DE-41 (DME)

YEAR 2023

NUST COLLEGE OF

ELECTRICAL & MECHANICAL ENGINEERING

DESIGN AND FABRICATION OF AN E-BICYCLE CONVERSION KIT

A PROJECT REPORT

DE-41 (DME)

Submitted by

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DECLARATION

We hereby declare that no portion of the work referred to in this Project Thesis has been submitted in support of an application for another degree or qualification of this of any other university or other institute of learning. If any act of plagiarism found, we are fully responsible for every disciplinary action taken against us depending upon the seriousness of the proven offence, even the cancellation of our degree.

ABSTRACT

The end of the 20th century saw the warmest decade ever on record. Typically linked to the increase in the use of fossil fuels for transport and energy generation, the phenomenon of global warming caught everyone's attention. Several studies predicting the earth's temperature to rise beyond bearable limits in future, since the start of 21st century have forced the concerned global institutions to enforce policies limiting the use of fossil fuels. The United Nations General Assembly has outlined a set of goals for a sustainable future for the nations to implement, to cut down the excessive dependence on fossil fuels. The transport sector alone is the world's largest consumer of fossil fuels. Therefore, globally it was agreed that a safer and cleaner mode of transport must replace the conventional fossil energy-based transport system. Thus, the start of the 21st century brought about a revolution in the transport sector. Subsequently, the implementation of Electric Vehicles (EVs) technology has been on the rise. Global automobile giants are in a competition to dominate the automobile markets with their EVs, courtesy to the support from respective governments. The evolution of EV technology is a welcoming step towards the goals of a sustained safer future.

A normal E-bicycle would cost somewhere between 600 to 1000 Dollars. Moreover, these factories assembled bikes don't provide the customer with the liability to install or remove the E-bicycle equipment according to their will. Thus, buying a dedicated E-bike is expensive.

This calls for an affordable alternative to these expensive electric bicycles. Therefore, this project aims at the design and fabrication of an "Electric bicycle conversion kit" that would allow its customers to convert their already available bicycles into electric ones within minutes. The kit comprises of the necessary components like a DC motor, a lithium-ion battery pack with battery management system, motor controller all packed inside a single kit at one place instead of them being installed at separate parts of a bicycle like in case of available electric bicycles. The kit would be easy to install and remove for its customers within minutes and would provide a sufficient distance to travel with one charge. Moreover, the kit would be integrable with the already available bicycles on the market and would cost a lot less than the available dedicated electric bicycles.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The transportation sector around the world is the single largest consumer of fossil fuels. Its dependance upon the different derivatives of petroleum used as fuels in different sorts of vehicles has been increasing with growth in the industrial sector as well as with the rise in human population. Derivatives of petroleum like petrol, diesel, and jet fuel combined are the heart of the global transport sector. The consumption of these fuels at ever increasing rates has been posing a huge risk to the Earth's atmosphere and its inhabitants directly and indirectly as well. These risks have been identified by scientists and researchers over time and the results presented at different platforms depict a grim picture of the Earth's future.

The chemical composition of fuels indicates carbon to be the major component. Therefore, when these fuels are burnt inside the Internal Combustion Engines (ICEs) to produce energy needed to perform the desired task, Carbon Dioxide is produced as a major by-product along with Carbon Monoxide, Nitrogen Dioxide, Nitric Oxide, Volatile Organic Compounds (VOCs) etc. All these by-products of burning carbon-based fuels are identified to be the primary pollutants damaging the environment. However, Carbon Dioxide emissions have been proved to be the major contributor aggravating the greenhouse effect and thus adding to the worsening situation of global warming.

Considering the results obtained by scientists and researchers, nations all around the world have been forced to revise their transport sector policies and to cut their dependence on carbon-based fuels. Several laws and regulations have been enforced globally to ensure that the consumption of carbon-based fuels is limited as much as possible.

Pertaining to the suggestions presented by scientists for a sustainable future, it was proposed that the ICEs based transport systems throughout the world should be replaced by a safer and cleaner transport system. Thus, this leads us to the start of the 21^{st} century which saw the start of a global revolution in the transportation industry. Nations started enforcing laws to replace the conventional ICE based means of transport with environmentally friendly electric vehicles (EVs). Policies are being formulated with the passage of time by the governments to promote the usage of EVs in place of ICE vehicles. Global automotive industries are switching to EV technology fast and new startups dedicated to EV productions are being set up.

Advancements in the EV sector is taking place at a rapid pace in the developed nations. Developing nations, like Pakistan still have a significant way to go before the EV technology becomes common. Pakistan has a large transport network, mostly run by carbon-based fuels. However, just like other nations, Pakistan has seen a slow yet a promising start to the EVs technology implementation journey. The local automotive industries are promoting electric bikes, rickshaws, and bicycles for daily life commute of the people. With the changes brought in automotive policies to make them EVs friendly, it is safe to say that Pakistan is now on the track to minimize its share of the global consumption of the carbon-based fuels.

A major portion of Pakistan's population has access to petrol powered motorbikes. Along with these, bicycles also hold their importance in society. This project aims at the development of an **e-bicycle kit** that can provide its customers with a cheap and easy alternative to expensive e-bicycles available in market and environment damaging traditional motorbikes. There is a demand for a reasonably priced e-bike conversion kit that would make it possible for individuals to travel effectively and securely. This kit must be economical for college students and others, many of whom already own bicycles, and ecologically friendly. Given that the conversion kit has installed safety features, it should be appealing to people who commute in urban areas. Lastly, those without extensive bicycle repair knowledge should have little trouble installing the kit.

The electric mode of transport involves an electric motor powered via a battery pack, instead of the conventional internal combustion (IC) based vehicle engines. Similarly, the electric bicycle kit to be developed in this project will also involve 4 basic components. These are mentioned as follows:

I. A DC motor
II. Rechargeable Li-ion battery pack to power the motor with the Battery Management System (BMS)
III. Motor controller
IV. Throttle and display system

1.1 Problem statement

With a population of more than 220 million people, Pakistan has a huge market for motorbikes as well as bicycles that are used by the people for their daily tasks. Almost all the motorbikes run on carbon-based fuel that depletes the environment. With bicycles, it becomes difficult to travel large distances, although they are environmentally friendly. Thus, it is the need of the hour to design a system that can not only convert the available bicycles to an electric powered platform but also provide a way forward to implement the same technology on motorbikes in future.

Modern E-bicycles can cost around 1500$. They are designed such that customers must buy these expensive bicycles without giving them the liability and ease to convert their own already available bicycles into an E-bike. The reason being the fact that such E-bikes have built-in electric bike equipment that is installed at different sections of the bike. Moreover, it is difficult for a lay man to install or remove this equipment when required.

To resolve these issues and to provide a cheaper alternate to buying expensive E-bikes to customers, this project specifically aims to design and fabricate a portable electric bike conversion kit that can easily be integrated on already available bicycles and provide the customers with a cleaner source of transport, cutting down their dependency on expensive and environment unfriendly motorbikes.

The kit would have all the required necessary equipment of an E-bike built into it and would be very easy for even a lay man to install or remove it at their own will.

1.2 Objectives

The objective of this project is developing an electric kit that can be integrated onto bicycles, thus providing a

- To design a reliable and safe electric bike kit.
- To make sure that the kit is integrable on already available bicycles.
- To keep the kit lightweight and easy to install.
- To develop the kit at economically friendly rates.
- To ensure that the kit can withstand different environmental effects and scenarios.

1.3 Scope

Pakistan is a major contributor to the global greenhouse emissions. The reason being the fact that almost all the modes of transport used are operated on carbon-based fuels. Most of society uses motorbikes and bicycles for daily use. Moreover, with the increase in fuel and automotive vehicles' prices, it is certainly difficult for the common working class to pay a hefty amount to acquire a motorbike and the fuel to power it. Therefore, a solution is needed that can not only counter the pricing factor but also provide a cleaner transport source.

Thus, the aim of this project is to design and fabricate an electric bicycle kit that is cost effective, user friendly and provides the customers with the liability to transform their normal daily life bicycles to electric bicycles within minutes. The kit would be integrable onto bikes already available and does not force its customers to buy a specific bike. However, one type of electric bicycle kit would be installed onto a bike according to which the kit is designed.

1.4 Expected results

Development of a portable, cost-effective, easy to install electric bicycle kit is to be expected at the end of the project. This kit would give its customers the liability to install it easily and convert their normal bikes to electric ones in minutes. The kit would provide a sufficient travel distance on one charge. Moreover, on the same terms, this kit can pave way for the development of similar kits for motorbikes as well soon.

CHAPTER 2

LITERATURE REVIEW

2.1EVs and future

“Electric Vehicles (EVs) are the future,” a sentence that has grabbed the attention of every person for quite some time, now seems to be becoming a reality. The developed nations have outlined their plans for a sustainable future, and the EVs are a major part of all such plans. Automobile giants around the globe have already started competing in implementing the “electric vehicles” technology. Therefore, every now and then, we hear news about the introduction of a new electric vehicle in the automobile markets.

The electric mode of transport involves an electric motor powered via a battery pack, instead of the conventional internal combustion (IC) based vehicle engines. This transition from conventional fossil energy-based engines to electric ones saw a rise ever since the phenomenon of global warming leading to rapid degradation of Earth’s atmosphere captured the attention of scientists. Based upon their observations, suggestions were made that the countries around the globe should start looking for ways to reduce their carbon footprints. In this regard, the conventional IC engines were found to be major contributors towards the increasing effects of global warming on the environment. Therefore, since the start of the 21st century there has been exponential growth in the EV sector and this trend is predicted to be taking over the transport industry just a few years from now. A glimpse of this trend is found readily in the developed nations, however there is still a long way to go for the developing nations before the EVs take over the ICE based vehicles.

2.1.2 EVs sector and Pakistan

Pakistan’s automobile market is saturated with the IC engine vehicles. Moreover, there is also a rise in the acquisition of hybrid vehicles amongst automotive customers. The Government of Pakistan introduced the Electric Vehicles Policy (2020-2025) [1], encouraging the local manufacturers to “go green” and to introduce new hybrid and electric vehicles. Along with this, the leading automobile manufacturers like Japan, South Korea and China have also identified Pakistan to be among the few nations having high potential for the growth of EV sector. Several new automobile manufacturers have entered the Pakistani industry with their EVs and hybrid vehicles. Some very prominent among these are the Chinese Changan Automobiles Limited, BYD, Jinbei along with the UK based manufacturer Morris Garages (MG). Moreover, Malaysia based Proton also has plans to introduce their EVs in the country. With the passage of time, increased development in the EV sector in Pakistan is the part of country’s plan to cut down its dependence on increased use of fossil energy in the transport sector and to strive for a cleaner and greener environment which will lead to a safe and sustainable future.

A significant percentage of the Pakistani nation uses motorbikes, scooters, and auto rickshaws for their daily life commute. However, there has never been any development to run such vehicles with electric power. Until recently, there has been a major increase in the tendency to do so. This development is supported by several new startups and industries that are trying to tap the motorbike and auto rickshaw markets by introducing their products with enhanced designs and excellent value for money as well. A few very noticeable and prominent such companies are "Jolta" International. They specialize in the production of not only E-bikes but also electric bike kits which can easily replace the IC engines and convert a previously petrol-powered bike to an electric one. Another startup named "Economica" also introduced their electric bikes and rickshaws with an additional feature to charge them via solar power as well. Similarly, "Sazgar" motors are also the part of the competition to capture the electric bikes and auto rickshaws market with their products.

2.1.3 E-bicycles and the case of E-bicycle kits

According to the GEOFERRYROSE, JENNIFER DILL (2012) [2], electric bicycles are becoming more prevalent in China but are still relatively uncommon in the United States. The conversations revealed a few potential demographic markets for e bicycles that would increase the number of people who ride bicycles, including women, older adults, and those with physical limitations. Owners of electric bicycles observed that they could go further distances and up hills without any trouble and arrive at a destination, like work, less sweaty and exhausted than a traditional bike would allow. These benefits could outweigh some of the typical barriers to riding across all socioeconomic groups. Most e-bike owners we spoke with used their machines to replace either riding human-powered bikes or driving a traditional motor car. Thus, concerns about health problems associated from inertias, pollution, and other open strategy issues that private automobiles bring may be addressed by e-bikes. If explicit techniques are anticipated to increase acceptance of e-bikes, further study will be needed to make that determination. The possibility of conflict arising between users of electric bicycles and conventional bicycles because of speed differences is concerning. Speed differences may or may not be a significant problem, depending on the riders' characteristics as well as the variety of e-bikes available.

Even though electric bicycles might be riskier than conventional bicycles, the design of this e-bike conversion kit contributes to increasing the safety of e-bikes. Cyclists will be more alert of threats and barriers if safety elements like sensors, lights, and sound are added. For individuals who still desire the capability of an e-bike, the product will be a secure substitute for standard e-bikes. An e-bike also encourages users to exercise more than a regular bicycle does. Users will be encouraged to ride their e-bikes more frequently thanks to the design, which makes it easier for people to ride bicycles in the short term and supports the promotion of a healthy lifestyle. This design offers a more environmentally friendly and cost-effective means of transportation while also addressing safety issues with current e-bikes.

Many bike shops have noticed a sharp increase in bike sales during the COVID-19 pandemic. E-bikes are becoming more and more common as people look for new ways to commute that don't involve using public transportation. E-bikes encourage people to exercise more frequently. According to studies, people who use e-bikes spend more time exercising on their bikes than those who use standard bicycles. Additionally, e-bikes provide a more environmentally sustainable form of transportation for distances too far to walk on foot.

