DESIGN AND DEVELOPMENT OF AN ELECTRIC WHEEL

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

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June 2018

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ABSTRACT

Owing to the rapid increase in global warming over the past few years, the demand for non-polluting mechanized transportation has grown substantially in lieu of fossil fuel driven automobiles. The least expensive and greenest alternative to cars are bicycles. Even though the rate of technology over the past few years has risen exponentially in all areas and aspects, yet the realm of electric bicycles remains very much unexplored despite the concept of it being around for a long time. The basic principle for the working of an electric bike is that a battery operated/rechargeable DC motor is mechanically coupled with the wheels and provides electromagnetic propulsions which makes the wheel rotate. This ultimately eradicates the need to pedal and eliminates the need for human labor. In our research, we are looking to further economize the basic idea of a complete electric bicycle and boil it down to a single replaceable electric wheel. The wheel, when completed, will replace the front wheel of any standard manual bicycle and turn it into an electric one. We intend to manufacture an entire replaceable wheel itself, but the basic idea and technical workings of the wheel will be somewhat similar to that of the electric bicycle.

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PREFACE

As people are getting more educated, awareness about saving the environment is increasing. Considering the increasing rate of global warming and the rapid depletion of fossil fuels, the modern world is moving towards developing more alternate environment friendly ways of doing things. Narrowing our perspective to transportation, people are actively wanting to adopt greener methods like electric or hybrid cars, but their extremely high price makes it almost impossible for most of the population to afford. On the other hand, using a standard manual bicycle will although eliminate the pollution produced by cars and motorbikes but this requires a lot of human effort and seems like a tedious and tiring solution. The most obvious, middle ground solution for this paradox seems to be electric bicycles which are clearly much cheaper than E/Hybrid vehicles and eradicate the input of human labor used in standard bicycles. Taking inspiration from and building off the already existing technology for electric bicycles, we've decided to do additional research in this realm and take it a step further by developing replaceable electrical wheels.

ACKNOWLEDGMENTS

We are most grateful to Almighty Allah for providing us the brains and resources to work on this project and produce this report. No doubt, nothing can be done in this world without His will.

We are then thankful to our parents, for not giving up on us, sacrificing their own selves for us and making sure we get the best of everything, especially in education.

We are also extremely grateful to our instructor, Dr. Mian Ashfaq Ali. Without his constant guidance, support and feedback we would have not been able to produce this report. Thank you for being so patient with us.

We thank all the NUST (National University of Sciences and Technology) and especially SMME (School of Mechanical and Manufacturing Engineering) administration and all the people that make sure things run smoothly around here, thank you all.

Lastly, a big thank you to all our friends, who made sure we stayed sane during tiring times and for providing us with comic relief whenever we needed any.

ORIGINALITY REPORT

WE CERTIFY THAT THIS RESEARCH WORK TITLED "DESIGN AND DEVELOPMENT OF AN ELECTRIC WHEEL" IS OUR OWN WORK. THE WORK HAS NOT BEEN PRESENTED ELSEWHERE FOR ASSESSMENT. THE MATERIAL THAT HAS BEEN USED FROM OTHER SOURCES IT HAS BEEN PROPERLY ACKNOWLEDGED / REFERRED. WE HAVE NOT COPIED ANYTHING, OR ANYONE ELSE'S WORK AND THE WORK DONE IS ORIGINAL AND ALL RESULT OF OUR OWN HARD WORK.

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TABLE OF CONTENTS

ABSTRACT ii

PREFACE iii

ACKNOWLEDGMENTS iv

ORIGINALITY REPORT v

COPYRIGHT vii

LIST OF FIGURES xiii

ABBREVIATIONS xv

NOMENCLATURE xvi

CHAPTER 1: INTRODUCTION 1

1.1 Why is there a need for this? 1

1.2 Why is this better than electric bicycles? 4

1.3 History of Electric Bicycles 5

1.4 Market Research 6

CHAPTER 2: LITERATURE REVIEW 11

2.1 Existing Similar Vehicles 11

2.1.1 Simple Bicycle 11

2.1.2 Electric Bicycle 13

2.1.3 Segway.. 16

2.1.4 Geo-orbital Wheel 17

2.2 Existing Braking Systems 18

2.2.1 Regenerative Braking System 19

2.2.2 Friction Braking System 19

2.2.3 Combination of Regenerative and Friction Based Braking System...... 20

2.3 Existing Motors 21

2.3.1 Brushless DC Motors 21

2.3.2 Hub Motors... 24

2.4 Existing Batteries 24

2.4.1 Advantages: 24

2.4.2 Disadvantages:.. 25

2.4.3 Lithium ion polymer batteries:... 25

2.5 Dynamometer:.. 26

2.5.1 Disadvantage: 27

CHAPTER 3: DESIGN AND SIMULATION 28

3.1 Front wheel assembly approach:... 28

3.2 Aluminum Frame: 29

CHAPTER 4: COMPONENTS...33

4.1 Wheel.. 33

4.2 Material Selection 34

4.2.1 Roller Mechanism 34

4.2.2 Bearings 34

4.3 Motor.. 35

4.3.1 Motor Controller.. 37

4.4 Thumb Throttle.. 39

4.5 Battery.. 39

CHAPTER 5: RESULTS and DISCUSSIONS...40

5.1 Objective:.. 40

5.2 Overview:.. 40

5.3 Attainments: 40

5.4 Challenges:... 41

5.5 Skills Gained: 41

CHAPTER 6: CONCLUSION AND RECOMMENDATION................42

6.1 Recommendations:... 42

REFERENCES 43

LIST OF FIGURES

Figure 1: Schematic drawing, causes and effects of air pollution [1]................................2

Figure 2 A major chunk of pollution is due to transportation exhaust gases......................3

Figure 3 Annual E-bicycles forecast scenario 9

Figure 4: The most popular bicycle model—and most popular vehicle of any kind in the world—is the Chinese Flying Pigeon, with about 500 million produced. [8] 12

