, N. A review on the state-of-the-art technologies of electric vehicles, its impacts and prospects. Renew. Sustain. Energy Rev. 2015, 49, 365–385

[2] Richardson, D.B. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renew. Sustain. Energy Rev. 2013, 19, 247–254.

[3] Romani, L., Vichi, G., Bianchini, A., Ferrari, L., Ferrara, G. "Optimization of the Performance of a Formula SAE Engine by Means of a Wastegate Valve Electronically Actuated", Energy Procedia, 101, pp. 654–661, 2016.https://doi.org/10.1016/j.egypro.2016.11.083

[4] Gwangmin Park, Seonghun Lee, Sungho Jin, Sangshin Kwak, Integrated modeling and analysis of dynamics for electric vehicle powertrains, Expert Systems with Applications,Volume 41, Issue 5,2014,Pages 2595-2607,ISSN 0957-4174,https://doi.org/10.1016/j.eswa.2013.10.007.

[5] Kuntzer, G., & Martins, M. E. (2015). Development of a FSAE Racecar cooling system. SAE Technical Paper Series. https://doi.org/10.4271/2015-36-0409

[6] 3000W 205 car motor. (2018, June 14). Bicycle Motor, Scooter Motor, Car Motor from QS Motor.

[7] What are the advantages of a mid-drive motor? (2022, April 12). Suzhou Shengyi Motor Co., Ltd. https://www.syimotor.com/what-are-the-advantages-of-a-mid-drive-motor.html

[8] Votol controller EM-100. (2020, October 24). Bicycle Motor, Scooter Motor, Car Motor from QS Motor. https://www.qsmotor.com/product/votol-controller-em-100/

[9] Zhang, Ronghui & Li, Kening & He, Zhaocheng & Wang, Haiwei & You, Feng. (2017). Advanced Emergency Braking Control Based on a Nonlinear Model Predictive Algorithm for Intelligent Vehicles. Applied Sciences. 7. 504. 10.3390/app7050504.

[10] SAE Transactions Vol. 80, SECTION 3: Papers 710368–710618 (1971), pp. 2175-2193

[11] RacingDiffs. (n.d.). Benefits of limited slip differential. https://racingdiffs.com/pages/benefits-of-lsd