Modern e-bikes cost about 600-1000$, however there are less costly options, such as "E-bicycle conversion kits." By attaching a motor and battery to the bicycle, a conversion kit may turn a regular bicycle into an electric one. There is a demand for a reasonably priced e-bike conversion kit that makes it possible for individuals to travel effectively and securely. This kit must be economical for college students, many of whom already own bicycles, and ecologically friendly. Given that the conversion kit has safety features that prevent cyclists from colliding with cars, it should be especially appealing to people who commute in urban areas. Lastly, those without extensive bicycle repair knowledge should have little trouble installing the kit.

2.2 Introduction to E-bicycle kit

In this chapter, information about the different components of the E-bicycle kit will be discussed one by one. The electric mode of transport involves the use of a power source in the form of a battery pack to run an electric motor that in return runs the bicycle. Modern electric bikes use a brushless DC motor (BLDC) in place of traditional DC motors. BLDCs also involve an additional motor controller for smooth operation. Apart from these, an E-bicycle kit also has a throttle and a display system to indicate battery levels and other information to the riders. This chapter will focus on different studies regarding E-bikes available and upon the above-mentioned components of the E-bike kit that this project aims for.

2.2.1 The Motor

According to our objective, we want to develop an efficient and economical E-bike conversion kit. Therefore, considering this aim, we want to select reliable and efficient components for the project. Every component has its own role in the performance of the whole system. One of the central components for any EV is the electric motor. Motor is a central power providing component and act as an engine for EV. The whole efficiency and reliability of an EV system is directly dependent on the type of motor used. Other than efficiency, the safety of the system also depends on the performance of the motor. Considering the importance of motors, we study all types of available motors and try to select the best choice. The motors which are studied for this project are:

1. Induction motors
2. Simple DC motors
3. BLDC motors (Brush less DC).

These types of motors are easily available and can be used in any electric bike. These all produce rotational energy for the system, but their properties are not the same. These properties include torque, speed, frequency, resistance to disturbance, etc. These properties decide the selection of motor for specific situation. Moreover, the type of electrical supply which is needed for the motor also depends on the type of motor used. Induction motor needs alternating current supply, while simple DC and BLDC motor operate on direct current.

Induction motor

A motor needs alternating current and used for many daily life applications. In induction motor, rotor speed lags the speed of the magnetic field in the state. This phenomenon is called slip. Initially, induction motor needs high current and have low torque [3]. When it reaches its full speed, then it gives more torque with small slip and low current. The rotor and stator of the induction motor have prominent size, therefore the output power to size ratio of the motor is high.

DC motors

This type of motor needs direct current and is used for many applications such as industrial, automotive, and domestic. It has moderate output power to size ratio. The output torque of DC motor is inversely proportion to angular speed of the motor. These motors consist of carbon brushes which provide voltage supply connection to rotor. These brushes come physically in contact with rotor.

BLDC

Brush-less DC motors are the advanced type of motors used for many applications such as automotive, industrial, aerospace, etc. This type of motor doesn't have contacting brushes. Due to the absence of the brushes, it has low noise and low power dissipation [4]. Because of no wear and tear, it has more life as compared to common DC motor. It has a permanent magnet on the rotor. Ferrite magnets are mostly used to make permanent magnets on the rotor.

Two methods are used to detect the position of the rotor in BLDC motor. One method uses position sensors for the detection of the rotor. The most popular sensors are used in BLDC Hall sensors. These sensors are mounted on the stator of the motor which detect the position of rotor and send signal to controller. The controller then decides the required current for the motor. The second method is sensor less in which no sensors are used. This method is used in applications where the motor is enclosed in a housing and there requires no electrical entries such as compressors or when the motor is immersed in liquid. BLDC sensor-less motor monitor Back EMF coming from the rotor and take decision. However, BEMF is directly proportion to the speed of rotor; therefore, under very low speed another detector is also connected such as BEMF amplifier [5].

2.2.2 The Battery pack

The heart of the electric bike would be the battery pack that would provide power to the BLDC. It is a fact the most expensive part of an e-bike is the battery pack. In comparison to the older versions of batteries, which were lead acid or Nickel Cadmium based, the latest and modern batteries are lithium-ion ones.

The reason being that Li-ion batteries can be recharged repeatedly and have a lesser self-discharge rate than the lead acid or Ni-Cd batteries [6]. Moreover, Li-ion batteries offer a higher energy density along with a higher voltage capacity as well. Apart from this, the Li-ion batteries require less maintenance. The Li-ion battery packs are made by connecting multiple smaller cylindrical shaped Li-ion cells. These cells can be found in different shapes and sizes, but usually cylindrical ones are preferred. These cells are safer and dependable than types found in the market. An additional requirement with the Li-ion battery pack is of a battery management system (BMS). The BMS serves a particularly important purpose. It prevents the individual cells inside the pack from getting overcharged. Also, it prevents over-discharging of the cells, thus increasing battery life.

This project also involves the use of small multiple Li-ion cells which will be brought together to make a single rechargeable battery pack. The purpose of using small cells is to keep the size of battery pack limited and according to the shape and available space to install the kit on the bicycle.

The capacity of the pack will depend upon the power requirements of the motor and how much range is to be expected. However, to keep the weight to a certain limit, battery pack will also fall within a certain weight and size range.

2.2.3 Motor Controller

A motor controller is also a critical part of the E-bike kits. In conventional DC motors, the carbon brushes provide a link between the stator and rotor of the motor. This link provides a passage for the current to flow through. But, since a BLDC does not have these brushes, it cannot be directly connected to a battery pack. This requires an additional motor controller. Apart from this, the motor controller does the following jobs as well.

- It adjusts the voltage to the motor according to the throttle position set by the rider.
- The BLDC cannot rotate unless the motor windings are supplied with a three phase AC. The controller converts the DC voltage coming from the battery pack into the required three phase AC by the motor windings for the normal rotation operation by motor.

2.2.4 Data display and throttle

To give the liability of increasing or decreasing the speed of the bike to the rider, a throttle is added at the normal bike grip position. It has also been decided to include some data displays in this system. These displays will show the speed of the motor and battery information to the riders.

CHAPTER 3

DESIGN PROCESS

3.1 Motor power calculations

Determining the required motor power is the first significant step throughout the whole design process. Literature review suggests that the required motor power to be determined is based upon the total load the bicycle is to carry as well as some other parameters. The power required is determined by finding the total resistive force resisting the motor propulsion force. The major resistive forces in motor power calculations include the rolling resistance, the aerodynamic drag, and the resistive weight component (on an inclined surface).

Figure 3.1 depicts the scenario when the bicycle is moving uphill at an inclined surface having slope α.

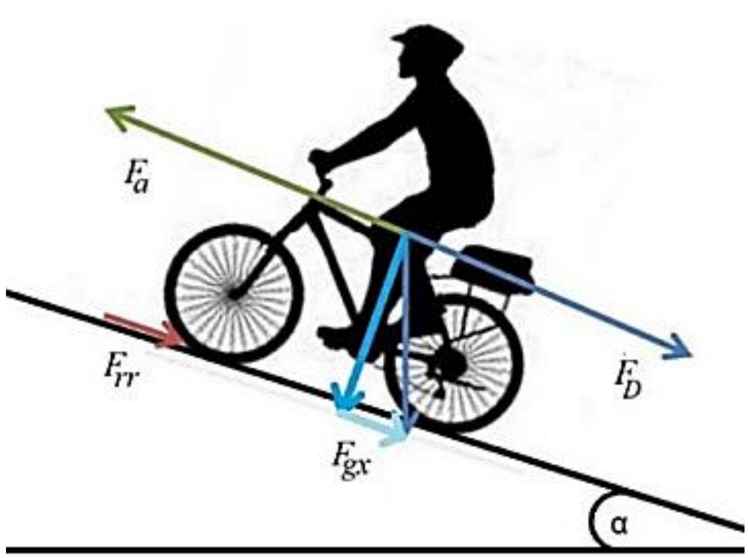

Figure 3.1: Resistive forces and components

The forces shown on the diagram are.

- F_a = Motor Propulsion force
- F_D = Aerodynamic drag force

- F_{rr} = Rolling resistance
- F_{gx} = Resistive component of weight

The rolling resistance force is determined as

$$\boldsymbol{Frr = mg\ Crr\ cos}(\boldsymbol{\alpha})$$

Where, C_{rr} = Coefficient of rolling resistance (0.004 for asphalt road)

The aerodynamic drag force is determined as

$$\boldsymbol{FD = 1/\ 2\ \rho v\ 2Cd\ Af}$$

Where, C_d = aerodynamic drag coefficient (0.7 - 1.0), ρ is air density (1.23 kg/m^3 at sea level), A_f is frontal area, v is vehicle speed.

The resistive component of the weight on inclined surface is determined as

$$\boldsymbol{Frr = mg\ sin}(\boldsymbol{\alpha})$$

The total resistive force resisting the motor propulsion force when bicycle is moving uphill is simply the sum of all three resistive forces.

$$\boldsymbol{Ftotal = FD + Frr + Fgx}$$

The aerodynamic drag can be neglected at low speeds.

The required motor power is calculated as

$$\boldsymbol{P = Ftotal * v}$$

Where v is desired velocity of bicycle under motor propulsion.

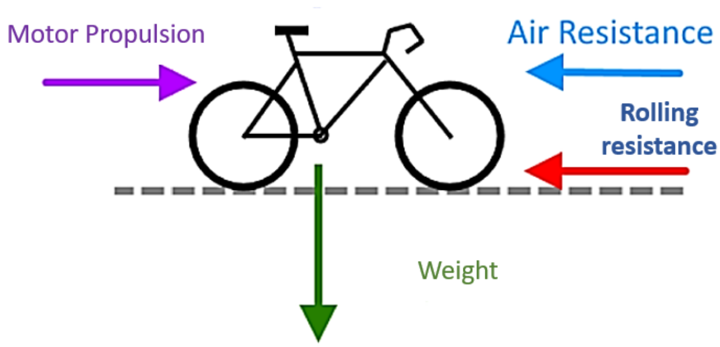

Figure 3.2: Forces on bicycle

For the flat surface scenario, we will calculate the required power for the motor by simply taking the inclination angle α as zero. This implied that the resistive component of weight approaches zero. Therefore, a major portion of the required power is taken away by the removal of the resistive weight component. in this case the total resistive force is determined as,

$$\boldsymbol{Ftotal}\ (\boldsymbol{\alpha} = \mathbf{0})\ =\ \boldsymbol{FD}\ +\ \boldsymbol{Frr}$$

The required motor power is then determined for a desired velocity v on flat surface as,

$$\boldsymbol{P}\ =\ \boldsymbol{Ftotal}(\boldsymbol{\alpha} = \mathbf{0})\ *\ \boldsymbol{v}$$

It is to be noted that the power requirement on the flat surface is different than that on inclined surface. Thus, if we select the motor based upon the flat surface calculations, the velocity of the cycle will reduce when travelling on inclined surface to compensate for the additional resistive weight component.

Before calculating the power of the motor, it is necessary to know about the type of cycle being used, the road on which the cycle will run and how much speed is desired.

For this cycle, the general weight limit is set to maximum of 130kg. The standard road grades according to the GTA 308 (Global Transport Atlas) in the US are:

Maximum road grade = 4% to 6% = 2.5 to 4 degrees

When a cycle runs on a **flat horizontal road**, the resistive forces are aerodynamic drag F_d and rolling resistance force F_{rr}.

Total resistance force being faced on flat surface is:

$$\boldsymbol{Ft} = \boldsymbol{Fd} + \boldsymbol{Frr}$$

3.1.1 Rolling resistance:

The force due to rolling resistance is:

$$Frr = Crr * N = Cmg$$

Where C is the rolling resistance coefficient. Its value can be found from the rolling resistance chart. From the chart, as we have selected asphalt road, therefore value of C is,

$$C = 0.004$$

Table 3.1: Rolling resistance coefficient values

Rolling Resistance Coefficient		
c	c_1(mm)	
0.001 - 0.002	0.5	Railroad steel wheels on steel rails
0.001		Bicycle tire on wooden track
0.002 - 0.005		Low resistance tubeless tires
0.002		Bicycle tire on concrete
0.004		Bicycle tire on asphalt road
0.005		Dirty tram rails
0.006 - 0.01		Truck tire on asphalt
0.008		Bicycle tire on rough paved road
0.01 -0.015		Ordinary car tires on concrete, new asphalt, cobbles small new
0.02		Car tires on tar or asphalt
0.02		Car tires on gravel - rolled new
0.03		Car tires on cobbles - large worn
0.04 - 0.08		Car tire on solid sand, gravel loose worn, soil medium hard
0.2 - 0.4		Car tire on loose sand

3.1.2 Aerodynamic Drag

The aerodynamic drag force is given by:

$$FD = 1/2\ \rho v\ 2Cd\ Af$$

Where Cd is the coefficient of drag. Cd ranges from 0.7 – 1.0. ρ is air density (**1.23** kg/m^3 at sea level). A_f is **frontal area**. And v is the speed of drag.

For determining the front area of bicycle, consider the figure below.