Figure 5: An example of e-bike 14

Figure 6: Pedal Assist System..15

Figure 7: Power on Demand System 15

Figure 8: Traditional Segway..16

Figure 9: Geo-Orbital Wheel 18

Figure 10: Comparison b/w DC & BLDC motor [15]...22

Figure 11: A simple dynamometer 27

Figure 12: Concept model using Solid works...28

Figure 13, Sheet thickness calculation..29

Figure 14. CAD design for aluminum frame 30

Figure 15. Stress under safe limit 31

Figure 16. 2D drawing of CAD model 32

Figure 17. Components used for electric wheel....33

Figure 18. Specifications of the motor....35

Figure 19. Dimensions of motor....36

Figure 20. Side view of motor....36

Figure 21. Wiring coming out of controller....38

Figure 22. Connections of extended wiring....38

Figure 23. Final assembly of the wheel....39

ABBREVIATIONS

UV	Ultraviolet
CFC	Cloro Floro Carbons
DC	Direct Current
AC	Alternate Current
BLDC	Brushless Direct Current
PM	Permanent Magnet
PMDC	Permanent Magnet Direct Current
CAGR	Compound annual growth rate
SDG	Sustainable development goals
CNC	Computer Numeric Control
RPM	Rotations per minute
PT	Personal Transporter
PKR	Pakistani Rupees
CAD	Computer Aided Design
AH	Ampere hour
HP	Horsepower

NOMENCLATURE

A	Ampere
V	Voltage
I	Current
w	watts
V	Voltage
T	Torque
F	Force
P	Power
R	Resistance
ω	Angular speed

CHAPTER 1: INTRODUCTION

When we sat down to choose something for our final year project, all of us unanimously agreed that we wanted to use our education by focusing our energies on something that will help our increasingly depleting environment. After much deliberation we decided to delve into the domain of electric bicycles, particularly an electric replaceable wheel. The electric replaceable wheel is a device that, as the name suggests, is an electrically powered contraption that can be fitted in the place of the front wheel of any standard manual bicycle and instantly turn it into a electric bicycle. The genius of this device lies in the fact that it gives all the functions and utility of an electric bicycle without having to purchase the e-bike in its entirety. This works on the principle of electromagnetic propulsions to an existing bicycle therefore relieving the user of producing the energy required to run the bicycle. It contains a strong motor and enough battery power that just requires charging to help in hill climbing, generate greater motoring speeds and provide completely free electric transportation. Electromagnetic propulsions run the bicycle, so the user does not have to put in energy to drive. The strong motor coupled with a high rechargeable battery power is sufficient enough to climb hill and generate high speeds.

1.1 Why is there a need for this?

The number of cars and automobile in the world has been rapidly increasing, with single families owning and driving up to three cars. According to recent studies, the number of automobile on roads has been growing exponentially each year. If this current trend persists, is has been estimated that by the year 2050, there might be 3 billion vehicles on our roads, meaning over 20 cars per 100 people. Even an uneducated person can predict that this dangerously increasing number of cars on the road will have acutely adverse effects on our environment. Air and noise pollution, and global warming owing to the emission of carbon dioxide and other greenhouse gases by these cars. In addition to carbon dioxide, other harmful gases like various sulfur and nitrous oxides emitted by these cars lead to acid rain which in turn causes a plethora of problems including depletion of infrastructure, destruction of crops and even causing skin cancer. The following figure sums up the effects of air pollution.