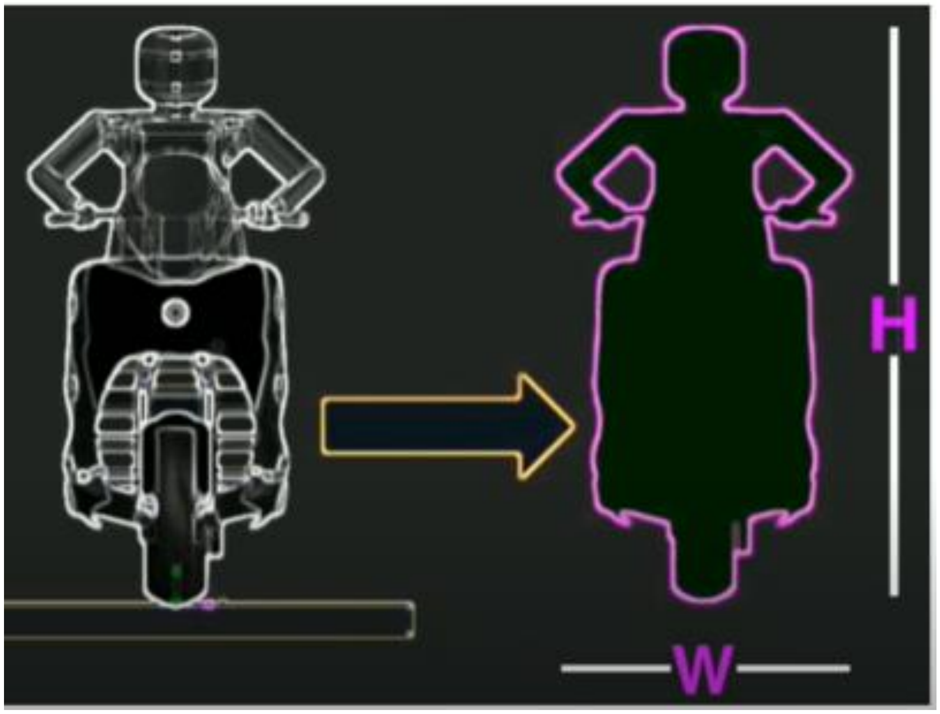

Figure 3.3: Normal area to drag force

Let,

W = Length of handlebar

H= Height of bicycle from ground to helmet

There is also a correction factor involved in the frontal area.

So, the frontal area is:

A_f = (W*H) * Correction factor

The frontal area is approximated as 0.4m^2 for crouched cyclist, 0.6m^2 for upright cyclist and bicycle. And for bicycles, the correction factor is about 0.70.

3.1.3 Calculation of required motor Power

For power calculations, we must know the actual total load the bicycle will have to lift and the max speed the bicycle would achieve under that load. We performed power calculations for a load of 130kg and a top speed of 25Kmph on a flat road. The results are given below.

The aerodynamic force found using the above given formula was.

$$FD = 17.77\ N$$

The rolling resistance force found using the above given formula was.

$$Frr = 5.101\ N$$

Thus, the motor power calculated using the total resisting force is given below.

$$P = 158.72\ watts$$

Using this power value, we calculated the maximum speeds the bicycle could attain on a graded surface. This was done for a slope (α) of 5 degrees and 7 degrees. The results are attached below.

$$\alpha\ =\ 5\ degrees, V = 4.28\ kmph$$

$$\alpha\ =\ 7\ degrees, V = 3.24\ kmph$$

Now these velocities are not such that a smooth easy uphill ride can be achieved. Thus, we resorted to motor of 250 watts and same load of 130kg and again found the maximum velocities that can be achieved on flat road as well as for a 5- and 7-degrees slope. The results are shown below.

$$Flat\ road\ maximum\ velocity\ v = 39.34 kmph$$

$$On\ graded\ surfaces\ when,$$

$$\alpha\ =\ 5\ degrees, V = 6.69\ kmph$$

$$\alpha\ =\ 7\ degrees, V = 5.04\ kmph$$

However, now the velocities achieved with 250 watts are enough to ensure a smooth uphill ride with the max load of 130 kgs. Moreover, the velocities of e-bikes are limited to 25km/hr according to EN 15194 Safety Guidelines and thus the motor controller implements this limit effectively. Depending upon these calculations, we have decided to choose a motor of 250 watts.

3.1.4 Calculation for torque

Torque is the ability to turn a wheel. It is given by:

$$P = \frac{2\pi NT}{60}$$

Where N is the speed of motor in rpm and P is the power.

3.2 Battery Pack

The battery that we selected is the Lithium cells integrated together to make a battery pack. Cathode, anode, and electrolyte are the three electrodes used in lithium-ion batteries. In a battery that is discharging, the cathode is positive, and the anode is negative. The anode is made of porous carbon, whereas the cathode is made of metal oxide. When in discharge mode, ions go through the electrolyte and separator from the anode to the cathode; when in charge mode, ions move in the opposite manner from cathode to anode. [9]

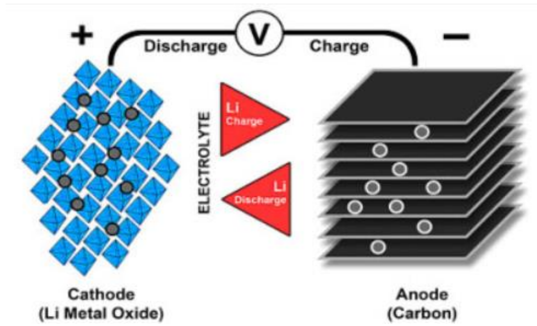

Figure 3.4: Ions flow in lithium battery

Ions move back and forth between the cathode (positive electrode) and anode during cell charging and discharge (negative electrode). The anode experiences oxidation, or the loss of electrons, during discharge, whereas the cathode experiences reduction, or the gain of electrons. Charge turns the motion around.

3.2.1 Advantages

- Power Cells have a high specific energy and high load capacity.
- Extended shelf life and long cycle; no maintenance.
- Excellent coulombic efficiency, low internal resistance, and high capacity.
- Reasonable charging times and a simple charge methodology.
- Minimal self-discharge (less than half that of Ni-Cd and Ni-MH).

3.2.2 Limitations

- Protection circuit is necessary to stop thermal runaway in a strained situation.
- When kept at high voltage and at high temperatures, it degrades.
- No quick charging is feasible at 0°C, 32°F, or below.

3.2.3 Calculations

The total power of the DC motor is,

$$P = 250W$$

Voltage required to run DC motor is,

$$V = 36V$$

Therefore, the current I from will be,

$$I = P/V$$

$$I = 250/36$$

$$I = 6.94A$$

The assumed time for the battery working to run is,

$$t = 3hrs$$

Therefore, the battery capacity is,

$$Capacity = I * t$$

$$Capacity = 10.4 * 3$$

$$Capacity = 20.82\ AH$$

From the market and online platforms such as Daraz.com, pkmart.com, the available **Li-ion** cell has a voltage ranging from 3.6V to 3.7V with a capacity of 2.0 AH. The diameter of the cell is 1.8cm and height of 6.5cm [1].

The price of a Li-cell available is Rs.250.

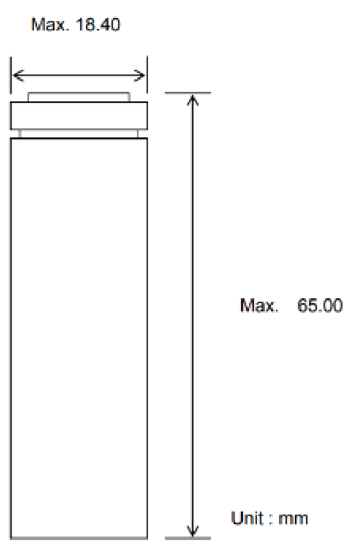

Figure 3.5: Dimensions of single cell

So, as the motor requires voltage of 36V and capacity of 20.82AH, the required number of Li-cells will be as follows.

As the single lithium cell has an energy capacity of 2.0Ahr.

The required power for the operation is about 20.82AH.

As for the safety of the battery, it should be operated above a certain charged level. Because its life can be affected when it is operated in a condition in which it is emptied completely. The following figure shows the relationship between the depth of discharge and the expected life of the battery [9].

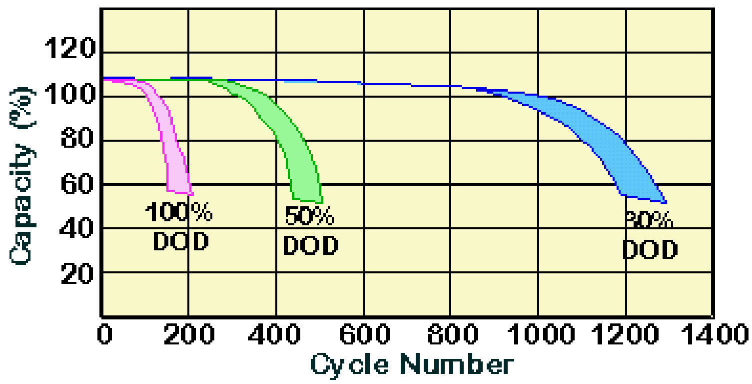

Figure 3.6: Depth of battery discharge and the number of possible cycles

To avoid 100% depth of discharge, we will use some factor of safety. Therefore, for safety purposes the operation time should be less than 3 hours.

$$\text{Number of required cells in series} = \frac{36\text{V}}{3.6\text{V/cell}} = 10$$

$$\text{expected No of total cells} = 20.82/2 = 10$$

Considering the group of 7 cells in series, the possible number should be.

$$\text{Total No of cells} = 10$$

After the above calculation, the battery pack will have two groups' cells. Each group will have 10 cells in series and both groups will be connected parallel to each other. The following pattern shows the alignment if cells in battery pack.

Therefore, the total estimated **cost** of 20 Li-cells is Rs.8500.

3.3 The sprockets

3.3.1 Purpose of Sprocket

A sprocket is generally used in bicycles to pull a linked chain to convert the motion of rider's feet into the rotating motion of bicycle's wheel. Basically, it is a type of wheel with multiple teeth that can mesh with a chain and get attached to it. It is different from the gear as it can never be meshed, and it is also different from the pulley as sprocket has teeth. Sprockets are designed to bear heavy torque. Sprockets with more teeth can move a heavier number of weights but they produce more friction which lowers the operating speed. Sprockets are designed for use with a specific chain. Every chain is identified by the **pitch**. Pitch is the size of chain. **The pitch** of a chain can be defined as the distance between the center of one pin to the center of the next pin.

3.3.2 Difference between Pulley and Sprocket

It is also different from the pulley as sprocket has teeth. A pulley is a wheel with a groove in which a rope or cable can ride unlike sprockets that are designed to be used with specific chain or belt.

3.3.3 Classifications of Sprocket

Sprockets are characterized by the type which indicates the hub style.

Type A sprocket:

Type A sprockets are flat plates with no added thickness or hub. They are mostly mounted on the flanges or hubs of the machines they are driving through a series of holes that are plan or taper.

.

Figure 3.7: Type A sprocket

Type B sprocket

Type B sprockets are sprockets which have hubs on one side. This helps the sprocket to fit closely to the machinery on which it is mounted as well as reduces a large overhang load on the bearings of the equipment.

Figure 3.8: Type B sprocket

Type C sprocket

Type C sprockets are type of sprocket that have hubs of equal thickness on both the sides of the sprocket plate. It is usually used in such applications where the pitch diameter is more and there is more weight to support on the shaft. Larger loads require bigger hubs.

Figure 3.9: Type C sprocket

Type D sprocket

Sprocket with a detachable bolt on hub attached to a plate. The sprocket is easily splinted for removal and bolted to the hub. No need to remove bearings and other components because without it the speed ratio can be changed.

Figure 3.10: Type D sprocket

3.3.4 Types of Sprockets based on their function:

1.Roller Chain Sprocket

Roller Chain sprockets are one of the most common types of sprockets. They are found working with the specific chain that are interconnected by the pins. Each chain is designed to have a specific sprocket. Roller chains have a gap that fits the teeth of the sprocket in order to transfer the rotatory motion. A roller chain sprocket usually connects two sprockets. Roller chain sprocket is usually used in bicycles where sprockets on two different wheels are connected by the chain. They are mainly used in transmission equipment applications [3].

Figure 3.11: Roller chain sprocket

2.Sprockets used with motor shafts

Sometimes sprockets are also installed on the shaft of the motor for power transmission purposes.

3.Idler Sprocket

Idler Sprocket is used where long lengths of the chain and chain are not held tightly held in the position. It is used to prevent chain slack due to long lengths. Idler sprocket is also used to prevent unequal load distribution. An idler sprocket can be used as chain tensioner. Idler Sprocket are also used where there is a nonadjustable drive shaft.

Figure 3.12: Idler sprocket

4. Rum sprocket

These sprockets are referred to as the stronger and thicker sprockets which focus is to lower the contact pressure through the increased surface area. Drum Sprockets are used for heavy duty and industrial application.

5. Industrial sprocket

Industrial sprockets are usually made from graded stainless steel, cast iron and mild steel as they are responsible for giving high tensile strength. They are generally used with timing belts that have flanges to keep the timing belt centered.

Figure 3.13: Industrial sprocket

6. Steel split sprocket

Many sprockets are required by loosening the chain, putting the sprocket and tightening the chain again. As a steel spit sprocket consists of two parts that are split through the center and are bolted back together helping easy fitting into the system

Figure 3.14: Steel split sprocket

7. Multi strand sprockets

Multi Strand sprockets are used where high torque and power are required or two or more items are being driven by a drive shaft. These are available with 40 to 160 chain pitches with plain, finished, taper- locked style hubs.

8. Single Pitch and Double Pitch Sprocket

Pitch sprockets are available with single pitch and double pitch sprocket. The two sprockets are different in function. Single pitch sprockets have teeth that allow the chain roller pin to fall into each tooth. On the other hand, double pitch sprockets have teeth that allow the pin to fall into each gap. It is commonly used in conveyor systems.

3.3.5 Technical terms

Number of teeth

The total number of teeth on the sprocket are of an important measure and concern. Ideally sprocket must have a minimum of 19 teeth. One must check the tooth pitch before selecting the sprocket so that the sprocket gets the right fit for the chain's pitch.

Bore

The hole through the center of the sprocket is called bore. Bore size holds an important consideration when designing a sprocket. One must ensure that the selected sprocket does not have a sprocket bore which is too small or too large to fit.

Caliper diameter

It is responsible for measuring the diameter of the sprocket without including the teeth. In case if there is a broken teeth or the sprocket is worn out then caliper diameter is the only way to identify the dimensions of the sprocket

Tooth pitch

Tooth pitch refers to the number of teeth per inch.

Length through bore (LTB)

Length through bore refers to the thickness of the sprocket. It also refers to the inside hub diameter and the length to which it is machined. It is also important in determining the actual length of the rotating shaft.

Outside diameter

Outside diameter is measured from the highest point of the sprocket teeth. It is measured from the peak of the tooth sprocket on one side to the peak of the tooth sprocket on the other side.

Bottom diameter

The diameter from the lowest points between the teeth on the sprocket is called bottom diameter.

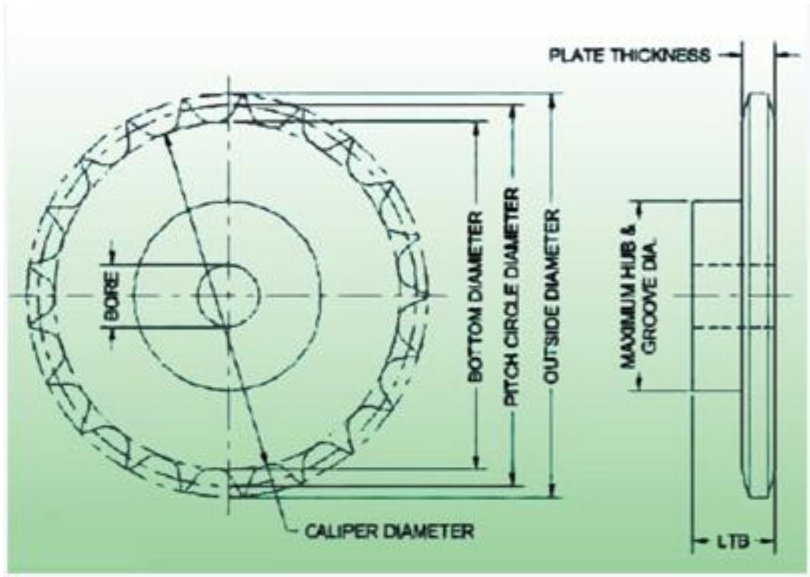

Figure 3.15: Basic terminologies of sprocket

3.3.6 Mathematical calculations

It is most important to connect the system with the chain of bicycle. For this connection, a small sprocket should be engaged with the chain between the pedal and rear wheel. After analyzing the dimensions of the bicycle, it has been concluded that the available space for the sprocket has the capacity to have a maximum diameter of 22mm. Considering this limit, the sprocket should have a diameter below this limit.

According to the book **Shigley's Mechanical Engineering Design.**

$$\boldsymbol{Sin}\left(\frac{\gamma}{2}\right) = \frac{\left(\frac{p}{2}\right)}{\frac{D}{2}}$$

Where **D** is the pitch diameter and **P is** the pitch of the sprocket.

Or we can say:

$$D = (p)/\,(\boldsymbol{Sin}(\gamma/2))$$

Since,

$$\gamma = \frac{(360\,°)}{N}$$

We can say:

$$D = (p)\ /\ (\boldsymbol{Sin}(180°/N))$$

Where N is the number of teeth on the sprocket.

Suppose if we have a sprocket with pitch diameter (D) = 50.664 mm and pitch (p) = 6.35 mm

Substituting the value of pitch diameter and pitch in the above formula we can calculate the number of teeth on the sprocket.

$$50.664\ mm\ =\ (6.35\ mm)\ /\ (\boldsymbol{Sin}(180°/N))$$

Total number of teeth N = 25

Hence the above formula is very useful in calculating the number of teeth if we know the pitch diameter and pitch of the sprocket.

CHAPTER 4

DESIGN AND MODELLING

4.1 <u>Initial ideation phase</u>

In a design process, focus lies around the main objectives of the project. After focusing on the objectives of the project, different methods, and positions for the placement of final system have been proposed. One of the objective of the project is to avoid any modification to the bicycle. After designing the specifications of the system, the project faces a challenging stage. This task is too challenging due to the limited freedom available in the design of Sohrab bicycle. After studying different possibilities of mounting the kit on Sohrab cycle, some suggestions were proposed. These methods are given below.

4.1.1 <u>First Method</u>

In this method, the main housing with the kit components will be placed in the central space below the rider. Due to the limited space available near the paddle, a chain sprocket mechanisms will be extended from the motor, and it will be attached to the sprocket. The component's housing and chain sprocket linkage will be inside a single case.

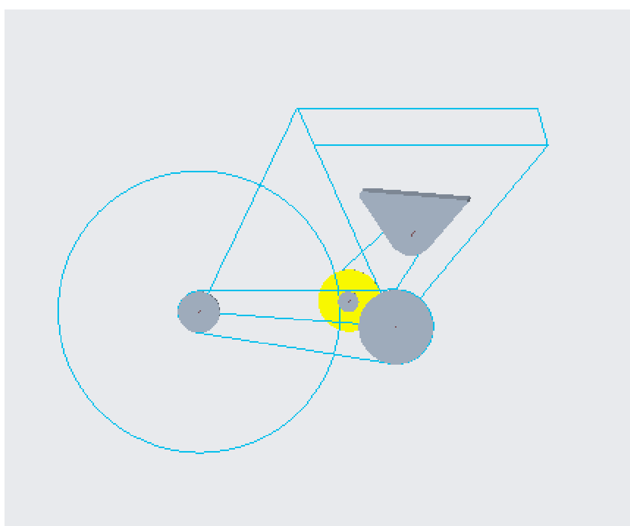

Figure 4.1: Proposed Method 1

4.1.2 Second method

In this design the kit will be directly attached to the rear portion of the frame and direct power transmission will take place from motor sprocket to the chain of bicycle. In this method we will have more free space available. But here the fitting of the system is challenging.

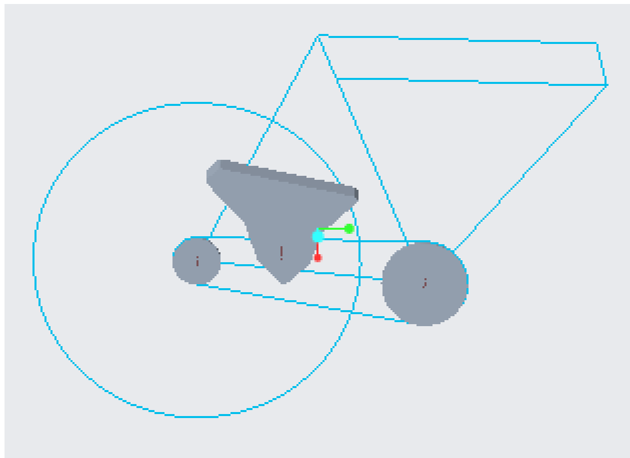

Figure 4.2: Proposed Method 2

4.2 CAD modelling

To have a clear view of the components inside the kit and their locations along with the kit housing designs, it is important to have a CAD model of the kit. The CAD models shown here will first describe the possible designs of the kit for a mid-drive and rear drive scenario respectively. Followed by the possible locations where the kit can be installed on the bicycle frame. This clears the path for fabrication phase and thus helps in smooth progress.

To get clearer picture of the above planar views pointing towards the possible locations on the bicycle where the kit can be installed, it is important to have 3D models of the scenarios. For this purpose, 2 modelling software, namely SolidWorks and Fusion 360, were used. Since design is an iterative process, the models which were being made using these software at this stage is yet not finalized and subject to changes once they are being tested in the next phase of the project.

So far, the 2 proposed possibilities for installing the kit are at the mid-section of the cycle and at the rear wheel. The driving mechanism in both cases would be having a connection of the sprocket mounted on the motor shaft with the bicycle chain. Apart from this one other possibility is to have a dedicated sprocket mounted at the rear wheel's hub or at the center paddle shaft and have a separate chain running from this sprocket to the motor shaft directly.

The first suggestion that was analyzed was focused at having an idler or tensioner sprocket along with the sprocket mounted on the motor shaft. The idler sprocket would induce a tension in the bicycle chain first and the chain would then pass over the sprocket mounted on the motor shaft. Thus, this would uphold the basic and the foremost important goal of the project that is not having a permanent or any change in the bicycle itself.

The CAD models of the 2 scenarios for kit designs and consequently the possible locations of kit installation are shown below in the pictures.

4.2.1 Kit design

Before moving towards the phase of designing the kit installed at the different possible locations on the bicycle frame, it is necessary to have a design of the kit housing with the components of the kit. This will give us a fair idea about the possible positions of the battery, motor, controller inside the kit and thus simplifies the fabrication phase by providing a clear roadmap. For this reason, the kit was designed on SolidWorks. There seems to be two design possibilities for the kit. One is for the kit being placed at the center of the bicycle frame between the rider's legs. While the other is the kit being attached at the rear wheel hub. In the second case, there seems to be more room available for installation of the kit easily. The two designs for the kit housing are shown below.

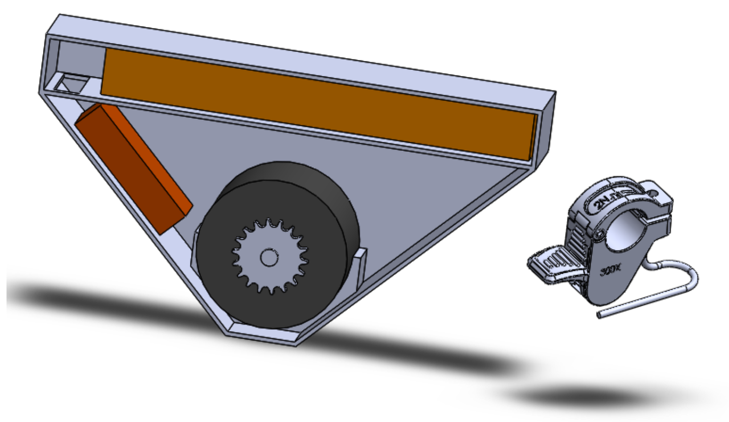

Figure 4.3: Isometric view of kit for mid drive case

The mid drive kit is also a good option since we have the frame supports available to hold the kit housing in place well. However, the other possibility is to be evaluated as well and the final decision is to be made after analyzing the available spaces and the feasibility of the mechanism developed using both types of kit designs. The other kit design when kit will be mounted close to the rear hub is also shown below.

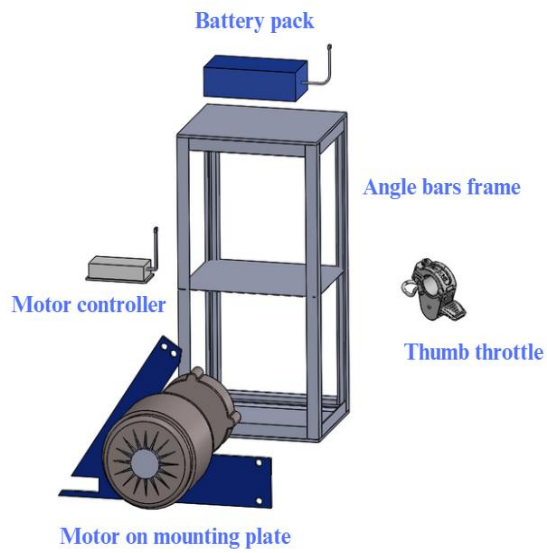

Figure 4.4: Isometric view of kit for rear drive case

4.2.2 <u>Design type 1</u>

As evident, this design focuses on making use of mid-section of the bicycle. The driving mechanism would be the one mentioned above that involves the use of an idler sprocket along with the main sprocket. However, this design is also subject to changes depending upon the availability of the space between the rear wheel and the bicycle frame. The design was made on Fusion 360.

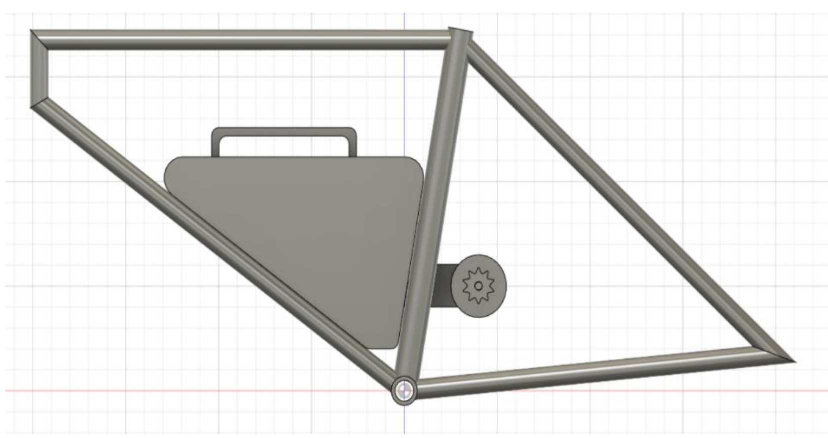

Figure 4.5: Front view of design type 1

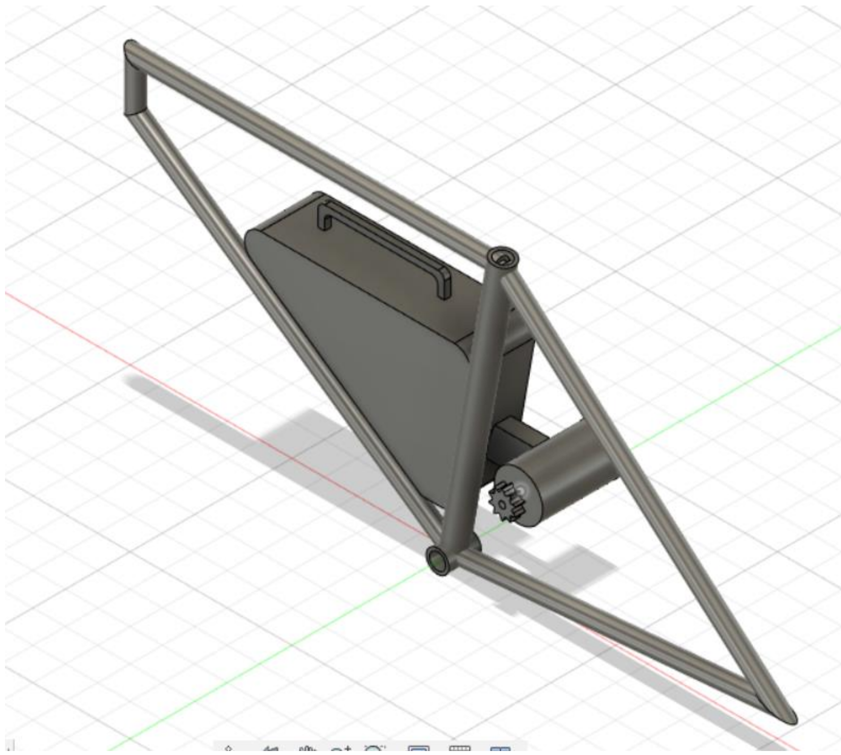

Figure 4.6: Isometric view of design type 1

4.2.3 Design type 2

This design involves the placement of the kit at the rear wheel of the bicycle. The driving mechanism is the same as described above. This design allows the rider to have more space available than the first design type at the mid-section of the bicycle. The idler induces the tension in the chain and the chain goes over the motor sprocket without slipping that is chain wrap is not encountered. The design was done on SolidWorks.