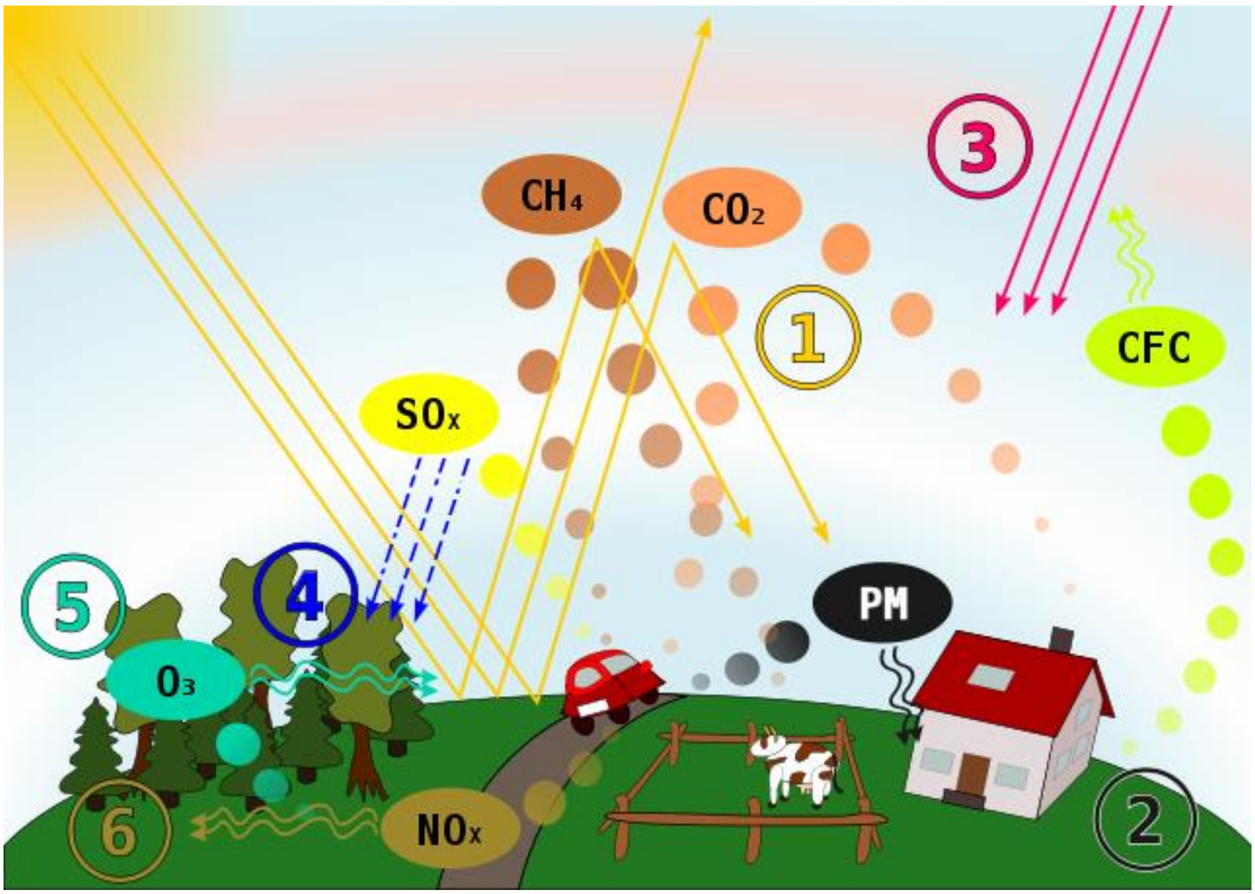

Figure 1: Schematic drawing, causes and effects of air pollution [1]

1. Greenhouse effect by keeping sun warmth and light from reflecting into space
2. Particulate contamination affecting respiratory systems
3. Raised UV radiation levels by destruction of the ozone layer
4. Acid rain leads to acidification and forest dieback

5. Increased ozone levels affecting respiratory systems
6. Contamination by nitrogen oxides affecting respiratory systems

Reasons and effects of air pollution

- Carbon dioxide from exhausts and energy production
- Methane from cattle breeding
- Sulfur oxides from exhausts and industry
- CFCs from refrigerants and propellants
- Nitrogen oxides from exhausts and industry
- Ozone from air with high oxygen level, catalyzed by nitrogen oxides
- Soot and particulate from exhausts and industry

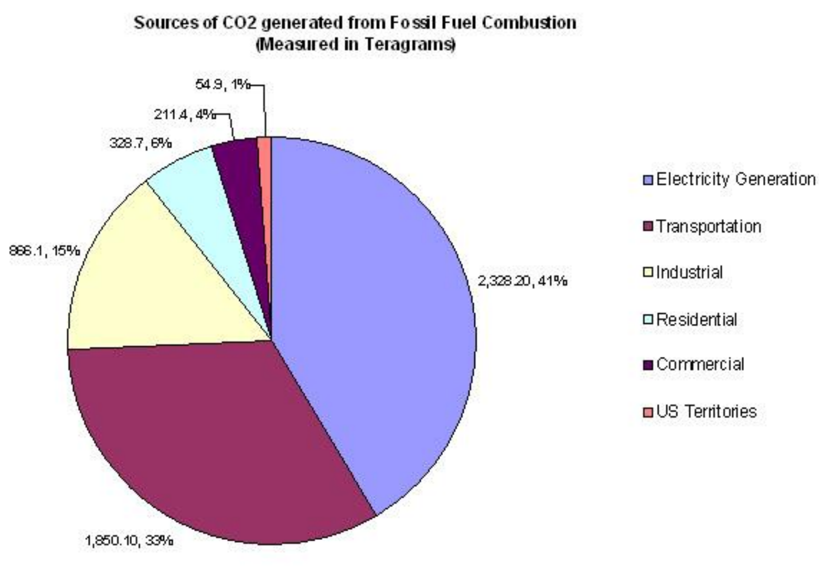

Figure 2 A major chunk of pollution is due to transportation exhaust gases

In addition to the obliteration of our atmosphere, this increasing number of cars has other consequences as well. These cars are all fossil fuel driven and they are eating up our reserves of oil and gas very fast. If this trend continues, we will run of our oil reserves in

53 years, natural gas in 54 and coal in 110. [2]. Depletion of these reserves isn't the only problem though. Following the laws of economics, the decrease in the supply of oil, increases its demand that raises its price. The price of crude oil have been increasing significantly over the past few years and there seems to be no stopping it. This project will not only endorse environment friendly technology but will also decrease our reliance on crude oil. Thus, we will be able to show the public just how economically feasible this mode of transportation is in comparison to cars. Ever since the global economic downfall of 2009, we have countless opportunities to help and make this planet greener and help pull us out of this depression.

Electric vehicles, whether it be cars or bicycles, have been left ignored for a very long time with little to none research done in that department. They do not perform as efficiently as other fossil fuel (oil or gas) driven vehicles which is not surprising as these have gone through decades of intensive research and development while the electric vehicles remained somewhat overlooked which is an added reason as to why we wanted to investigate in this section.

In conclusion, we have chosen to overtake this project because we want to give our due in reducing the destruction of our atmosphere and the depletion of fossil fuels and coping with the increased prices of oil and gas. Lastly, we believe it is our duty as educated engineers to use our privilege and knowledge in making this world a better place for us and the future generations to live in.

1.2 Why is this better than electric bicycles?

The reasons as to why the electric replaceable wheel is better than electric bicycles are twofold.

1.1.1 Cheaper. Since this is just a wheel as opposed to a full-fledged e-bike, the cost of manufacturing it is much cheaper than the bike. Evidently enough, the amount and variety of raw material needed to manufacture a wheel is lesser than a bike, thus it costs less to make it. And if it costs less to make it, the selling price will also be cheaper. An e-bike costs around 100,000 – 500,000 PKR while an electric wheel would cost a mere 60,000 to 100,000 PKR max.

1.1.2 Duality of function. Assuming someone does have enough disposable cash to buy an electric bicycle, the fundamental fact remaining is that it will only and only function as an electric bicycle and will be rendered useless when the batteries run out of power. Whereas, since this wheel is replaceable, it offers the user the choice of converting the same bicycle from manual to electrical and vice versa within minutes.

1.3 History of Electric Bicycles

It was in 1867, that the first known motorbike was invented by Sylvester Howard Roper of Boston, MA. [3] Thus, one can undoubtedly say that the idea of an automatic bike is not very novel, instead it has been thought of by scientists in the past century. Sylvester's motorbike was set in motion by utilizing energy from the steam engine, thus being called as “Roper Steam Velociopede".