Figure 4. 7: Front view of design type 2

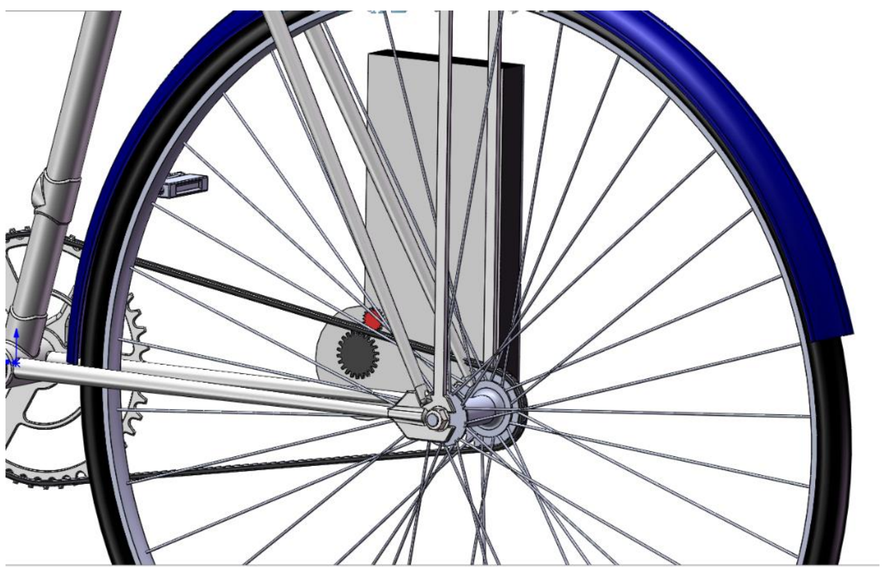

Figure 4.8: Isometric view of design type 2

4.2.4 <u>Design type 3</u>

This design is different from the other 2 as the driving mechanism here involves use of a dedicated sprocket being mounted on the center paddle shaft and a separate chain smaller in length running from this sprocket to the sprocket on motor shaft. This design, however, will be worked upon only if it is confirmed that this will not involve any changes to the original structure of the bicycle. This model is also made using SolidWorks.

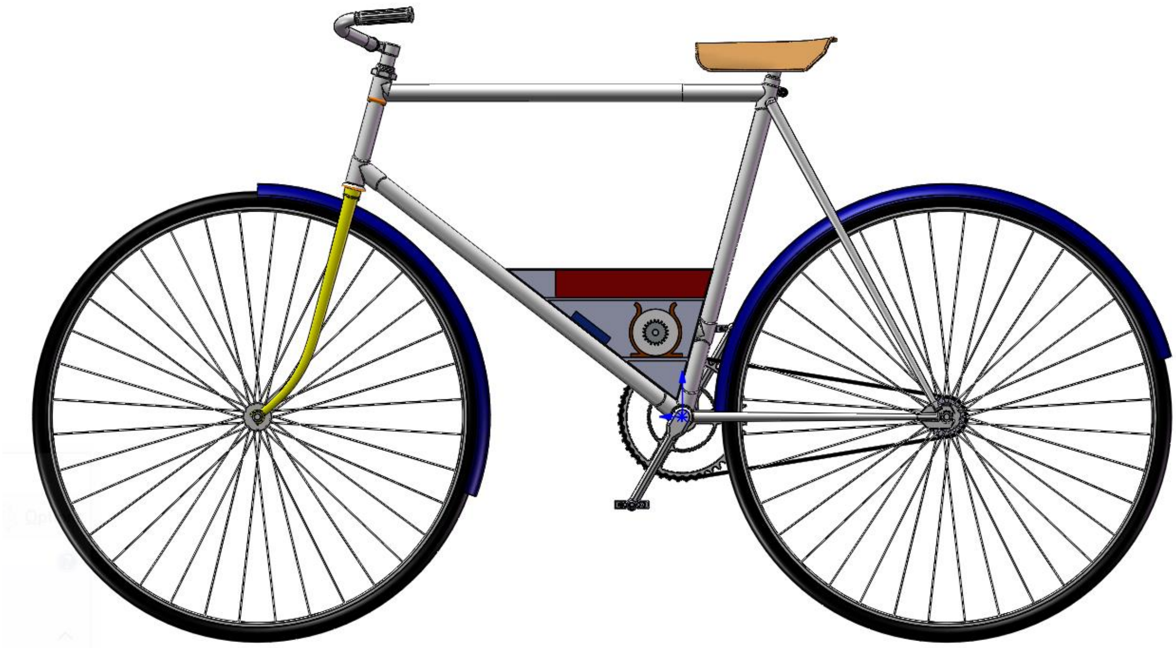

Figure 4.9: Front view of design type 3

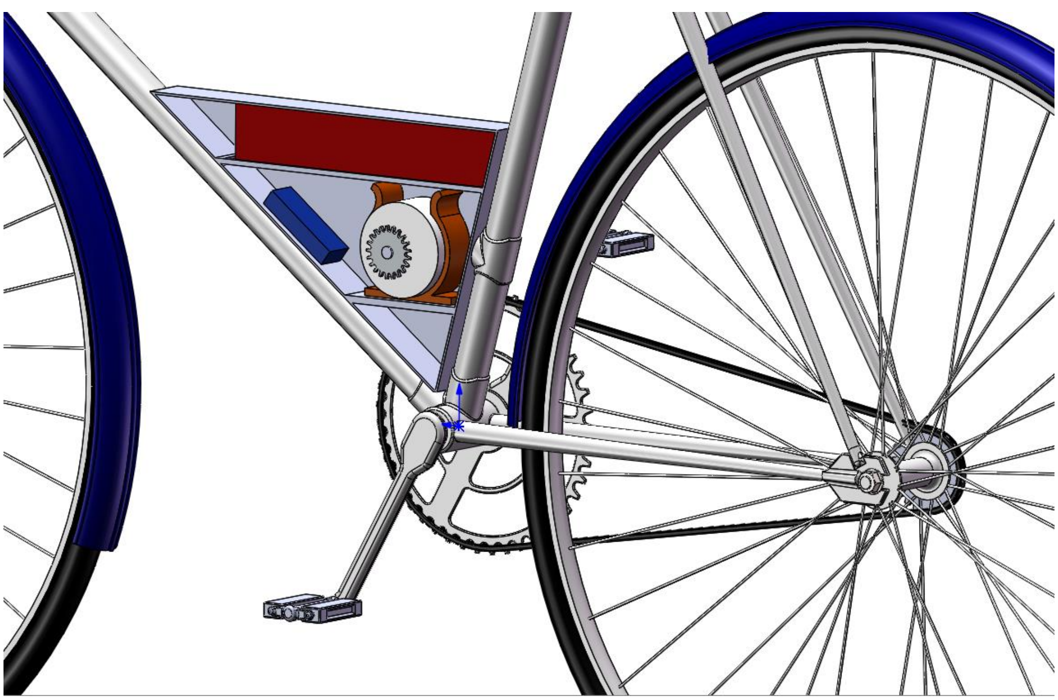

Figure 4.10: Isometric view of design type 3

4.3 Kinematic analysis

After careful observations, it was realized that the kit design for the mid drive case was not a possibility due to space constraints. Thus, the focus was shifted to the kit being mounted close to the rear hub of the bicycle. To progress towards fabrication phase, first a kinematic analysis was performed.

To verify if the proposed mechanisms will work or not, it is important to perform a kinematic analysis of the mechanism. For this reason, the kinematic analysis was performed for two cases. The first scenario is when the sprocket on the motor shaft will be directly connected to the chain of the bicycle and the direct power transmission will take place. And the second scenario is when the sprocket on motor shaft will first run another sprocket on a secondary shaft where a slightly larger sprocket will be mounted so that the output RPMs at the motor shaft can be reduced and thus there will be no issues of chain slippage on the sprocket.

In either case, there will be a sprocket that will be engaged with the chain of the bicycle and the power available at the motor shaft will be transmitted to the wheels of the cycle via the chain linkage of the cycle itself.

The objective of kinematic analysis is to determine and describe how objects will move, which in this case will be the movement of the chain of the bicycle relative to the motor sprocket once the kit is mounted. Thus, to perform the kinematic analysis, the components of the bicycle like the frame, the chain links and the kit are remodeled according to proper and actual dimensions and are assembled to perform the kinematic analysis. All this is done in SolidWorks part modelling module and the final assembly is performed in assembly module before the kinematic analysis is run.

The detailed process is given below along with supporting pictures of the steps performed in the whole process.

Figure 4. 11: Isometric view of bicycle frame

The next step is to model the inner and outer links of the bicycle chain according to size. Moreover, a path along which the chain will move is drawn and then the chain is made to pass through that path in assembly module using chain component pattern feature. Thus, the chain will pass through the rear sprocket, the mid sprocket and through the sprocket on motor shaft.

Figure 4. 12: Isometric view of outer chain link

Figure 4.13: Isometric view of inner chain link

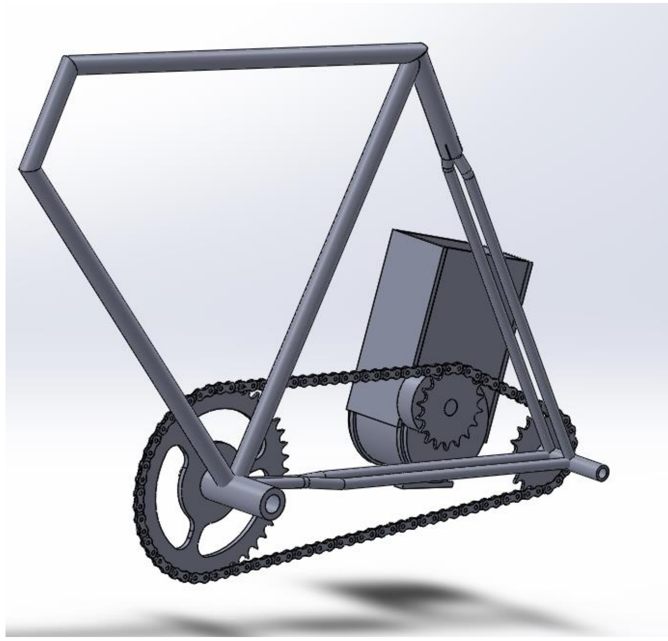

Figure 4.14: Isometric view of kinematic analysis of mechanism with the kit

CHAPTER 5

THE FABRICATION PROCESS

5.1 <u>The components of the kit</u>

After the background research, calculations, design and modelling phase and performing the kinematic analysis, for the conversion kit, it was decided to work on the direct power transmission mechanism as described earlier in the kinematic analysis phase. In this case, the motor with sprocket on its shaft will be directly connected to the chain of the bicycle and power transmission will take place thus driving the bicycle.

However, to make this happen the components that are required include the DC motor, a lithium-ion battery pack with BMS and motor controller along with the throttle device. It is also to be kept in mind that since the direct transmission of power will take place, the motor used shall not be a simple DC motor but a special Reduction type DC motor so that the RPMs available at the motor shaft shall be reduced inside the motor housing itself without the need of creating a speed reduction mechanism in the already confined space.

Thus now, all the components that will constitute the conversion kit in the final fabrication phase are discussed here.

5.1.1 <u>The reduction DC motor</u>

The motor installed in the conversion kit is 36 volts, with a power rating of 250W, containing a sprocket in the end. So, it requires a voltage of 36V which is supplied by the Lithium battery containing 10 Lithium cells each of 3.6V. The life span of the motor is 5 years and it's a brushed DC motor containing gears. Therefore, the output torque is high and has speed of 330 rpm. And the weight of the motor is around 2.3 kg. The efficiency of the motor is around 78%. The size of the Sohrab bicycle is 22 inch. The motor is mounted at the rear end at the side area below the chain, so that the chain is directly passing on the sprocket of the motor, such that the chain settles on the teeth of the motor sprocket. The motor mounting is done at 2 points on the frame of the bicycle, one side is mounted at the tilted frame and one side is mounted at the horizontal frame of the bicycle. One advantage of this motor is that it is noise free as compared to other forms of transportation like Motorcycle, Rickshaw, Loader Rickshaw etc. The DC motor winding is made up of copper which is an excellent conductor of electricity and offers a low resistance to losses. The housing or the frame of the motor is made of aluminum.

So, during the mounting, while directly giving the power supply to the motor, the motor gives a jerk at start and gets smooth afterwards. Therefore, the electric power from the Li-ion battery pack is provided to the motor via the controller.