With further advancements in this particular field, the steam engine that was being used previously, to power motorbikes, was eventually replaced with electricity. This was back in 1895 when electric bicycles finally made their place in history. This was the same year in which Ogden Bolten was given US Patent 552,271 for a battery powered bicycle with a six-pack brush and commutator DC hub motor mounted in the rear wheel. His bike was able to draw 100A current using only a 10V battery without any gears or motor of any sort. This was the point in history, when electric motors finally gained practicality.

A variety of bicycles, each with a different driving mechanism, were being set in motion. In some bikes, a belt was used to connect the motor and the wheel. Others included the ones in which the motor was displayed out on the front wheel, and the bikes moved with the help of friction.

The initial idea of electric motorbikes, coined in 1890s, was refurbished in the mid-1950s, to make the bikes eco-friendlier and less hazardous. This idea was given by Alber Parcelle of Boston, and the bike in which such a motor was incorporated was named as “electro motor traction wheel."

This idea hadn't gained much popularity up until 1998, when its production grew by 35%, and almost 49 different types of bikes were being manufactured by various companies of that time. [4]

1.4 Market Research

Health Benefits:

E-bicycles can be a useful part of cardiac rehabilitation programs since health professionals will often recommend a stationary bike be used in the early stages of these. Exercise-based cardiac rehabilitation programs can reduce deaths in people with coronary heart disease by around 27% and a patient may feel safer progressing from stationary bikes to e-bikes. They require less cardiac exertion for those who have experienced heart problems. E-bicycles can also provide a source of exercise for individuals who have trouble exercising for an extended time (due to injury or excessive weight, for example) as the bike can allow the rider to take short breaks from pedaling and provide confidence to the rider that they'll be able to complete the selected path without becoming too fatigued.

Environmental Effects:

E-bikes are zero-emissions vehicles, as they emit no combustion by-products. However, the environmental effects of electricity generation and power distribution and of manufacturing and disposing of (limited life) high storage density batteries must be considered. Even with these issues considered, e-bikes are claimed to have a significantly lower environmental impact than conventional automobiles and are generally seen as environmentally desirable in an urban environment. The environmental effects involved in recharging the batteries can of course be minimized. The small size of the battery pack on an e-bicycle, relative to the larger pack used in an electric car, makes them very good candidates for charging via solar power or other renewable energy resources. Sanyo capitalized on this benefit when it set up "solar parking lots," in which e-bicycle riders can charge their vehicles while parked under photovoltaic panels. Both land management regulators and mountain bike trail access advocates have argued for bans of electric bicycles on outdoor trails that are accessible to mountain bikes, citing potential safety hazards as well as the potential for electric bicycle to damage trails. A study conducted by the International Mountain Bicycling Association, however, found that the physical impacts of low-powered pedal-assist electric mountain bikes may be similar to traditional mountain bikes.

Growth of the market by country:

In the past few years electric cars have gained popularity on press media, but globally, the number of electric bicycles that were sold were more than the number of electric cars. Around 112,000 electric cars were sold across the globe in 2013. On the other side, about

40 million e-bicycles were sold worldwide in 2013. In China, the number of electric bikes exceeds the number of cars on roads

. The overall configuration for sales of e-bikes in 2013 allows China to stand at number 1, at about 32 million, tailed by Europe at 1.8 million, and Japan at 440,000. The U.S. had sales of approximately 185,000 electronic bikes. Further information for many countries with the largest e-bike sales is provided below.

The international market for e-bikes is subjugated by China, with an estimated 85 percent being sold in China. It was estimated by Macquarie that, in 2013, there were 180 million e-bikes on the road, and about 37million new e-bikes were manufactured in China. Applying this growth pattern into 2014, it suggests that the total number of e-bikes in China will surpass 200 million this year. It is to be noted that about 37 million e-bicycles were manufactured in China in the previous year, with an estimated 32 million sold nationally.

Sales of E-Bicycles in Europe [5]:

Year	2006	2007	2008	2009	2010	2011	2012
Sales	98,000	173,000	279,000	422,000	588,000	716,000	854,000

Forecast:

Trends show that the market of e-bikes will grow at a slow but steady rate of 3.1% Compound Annual Growth Rate between 2013 and 2020. Central and South Asia seem to be slow on getting on the e-bike trend but North and South America, along with most of

Europe have shown promising trends in the consumption of e-bikes. [6]. Generally, Western Europe is now the second largest market (behind China) with an expected 1 million sales in 2013 which will increase up to 1.9 million by 2020. The enormous Chinese market is likely to reach 28.0 million electronic bicycles in 2013, which makes up 92% of the entire world market. Owing to its size, China has not been shown in Chart 1.1 which serves the purpose of showing granularity of the other markets. The e-bicycle market in China is decelerating, however, due to a deteriorated economy, increased association of manufacturers, and supply chain, issues in the lead-acid battery market. China’s 2.8% CAGR is not likely to return to its historic rate of growth (13.4% CAGR between 2005 and 2013) in the near future, allowing the annual sales of electric bicycles to reach 33.9 million in China in 2020 [7].

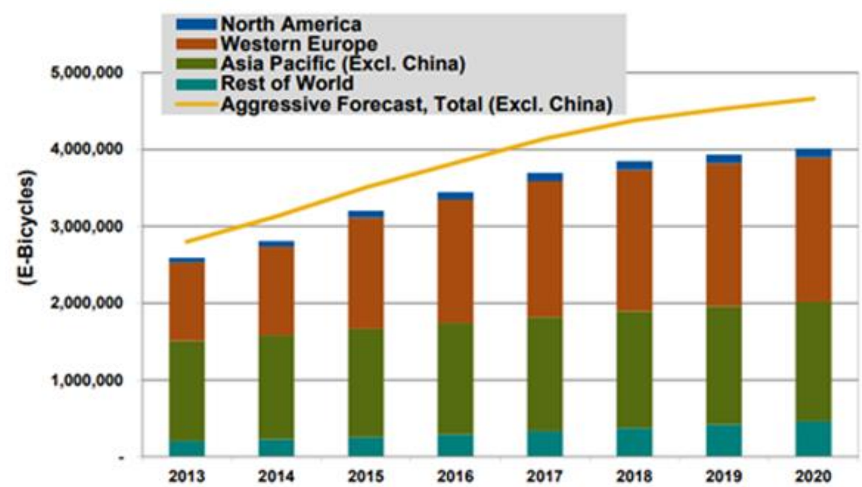

Figure 3 Annual E-bicycles forecast scenario

Forecast in Pakistan:

E-bicycle has becoming popular more and more as it is environmental friendly and is a cheaper mode of transport. Since Sustainable Development Goals (SDG’s) greatly emphasized on the use of e-vehicles in order to reduce pollution so the world is rapidly adapting it. Pakistan, in the similar fashion, been following the trend to overcome the pollution issue. Its market (global as well as in Pakistan) has a bright future as the world is turning towards the E-vehicles and Renewable Energy Resources.

CHAPTER 2: LITERATURE REVIEW

Before we go into too much detail of our project, we would like to start by presenting the existing technologies and machinery that helped us shape our project.

2.1 Existing Similar Vehicles

We took our inspiration majorly from these types of vehicles:

1. Simple Bicycle
2. Electric Bicycle
3. Segway
4. Geo-orbital Wheel

2.1.1 Simple Bicycle

A bicycle is known by a lot of different names, the most popular one being ‘bike’ or ‘cycle’. It is a human powered vehicle that requires no other form of energy to work other than manual pedaling. It consists mainly of a frame that has two pedals attached to it, one in the front and the other right behind it. The driver of a bicycle is often referred to as a ‘bicyclist’ or the more common term, ‘cyclist’.

Figure 4: The most popular bicycle model—and most popular vehicle of any kind in the world—is the Chinese Flying Pigeon, with about 500 million produced. [8]

The earliest record of a bicycle ever being made dates to the 19th century, somewhere around Europe. It gained popularity so fast that by early 21st century, more than a billion bicycles were manufactured and sold worldwide, proving it to be a very well-accepted mode of transportation. [9] It is interesting to also note that the number of bicycles easily outweigh the number of cars. [10] For billions of people worldwide, bicycles provide a fundamental mode of transportation because of its user friendly design and low cost. They also double as a form of leisure activity and people can adopt it as a hobby or as a form of physical exercise also.

Another fascinating fact is that the rudimentary shape and modeling of the bicycle has changed very little since it was first manufactured in 1885, the same chain driven model is still very much in use nowadays. [11] But due to the advent of new materials and the rising popularity of Computer Aided Design (CAD) modelling, many other features of the bike have been improved, specializing it for use in particular terrains.

The creation of the bicycle was the foundation for developing other forms of transport including cars and motorbikes and in fact, quite a number of parts that ultimately were very crucial in the manufacturing of automobiles like ball bearings, pneumatic tires, chain-driven sprockets and tension-spoked wheels were first used in bicycles. [12]

Some of the key parts of the bicycle worth noting are:

1. Frame
2. Drivetrain and gearing
3. Steering
4. Seating
5. Brakes
6. Suspension
7. Wheels and tires

2.1.2 Electric Bicycle

An electric bicycle is known by many names, ‘booster bike’, ‘e-bike’ or ‘powerbike’. It uses an electric motor for propulsion which rotates the wheel and drives it around. There’s all sorts of different e-bikes available in the market depending on the power of the attached motor. Some have a very small motor that just adds to the already pedaling power of the user, these are called ‘pedelecs’. Others have a very strong motor and the bikes seem almost like mopeds in functionality. All these bikes have rechargeable batteries or sometimes have solar panels to keep the battery running. They have varying speeds in accordance with the laws of the countries they are used in but the average speeds for the lower end e-bikes is from 25 to 32km/h and the more powerful ones can go higher than even 45km/h. These bikes are slowly gaining popularity, especially in European countries like Germany and France. [13] But in the more industry based countries like China, these bikes have already replaced fossil fuel-powered mopeds and small motorcycles. [14]

Figure 5: An example of e-bike

In widely broad terms, e-bikes can be divided into two categories, pedal-assist system and power-on-demand system. In the pedal-assist system, the electric motor is controlled by pedaling. It adds to the power input of the user while pedaling and usually are equipped with sensors to find the pedaling speed, force, or both. These e-bikes are referred to as 'pedelecs'. In the power on demand system, the electric motor is stimulated and regulated by a throttle, which is usually affixed to the handlebar of the bike. The figures below explain this concept comprehensively.

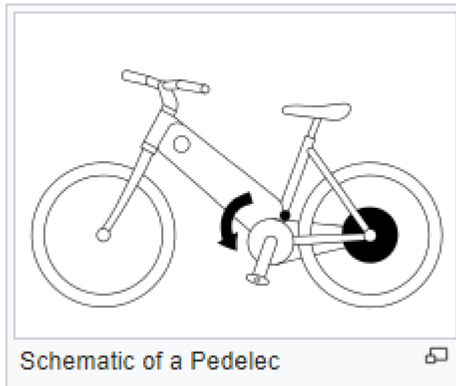

Figure 6: Pedal Assist System

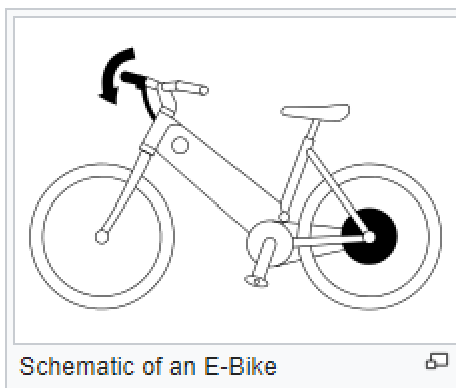

Figure 7: Power on Demand System

E-bikes can further be classified into:

1. Pedal-assist only. This has further two types:
    a. Pedelecs: They use only the pedal-assist system, the power of the motor is usually 250 watts and can travel at a medium speed, around 25km/h.
    b. S-Pedelecs: Also, only use the pedal-assist system, with speeds reaching up to 45km/h or higher.