Figure 5.1: 36 volts, 250-watt reduction motor

The side length of the motor is 102 mm in which 19.5 mm is the length of the gear system in the motor while 82.5 mm is the length of the motor pack with a diameter of 101 mm approximately.

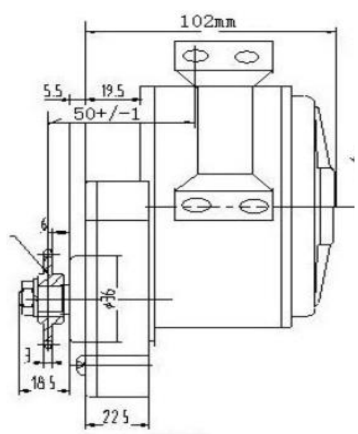

Figure 5.2: Dimensions of the 36 volts, 250-watt reduction motor

5.1.2 <u>Lithium-ion battery pack</u>

The motor used in the conversion kit has a power rating of 36 volts and 250 watts. Thus, to power it, the pack must output 36 volts along with a peak required current that can be calculated as below.

$$\frac{\mathbf{250\ watts}}{\mathbf{36\ volts}} = 6.94\ Amperes$$

Moreover, as calculated earlier, for a desired range of 35 Km per charge, the required capacity in Ampere-Hours was 31AH.

Thus, to design the battery pack all these requirements are to be kept in mind. Moreover, lithium-ion packs are not safe to use without a BMS (battery management system) and so that is also made the part of the pack. The BMS acts as a protective device to keep the charging and discharging levels of the lithium ion cells within safe levels of operations as well as prevent the cells in the pack from overheating.

Figure 5.3: 36 Volt, 10 S BMS

For the pack, individual lithium-ion cells rated at 3.7 volt and 4 Ampere hours each were used in series and parallel connections. Two rows of cells were made, and, in each row, 10 cells were connected so that the voltage output is 37 volts while the parallel connection between the rows gives the peak current of 8 amperes while fully charged. Also, since each cell was rated at 4AH, 10 cells connected with each other in parallel connection would give us 30 AH which were needed to achieve the desired range of 30 Km per charge.

5.1.3 <u>Motor Controller</u>

Motor controllers, also called the motor speed controller, are considered the heart of the E-bicycles. This serves as the center point for all the components to be connected to. Battery, motor, throttle, and any other accessories are also connected to this. Moreover, it manages and controls motor operations. It acts as a bridge between battery and motor and thus helps control and regulate the flow of current to control motor functionalities like speed, torque, and direction of rotation. The controller used here is 36 volts since the motor and battery pack both are designed for 36-volt operations [4].

A motor controller serves the following main functions and purposes:

Speed Control: The motor controller provides accurate rotational speed control for the motor. It enables smooth and precise speed regulation by adjusting the voltage and current given to the motor to reach the required speed.

Torque Control: The motor controller controls the output of torque by adjusting the current flow to the motor. In order to provide smooth acceleration and deceleration, it makes sure the motor produces the necessary torque for the particular application.

Direction Control: The motor may revolve in both the forward and backward directions thanks to the motor controller. To alter the motor's rotational direction, it modifies the power supply's polarity.

Control for Start and Stop: The motor controller makes it easier for the motor to start and stop smoothly. In order to avoid unexpected shocks or overloading, it controls the motor's power-up cycle, assuring a steady ramp-up in speed and torque.

Protection and safety: To protect the motor and the system as a whole, motor controllers frequently include a number of protective measures. To safeguard the motor and guarantee safe operation, they may include overcurrent protection, overtemperature protection, short-circuit safety, and other safety devices.

Efficiency & Energy Optimization: By controlling the motor's power consumption, motor controllers may aid in energy usage optimization. To improve overall energy efficiency, they can use methods like pulse-width modulation (PWM) to regulate the power sent to the motor.

The block diagram depicting the motor operation and the actual controller are also attached below.

Figure 5.4: 36 Volt motor controller

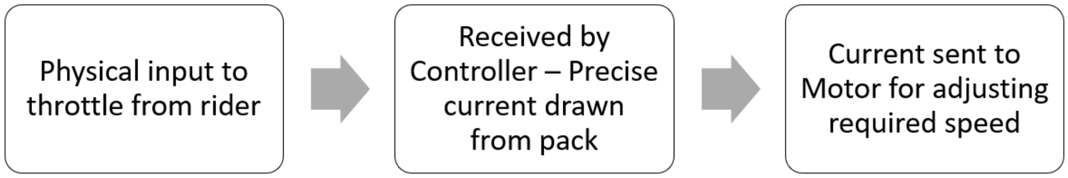

Figure 5.5: Motor controller's speed control

5.1.4 <u>Motor mounting plate</u>

A very crucial part of the whole kit is the mounting plate for the motor. The plate is made of heavy gauge steel and has the outline of the motor cut into it. This helps in holding the motor firmly on the mounting plate. Moreover, screws are used to mount the motor in place. It is important to note that the mounting plate used here is made for BMX bicycles and thus fits the frame of the BMX bicycles perfectly. However, in our case the bicycle frame differs from the BMX frame thus we need to make special adjustments in the plate mounting plate to fit the Sohrab bicycle frame. This requires a complete and comprehensive look into the changes needed to be made to the original mounting plate. Thus, with the passage of time, the plate was modified to fit our requirements.

Figure 5.6: Motor mounting plate

5.1.5 <u>Thumb Throttle</u>

The conversion kit includes a thumb throttle which regulates the speed of the motor by taking physical input from the rider. The thumb throttle used here is easy to install and use and comes in with a built-in battery charge indicator level. The three levels represent full, half, and empty states of the battery using green, yellow, and red LEDs.

Figure 5.7: Thumb throttle

5.1.6 <u>Chain idler</u>

An idler is a device used to induce a specific amount of tension in the chain of the bicycle. This is done to avoid chain slipping over the motor sprocket and helps in a smooth power transmission from motor to the chain of the bicycle. The idler used here was attached to the kit housing itself and tests were run to see the performance of the kit during the ride test. It was seen that during the travel over road bumps and irregular surfaces, the chain would jump over the motor sprocket giving the chain a chance to slip even with the idler. Thus, after testing, the idler was spring loaded by using a spring of high stiffness. This spring helps keep the idler down when travelling over bumps and irregular surfaces and thus reduces the chain slippage chances greatly.

Apart from inducing the required amount of tension in the chain, the idler also acts as a chain guide and thus helps in keeping the chain aligned with the motor and bicycle sprockets and ultimately helps in chain derailing.

Figure 5.8: Spring loaded idler arm

5.2 Fabrication phase

Design is an iterative process. At each step, the previous step must be consulted. Moreover, any step performed must be validated by solid reasoning. Since this project is also a design and fabrication process, each step was tested for desired results and the next process was investigated afterwards. The fabrication process starts with the motor being mounted onto a mounting plate and as per the finalized design all other components will be built around the motor. Moreover, the alignment of the motor sprocket with the ones of the bicycle is the most crucial part of the process because any misalignment will quickly derail the chain and thus no power transmission takes place.

5.2.1 Setting the motor

The first and foremost step in the fabrication phase is to set the motor on the rear hub and properly align the motor sprocket with rear sprocket of the bicycle. For this, the motor was mounted on the mounting plate and initially two supports were used to support the motor. These include the one at the wheel hub and the other at the inclined support rods of the bicycle frame. Once the alignment issues are dealt with, we can progress with the initial tests.

Figure 5.9: Setting the motor

5.2.2 Initial testing of the mechanism

The Sohrab bicycle frame is one of the most difficult to work with as there are very tight spaces to be availed for the purpose of making a connection with chain for direct power transmission. Thus, after continued trial and tests, one position was finalized, and tests were run to check for the feasibility of the working of the mechanism. This involves assembling the motor with battery and the controller and using the thumb throttle to check if the mechanism runs smoothly. Since two supports were used initially, it was observed that with initial throttle, there was a possibility of jerk due to initial high torque and thus the mounting plate was to be further worked on for a third extended support at the frame of the bicycle.

During testing, the sprockets were seen to be aligned and thus after continuous improvements, one specific position for motor orientation was chosen. This specific position not only was easy for installation of the motor but also provided a smooth power transmission while keeping the chain in a certain tension state such that when the rider pedaled, he would not have to exert an excessive force.

Furthermore, the issue of initial jerk due to torque felt was noted and the third support for the motor mounting plate was also finalized. This would hold the motor firmly in place and in case of any torque coming from the motor, the jerk felt was minimized.

Figure 5.10: Initial (static) test run

5.2.3 Dimensioning and fabricating the kit housing

Once the orientation of the motor was finalized, along with a third support for the motor mounting plate, the next step was to take dimensions for the kit housing. For this purpose, the motor was mounted onto the bicycle in the position finalized and dimensions were taken. It is to be taken into consideration that to have the kit as compact as possible, the dimensions were taken with clarity and keeping in mind the dimensions of the motor, battery, and the controller.

It is important to have correct dimensions for the kit housing because, with the pedal of the bicycle at zero degrees with the bicycle frame, there is hardly a space of 12 inches from pedal to the rear hub. This is necessary because an excessively large size of the kit housing would make it difficult to pedal the bicycle when the bicycle is not in use due to limited spaces.

After the dimensions were recorded, angle bars of half inch by half inch were used to make a skeleton for the kit housing. The angle bars were welded together for proper strength and holes were drilled into the bars for paneling the faces of the housing with sheet metal in the next steps. Finally, after the skeleton of the housing was made for the kit, it was welded onto the motor mounting plate so that the whole assembly would come in a single piece product form which can be carried easily.

Figure 5.11: Dimensioning for kit housing

Figure 5.12: Kit housing made form ½ inch by ½ inch angle bars

5.2.4 Sheet metal paneling of the kit housing

Once, the kit housing was made from angle bars, the next step was to cover the faces of the housing using sheet metal panels. The six faces were covered by precise cutting of the sheet metal panels. The panels were screwed onto the kit housing using 3mm screws. For inserting the screws, holes were drilled into the angle bars as well as the sheet metal panels. Once the holes were aligned, the screws were used to hold them together in place.

Figure 5.13: Sheet metal paneling of the kit housing

5.2.5 Spring loaded idler

After assembling the kit with the current state as described above, tests were run again to check for smooth working of the mechanism. It was realized that the kit works fine most of the time, however with certain conditions like road bumps the chain on the motor sprocket would slip and thus would provide a chance for the chain to be derailed and stop power transmission. This called for using an idler to induce tension in the chain. Tension would keep the chain pressed down and the chain would pass above the sprocket and below the tensioner to avoid any slippage.

It is important to note that the tensioner must be perfectly aligned with the motor and bicycle sprockets. Thus, the idler acts as a tensioner and in our case with a little adjustment, it also acts as a chain guide to keep the chain on a desired path.

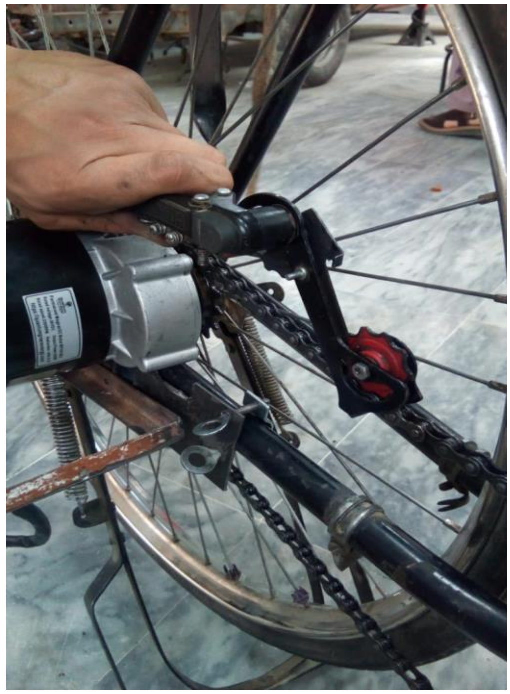

Figure 5.14: Initial estimates for idler position

After testing the idler, it was seen that the chain jump over the sprocket was taking place over bumps on the road. This called for a mechanism to always keep the idler in contact with the chain. Thus, the idler was spring loaded using a spring of high stiffness and not allowing the idler to undergo an excess travel over bumps and leaving the chain.

Figure 5.15: Spring loaded idler for proper tension

5.2.6 Final testing with the complete kit assembly

Finally, after the kit has been completely assembled, the kit was installed back on the bicycle frame and tests were run to ensure proper working of the mechanism. It was observed that the spring-loaded idler enhanced the smoothness of the mechanism and provided much better results. Moreover, the battery and controller were also placed in the upper compartment of the kit and the connectors were connected to power the motor for final testing. Static and ground tests were run to ensure that the kit performed as per the desired results.

CHAPTER 6

FEA ANALYSIS

6.1 Ansys simulations

After the fabrication process was completed, the next step was to simulate the different loading scenarios in a simulation software. For this purpose, Ansys was preferred to perform static structural analysis. The analysis was performed for 3 loading scenarios. The first one was dedicated to simulating the stress, strain, and other parameters when the kit is mounted on the bicycle frame. The other case is when the kit will be carried by the user and thus the stresses generated in the kit frame due to the load will be simulated. Furthermore, a third study was performed on the chain links as they undergo a cyclic loading by encountering the sprocket repeatedly.

6.1.1 Simulation results for case 1

This case delas with simulating the results when the kit is picked up by the user. Ultimately, the weight of the different components exert a downward force on the kit frame made by the angle bars. Furthermore, since the motor is mounted on the mounting plate, the mounting plate also experiences the effects of this loading. It is important to note that the yield strength of steel is 250 MPa and shear strength is 160 MPa. After simulating the results, we see that the frame performs well under loading and does not undergo any sort of yielding or failure.

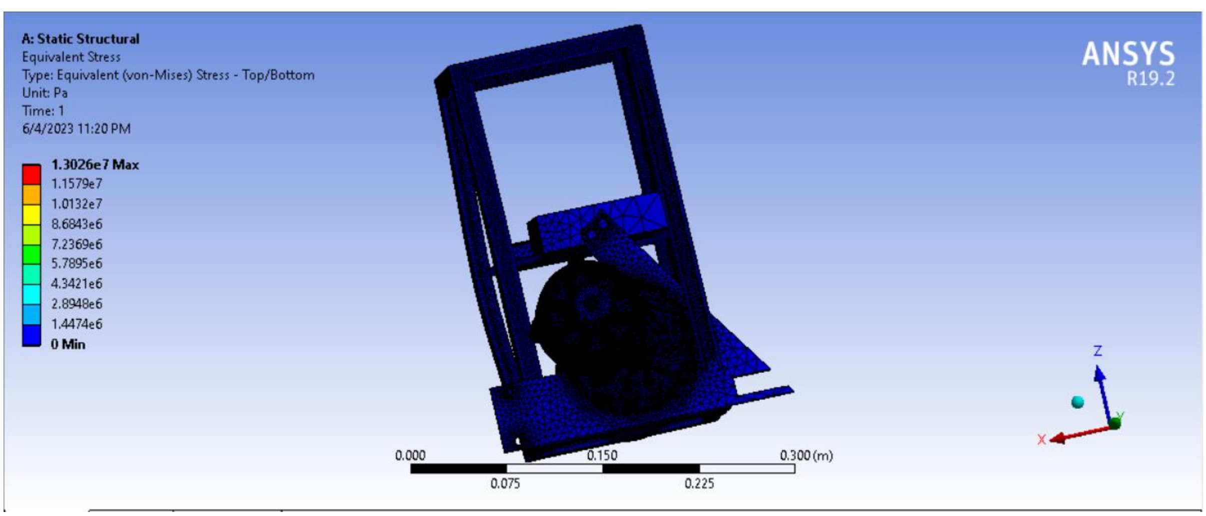

Figure 6.1: Equivalent stress result for kit frame

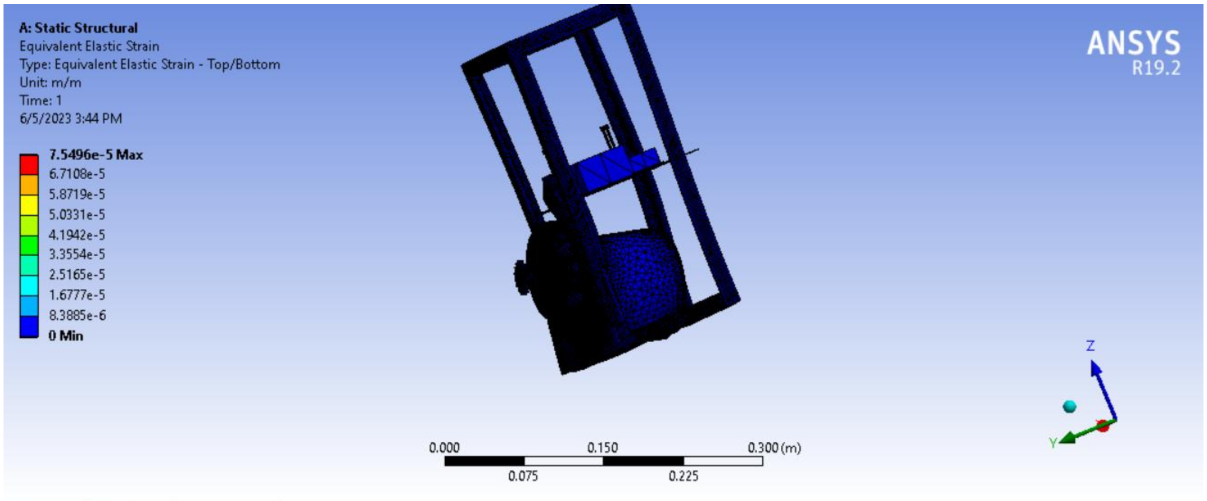

Figure 6.2: Equivalent strain result for kit frame

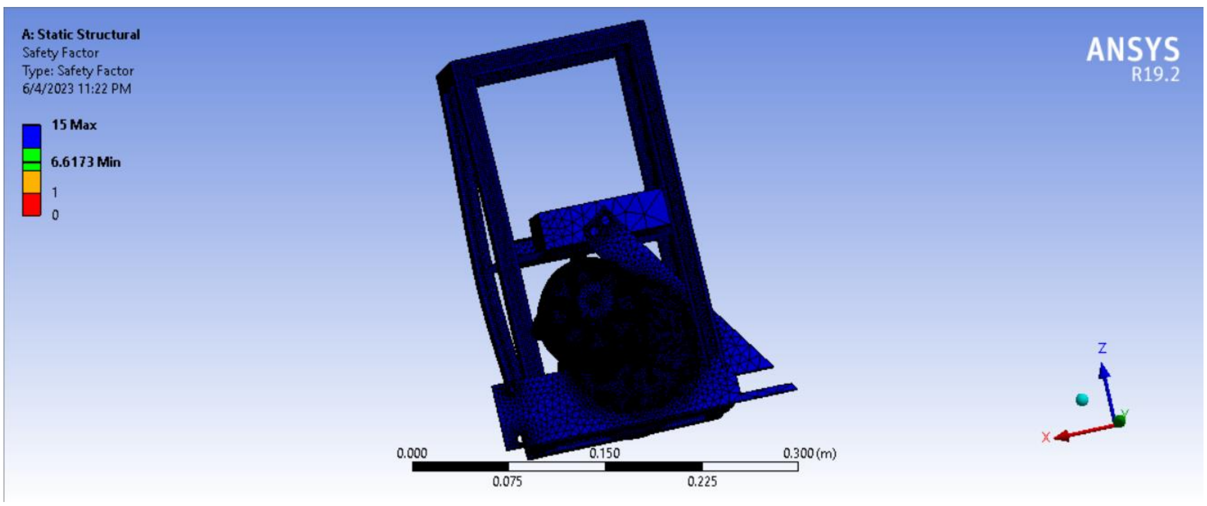

Figure 6.3: Factor of safety result for kit frame

6.1.2 <u>Simulation results for case 2</u>

This loading case deals with the situation when the kit will be mounted on the bicycle frame. The kit exerts a certain force at the mounting points as well as a downward force in general. The results were again simulated for stress, strain, and other parameters. The analysis confirms that the kit does not exert any such loading to the frame that may contribute to the failure of the bicycle frame. The frame consists of thick hollow walled structural steel material again with yield strength of 250 MPa and shear limits of 160 MPa. The results prove that the frame performs well under an applied load by the kit.