2. Power-on-demand and pedal-assist
3. Power-on-demand only: Typically, they have a higher power rating motor than pedelecs and are much closer to mopeds or motorbikes in function.

2.1.3 Segway

The Segway was designed and developed by Dean Kamen and was put out for customers to purchase in 2001. Its first official title was Segway HT (human transporter) and was later changed to Segway PT (personal transporter). In elementary terms, it is just a self-balancing scooter consisting of two wheels.

Figure 8: Traditional Segway

The underlying principle of the Segway can be easily modelled as an inverted pendulum control system. Each wheel is motorized by lithium-ion batteries which powers the brushless DC motors to achieve balance using tilt sensors, and gyroscopic sensors developed by BAE Systems' Advanced Technology Centre. The wheels are driven forward or backward as needed to return its pitch to upright.

These have made their place in the market share by having a diverse set of uses. It was advertised to the emergency medical services community in 2011 and to the police forces in the 2008 Olympics. This vehicle can go up to a maximum speed of 20.1 km/h and can travel around 39 km on a fully charged battery, of course, its performance is highly affected by the terrain, riding style and battery conditions.

2.1.4 Geo-orbital Wheel

The geo-orbital wheel is a patented technology developed by engineers from SpaceX and Ford and gained popularity by being on the American television show, SharkTank, where it was highly praised by the judges for its entrepreneurial abilities. This is a recent technology and it’s basically an electric wheel that takes 60 seconds to fix in place of the front wheel of a standard bicycle, turning it into an e-bike, without having to buy a whole e-bike. The body of this wheel is made up of aerospace-grade aluminum and weighs around 8 to 10 kg. The tire itself is made of flat proof foam with a rubber tread, eliminating the risk of deflation.

Figure 9: Geo-Orbital Wheel

It uses a 36V brushless DC motor with an average power of 500W, with a 750W peak power. The motor is a direct-drive with regenerative braking. The wheels can be rotated at variable speeds with a thumb throttle that can be fixed on the handlebar, the highest speed being 32km/h. On a fully charged battery, it can cover around 20 to 30 km without pedaling and 50 to 70 km with pedaling.

2.2 Existing Braking Systems

Braking system in electric bicycle is bit different as employed in common mechanically driven bicycle and reason is inclusion of motor and braking system. When brakes are employed in an electric bicycle, we need to cater response of motor during this time and to control its characteristics wherever required. Following two techniques are common when it comes to braking of an electric bicycle.

1. Regenerative Braking System
2. Friction Based System

2.2.1 Regenerative Braking System

Regenerative braking phenomena involves conversion of wheel's kinetic energy into stored electric power for operation of electric vehicle and thus helping in speed reduction by robbing vehicle of its kinetic energy. The process involves working of an electric motor as an electric generator, supplying energy back to its source for voltage i.e. battery.

In electric railway system, energy recovered through regenerative braking is fed back to the source of voltage and contributes a huge part owing to high speed movement of railway and most of hybrid and electric vehicles. However, when it comes to electric bicycles, speed is not that much to generate considerable electric power, which would have some significant effect of restoring power back to motor.

2.2.2 Friction Braking System

Friction based braking system involves dissipation of kinetic energy into heat which is usually wasted into the surroundings. In such a system braking pads are simply compressed against wheel's rim to make it stop and in the process, braking pads go through wear and tear.

It is quite a simple process to employ but it has some disadvantages like braking pads are needed to be replaced when used continuously for sometimes, and such systems are susceptible to what we call "brake fade" which involves decrease in efficiency of braking system.

2.2.3 Combination of Regenerative and Friction Based Braking System

Although regenerative braking seems like the best braking system to be used because it takes part in energy conservations, however it has some limitations as well and due to such limitations, it is suggested to use friction-based braking along with regenerative braking. Some of such processes are explained below

1. The efficiency of regenerative braking system is limited by state of charge of batteries of capacitors and it works best only batteries of capacitors are not fully charged and thus it is necessary to incorporate friction-based systems as well for times when system is fully charged
2. Under emergency conditions high amount of energy is dissipated immediately and sometimes batteries are not capable to receive such amount of energy at extreme rates and thus friction-based brakes are employed to be used in such emergency conditions
3. In regenerative braking systems braking power is applied to only some of the wheels, so to have controlled braking over the entire vehicle friction-based system is applied to other vehicle tires
4. Regenerative braking is not efficient at low speeds so frictional braking is required to bring the vehicle to complete rest and physical locking of rotor is also required to prevent vehicle from rolling down hills
5. It is always advisable to have friction-based system as a backup for failure of regenerative braking system due to some electrical circuit fault.

Thus, it is wise to use a system of regenerative and friction-based system instead of just one to achieve efficient braking.

2.3 Existing Motors

2.3.1 Brushless DC Motors

The first step to create an electric bike was to select a proper motor. It was, originally, decided that the bike would be set in motion with the help of DC micrometers that will be arranged in a way to turn a sprocket. The circulatory motion between two shafts is provided with the help of the sprocket. The diameter of the sprocket is also changed, to enable the bike to move at different speeds. To provide the sprockets with an increased current supply, to produce more output power, multiple micro motors were connected in parallel. This system was so perplexed, because the micro motors were unable to supply enough power and torque to support the bicycle at high speeds

With further research, it was finally decided that the best way to set this bike in motion is to use an electric DC motor, thus the idea of electric bike was born. In order to induce a static field flux in the DC motor, a permanent magnet or armature windings are used. The armature winding is placed on the rotor of the DC motor. The voltage is induced in the iron core. Around the iron core, series of conducting coils are wound in segments of a commutator. This whole set up forms the armature winding. If any of the wires is broken or damaged, the coil will not be able to rotate smoothly, thus the asymmetrical winding enables it to rotate otherwise. The coils of the armature are connected to an external DC motor which is further linked to an even number of brush heads to enable the DC motor to induce torque.

Because of technological advancements, the use of DC motor has increased greatly. This has led to the implementation of new and improved designs of the motor itself.

The BLDC motor system is being installed in a wide range of applications including domestic appliances such as low power fans, to large industrial appliances such as aviation robotic and servo drives.

The reason why DC motor is deemed more practical, as compared to an AC motor, is because it can operate at varying speeds, can move in different directions and has regenerative breaking. The only disadvantage of using a DC motor, is that the carbon brushes go through a lot of wear and tear that results in the formation of dust. Thus, DC motors require high maintenance, which sometimes lead to the complete replacement of the entire motor. The brush gears also generate high levels of Radio Frequency Interference and can cause failures by creating tribulations between certain aspects of the DC motor. Thus, the brushless DC motor was invented to have the same benefits as that of a conventional DC motor, without the problems caused by the brushes.

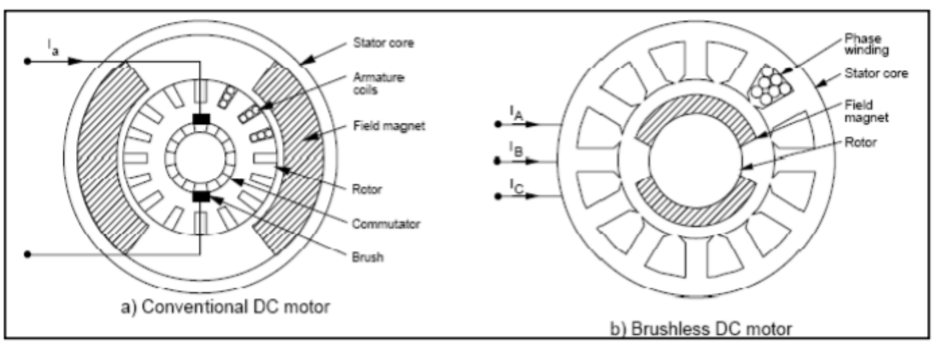

Figure 10: Comparison b/w DC & BLDC motor [15]

The main advantages of a BLDC motor compared to a conventional DC motor are as follows:

1. Increased lifespan and greater reliability
2. Heightened efficiency
3. Can be administered at higher speeds
4. Can reach peak torque from stand still

5. Construction of motor rigid
6. Functional in vacuums and other hazardous environments
7. Decreased Radio Frequency Interference
8. Generation of heat makes it easier to remove and maintain
9. Permanent magnets in the rotor makes it easier to start and stop
10. Linear torque/current relationship provides smooth acceleration
11. Lack of information between sectors helps to create a larger torque ripple
12. Less manufacturing cost
13. Low speed applications require a simple and economical design
14. Eco friendly and highly efficient
15. Speed proportionate to line frequency (50 or 60 Hz)
16. Complex control for variable speed and torque

It is because of the above-mentioned advantages, that we used BLDC for the electric bike. The bike provides an efficient and a practical mode of transportation.

The BLDC makes use of an electrical commutator which makes it even more reliable, instead of a mechanical commutator which is used in a conventional DC motor. Moreover, the rotor magnets in a BLDC motor develop the rotor's magnetic flux causing it work with greater productivity. A brushed DC commutator motor uses permanent magnets in the motor which rotate around the stationary conductor, making it the opposite of a BLDC. The brushes and the commutator help to maintain the polarity of the current. The current polarity is changed by the help of power transistors that switch simultaneously with respect to the rotor position in the BLDC. In addition to that, Hall Effector Sensors are used to direct the position of the rotor. Such sensors are not used in a simple DC motor.

With the installation of the hall sensors, the BLDC provides the most efficient way to power an electric bike.

2.3.2 Hub Motors

Hub motors is also a type of Brushless DC motor. It is incorporated in the hub of a wheel. The spokes of the wheel are directly attached to it which in result drive the wheel. For e-bikes, 250 w to 500 w motors are commonly used.

2.4 Existing Batteries

We selected lithium ion battery as a voltage source in our project and it was the optimum choice to be made based on its longer running hours, lighter weight with respect to its high output voltage and high energy density. At present it is the most popular choice for portable electronics. Although Lithium metal is slightly lower in energy, Lithium ion is safe provided that certain precautions are met when charging and discharging.

Specifications of battery involve rating of 36V and 12AH. Charging cycles of battery exceeds 800 cycles and maximum electrical output is expected at constant speed of 50Km/h (31mph). Weight of the battery is within the reasonable range of 12.12 pounds.

2.4.1 Advantages:

Advantages of lithium ion battery over other batteries are given as under

1. Its light weight gives it a huge advantage over other batteries as it is made of light weight lithium and carbon electrodes
2. It has high energy density and has best energy to weight ratio as compared to any other battery configuration. Moreover, lithium is a highly reactive metal and thus a lot of energy can be stored in its atomic bond.
3. It has relatively long storage periods with high residual capacity because its battery cells are able to hold their charge with minimum losses

4. One regular charge is all they need, and they are not harmful because they have no memory effect. It means you do not have to discharge them completely before charging them and no scheduled cycling is required to prolong battery life.
5. Golden motor through its protection circuit board for lithium ion battery provides extremely safe usage under extreme weather conditions and is also designed to prevent explosion on any impact or collision.

2.4.2 Disadvantages:

Besides its numerous advantages it has some disadvantages as well

1. Manufacturing process complexity increases with density of cells
2. Maximum charge and discharge current at most of the packs is limited to 1C or 2C
3. With separator thickness of only 20-25 micrometers, any small intrusion of small metallic particles can have devastating effects
4. Some capacity deterioration can be observed after just one year even if the battery is in use or not
5. Battery fails frequently after two or three years but at the same time lithium ions are known to have served for five years in some applications
6. Manufacturers recommend storage temperature to be around 15 degree Celsius and in addition to that battery should be partially charged to about 40% during storage.