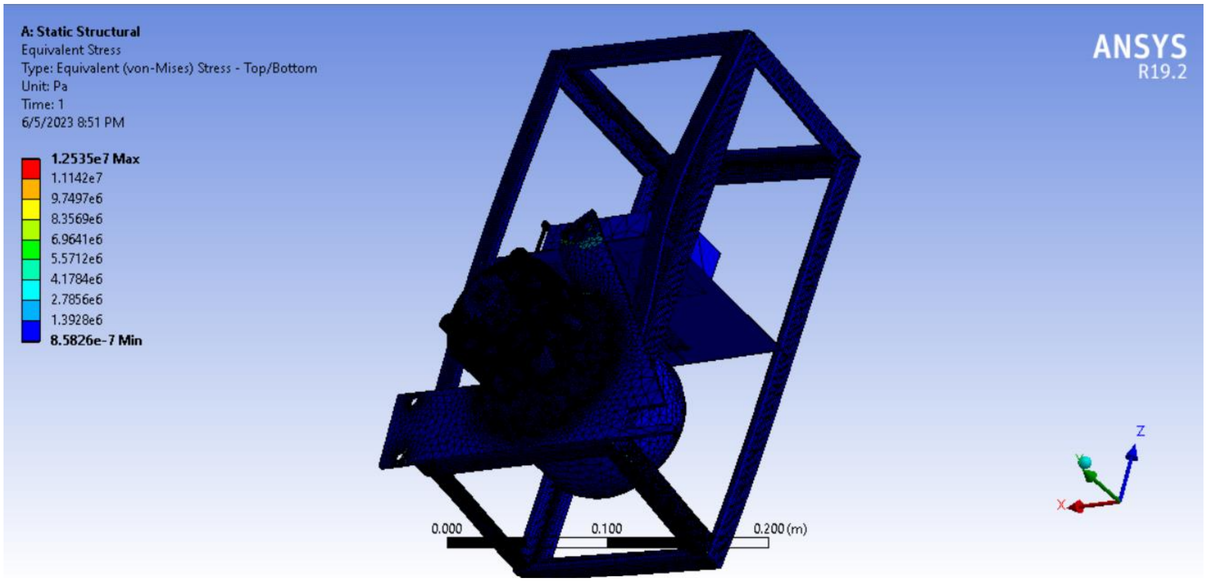

Figure 6.4: Elastic stress on the kit frame

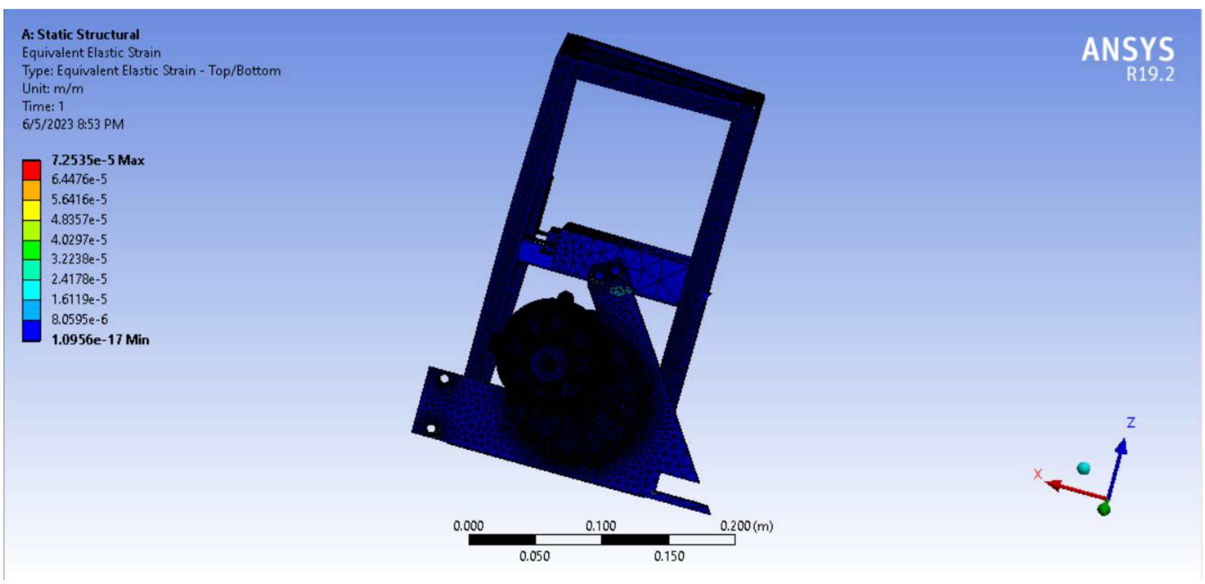

Figure 6.5: Equivalent Elastic Strain on the kit frame

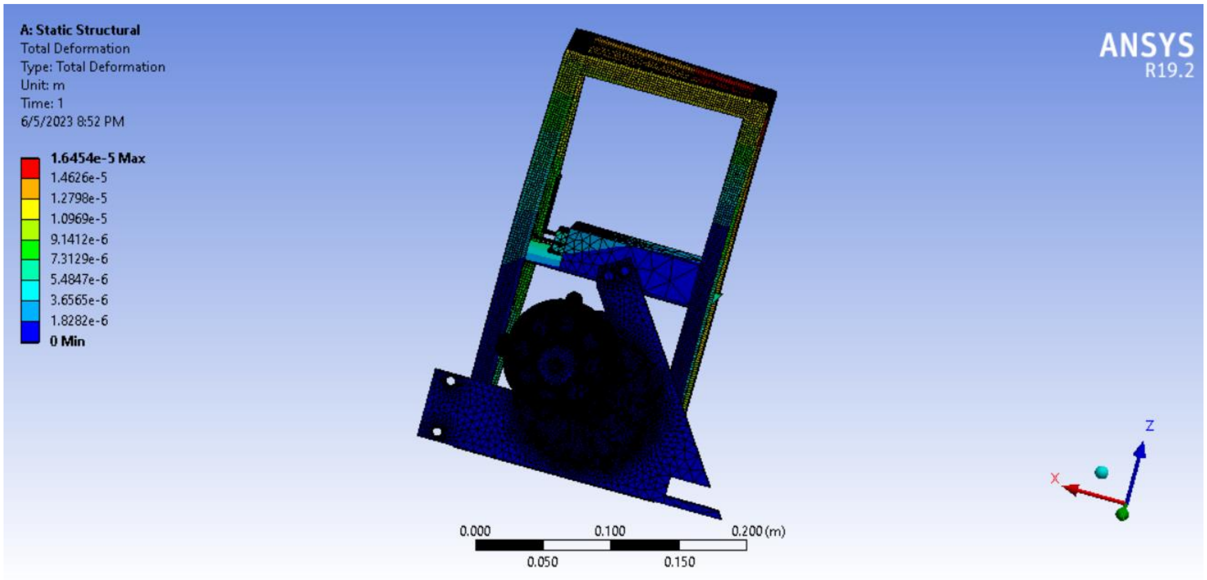

Figure 6.6: Total Deformation on the kit frame

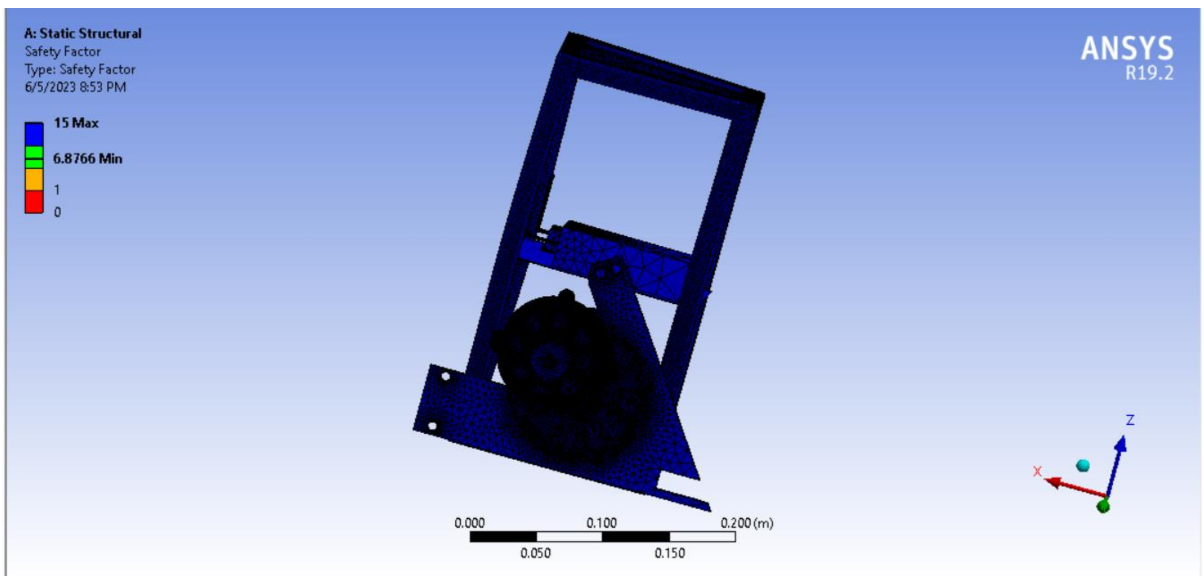

Figure 6.7: Factor of Safety of the kit frame

6.1.3 <u>Simulation results for case 3</u>

This situation deals with the effect of cyclic loading that the chain links undergo after interacting with the sprocket teeth. The sprocket has 16 teeth and the peak torque output by motor is 8 N-m. Since the radius of the sprocket is known, the force exerted by sprocket teeth can be calculated by the given formula.

$$T = r \times F$$

We see that the force comes out to be 253 N and since 3 teeth are properly engaged at one time, this force is divided evenly among these links.

The results were analyzed for any tensile, shear and fatigue failure. However, no such failures were encountered during analysis.

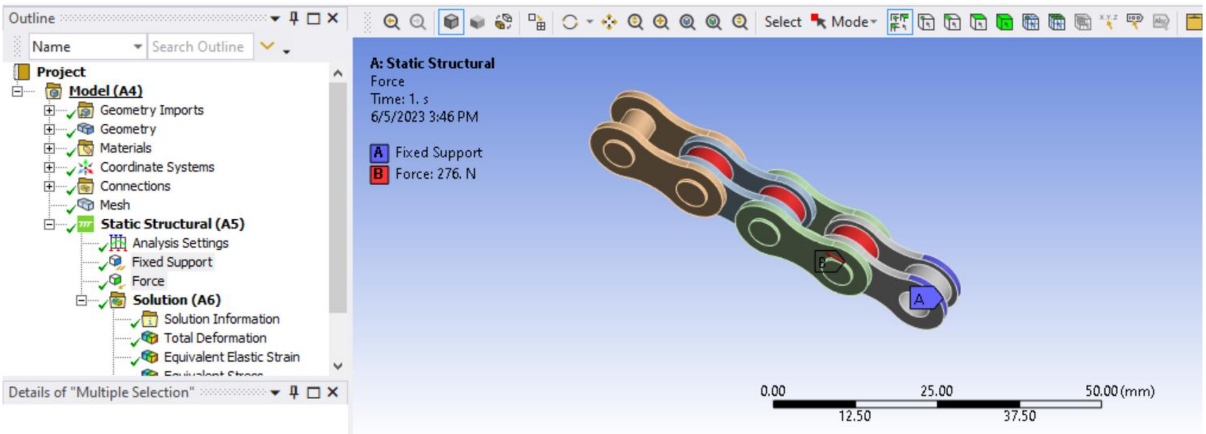

Figure 6.8: Boundary conditions for chain links

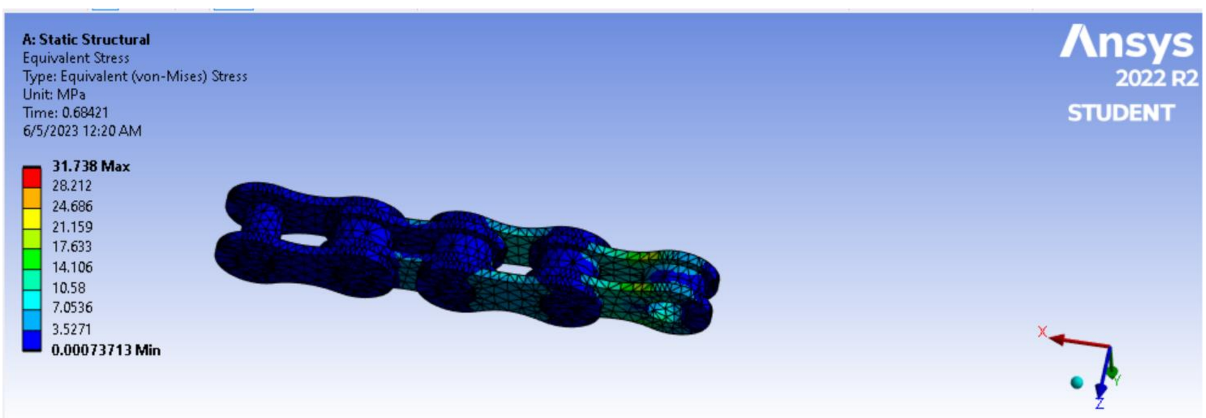

Figure 6.9: Equivalent stress result for chain links

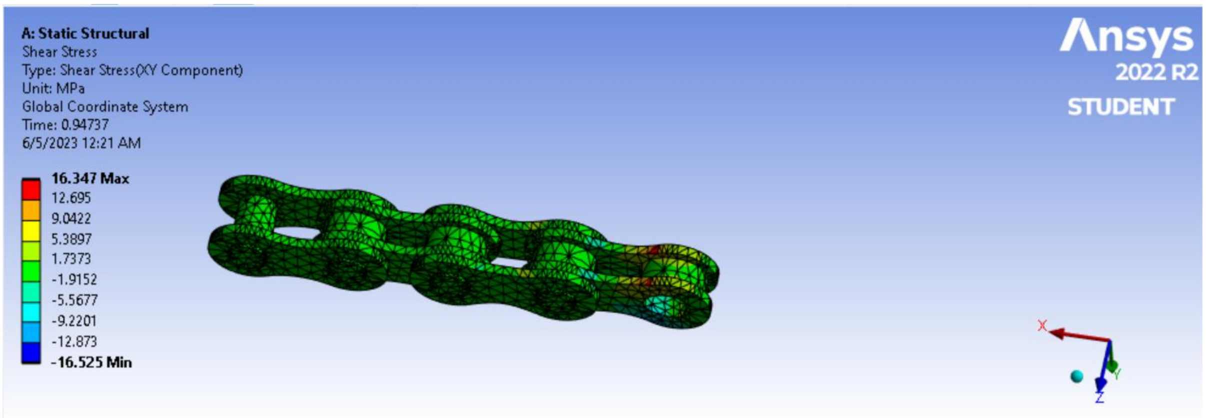

Figure 6.10: Shear test result for chain links

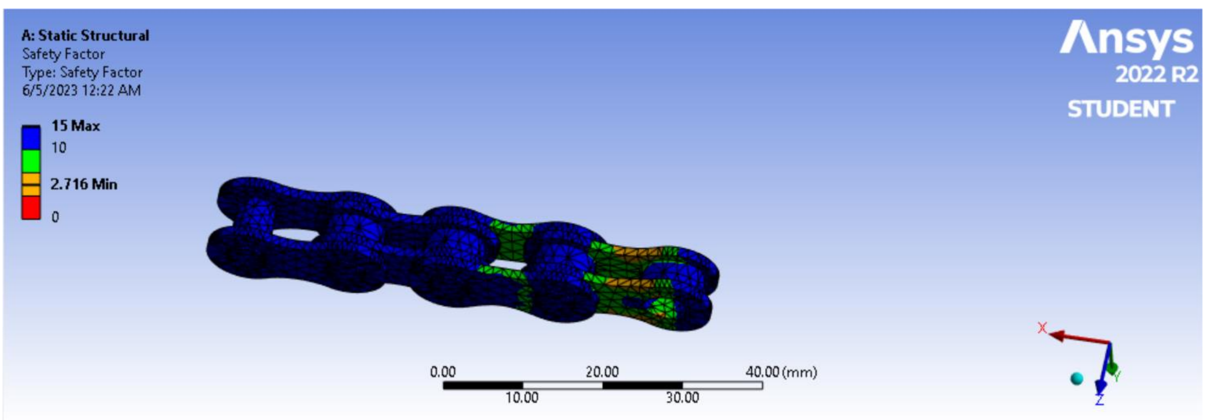

Figure 6.11: Fatigue factor of safety result for chain links

CHAPTER 7

PROJECT DELIVERABLE AND END GOALS

The end goal of the project is the design and fabrication of an electric bicycle kit that can easily be integrated on bicycles at will and to convert them into electric bicycles in minutes. The project aims at providing a way forward for the adoption of the same idea for developing electric kits for other fuel powered vehicles soon.

Placing our objectives in front of us, our end goals are:

- To achieve economical and less expensive alternate to E-bicycles.
- To make a reliable and safe system.
- To make a system which can be easily installed on every type of cycle.
- To make a system which can face environmental challenges.
- To make an environmentally friendly system.
- To commercialize the project.

CHAPTER 8

TARGETED SUSTAINABLE DEVELOPMENT GOALS (SDGs) OF THE PROJECT

The Sustainable Development Goals (SDGs) [7, p. 1] also called the Global Goals are a group of 17 goals set by the UN General Assembly in 2015 and will serve as a target to achieve till 2030. The SDGs basically are the set parameters for peace and prosperity for the inhabitants of Earth, at present and those who will come in future. According to these parameters, any development done on the planet shall serve for the peace and prosperity of its people and for the betterment and preservation of its environment. Leading global economies have introduced laws ever since the introduction of the SDGs, as their own targets to achieve by 2030.

Our Project Design and Manufacture of e-bicycle kit conversion also meets some of Sustainable Development Goals which will pay a great contribution in making society "green" and a live able place. Some of Sustainable Development Goals that are project meet are as follows:

SDG#7: Affordable and a clean energy

A major objective set by the SDGs is to develop and use environmentally friendly, low-cost energy and to increase the percentage of renewable energy. This project also aims at providing a better alternative to the use of carbon-based fuel transport systems. Especially, replacement of the petrol-powered motorbikes in a developing nation like Pakistan with electric powered bikes. This can serve as a benchmark for other developing nations as well as contribute positively to reducing the carbon footprint of these nations. Moreover, the proposed E-bike kits can be charged via solar energy, thereby limiting the use of fossil energy to generate electricity to charge the batteries.

SDG#9: Industry, innovation, and infrastructure

Innovative techniques and infrastructure to replace obsolete methodologies is also an important target set by the SDGs. In this regard this project focuses on developing a new solution which helps capitalize on the already produced bicycles by converting them to electric form. Thus, instead of discarding these bicycles to replace them with dedicated electric bicycles, this product provides an innovative alternative to E-bicycles.

SDG#11: <u>Sustainable cities and communities</u>

The goal of sustainable cities and communities has ten targets set by the UN. These ten targets include safe, affordable, accessible, and sustainable transport systems. Our e-bicycle is not only highly affordable but also easily accessible. Since it is an alternative fuel vehicle with zero emission, it is highly sustainable. One of targets of Sustainable cities and communities also includes lowering the percentage of carbon dioxide, carbon monoxide to improve the air quality. Thus, lowering smog is the prime objective of sustainable cities and communities. Our e- bicycle since it is based on zero emission will also pay great contribution in improving air quality if it is commercialized.

SDG#12: <u>Responsible consumption and production</u>

Fossil fuels are non-renewable sources of energy. If we continue to utilize these non- renewable sources of energy such, we will run out of these fossil fuels in a very less time. One of main objectives of SDGs is to lower the consumption of fossil fuels. For the same reason United Nations have asked countries to remove fossil fuel subsidiary to discourage fossil fuel consumption in public. Our e-bicycle is just a simple model that government bodies need to learn how they can discourage fuel consumption by making e- automobiles. More efforts need to be made. It's a need of era to make transportation backed by electricity rather than fossil fuels.

SDG#13: Climate action

Humanity is severely threatened by global warming. The earth's temperature is rising to intolerable levels. Drought and wildfire are the results of the summer's oppressive heat. Unexpected rains, on the other hand, present flooding risks. Automobiles powered by carbon fuels are the main producers of carbon dioxide. The growing greenhouse effect is related to the same carbon dioxide. As a result, an alternative energy source is required to power the vehicles. Our effort intends to reduce people's reliance on fossil fuel-powered automobiles. This project intends to create an electric bicycle kit that runs on energy instead of fuel, which reduces pollution in society. If this electric bicycle kit is used in a commercial setting among other vehicles powered by electricity, a significant decrease in global warming will be the result.

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