2.4.3 Lithium ion polymer batteries:

Lithium ion polymer battery would be best for this project rather than using lithium ion cells as it has following characteristics

1. They are much cheaper and cost efficient because they don't need any protection circuit board or advanced battery management system, moreover, type of material used has also significant effect on its cheap cost

2. They have faster charging capabilities and safer performances than traditional lithium ion batteries
3. Most common choice of polymers now-a-days is lithium iron phosphate ($LiFePO_4$), because it provides safer performance use, like lead acid batteries, but still remains as powerful as lithium ion cells. And C-coated lithium iron phosphate battery has been proven as the most environmental friendly battery.
4. They are also known as plastic batteries and are packed by aluminum coated foil and are much safer than liquid lithium ion cells with metal cases
5. Their energy densities are 10-15% higher than usual lithium ion batteries and suitable as portable batteries with high power to weight ratio.

2.5 Dynamometer:

Our main objective is to design a tire which can transform any common bicycle to electrical. There are few characteristics that are to be achieved to fulfill our purpose, first one being selecting a way to convert electrical energy to mechanical output and thus providing tire with specific torque necessary to make it rotate. There can be many ways to achieve it and our first attempt was to use a Dynamometer for our model which could be removed easily when required.

Figure 11: A simple dynamometer

2.5.1 Disadvantage:

Problem with using the dynamometer was its inability to provide necessary torque to make a bicycle wheel rotate and thus many dynamometers were required to achieve that specific torque and it made our model quite clumsy and difficult to control. And to keep the aesthetic sense of our approach we dropped dynamometer and looked for a way to achieve our goal with the most aesthetic design possible.

CHAPTER 3: DESIGN AND SIMULATION

3.1 Front wheel assembly approach:

Our quest for aesthetic design led us to front wheel assembly approach to use as our model which includes battery, motor and other support systems all assembled in a single front wheel assembly and thus making it a portable wheel which could be attached to any simple bicycle when needed, to make it electrical.

Our model consists of an aluminum unibody supportive frame, at center of the front wheel, designed specifically to adjust battery motor and frictionless rollers, for support at contacts with rim, in it. Battery used is lithium ion battery and motor being used in brushless DC motor because of its various advantages over the ordinary motor.

Figure 12: Concept model using Solid works

Manufacturing and design of the front wheel includes many technicalities and problems which were solved either through software or through engineering knowledge gained by related subjects. Some of the highlighted parameters are mentioned below.

3.2 Aluminum Frame:

Raw material for frame was plain aluminum sheets of 3mm thickness which we calculated from our simulations on designing software using stress analysis and taking vulnerable surfaces in consideration. We used aluminum because of many factors including its light weight properties and it was to be used in bicycle so we also had to choose a material which is corrosion resistant. Simulations that were run for calculating the required thickness are showed as under, which shows that central axis point was under maximum stress and sheet thickness was to be decided based on this point.

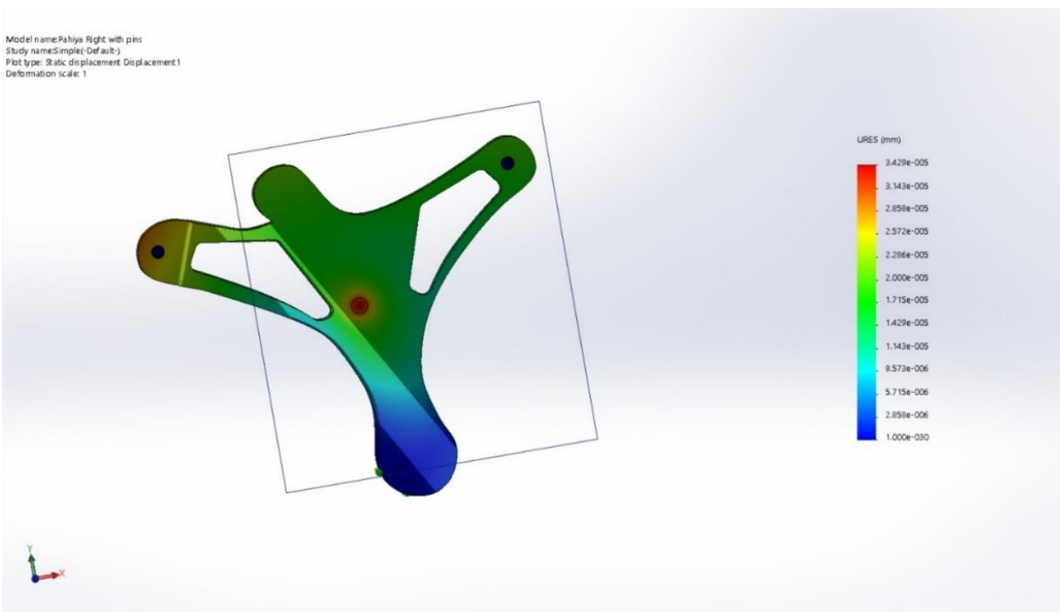

Figure 13, Sheet thickness calculation

First step was to make a CAD model with exact dimensions that would incorporate all components in its assembly. For that purpose, we used the SolidWorks software. This CAD design was later used for cutting of aluminum sheets through machining into specific shapes.

Final CAD design is mentioned below

Figure 14. CAD design for aluminum frame

Next step was to make bends at several points on the sheet. Bending was done at hydraulic presses. Some bends were at 45 degrees and some were at 90 degrees to the surface, keeping in view the arrangement of components inside the assembly as well as the aesthetic sense of the final design. Also, from the simulations we marked the most vulnerable area of the surface and bending points were chosen in a way as not to compromise the sustainability of the frame. Simulations that were run after applying bend is mentioned below and shows that the vulnerable are between axle and motor was in safe limits.

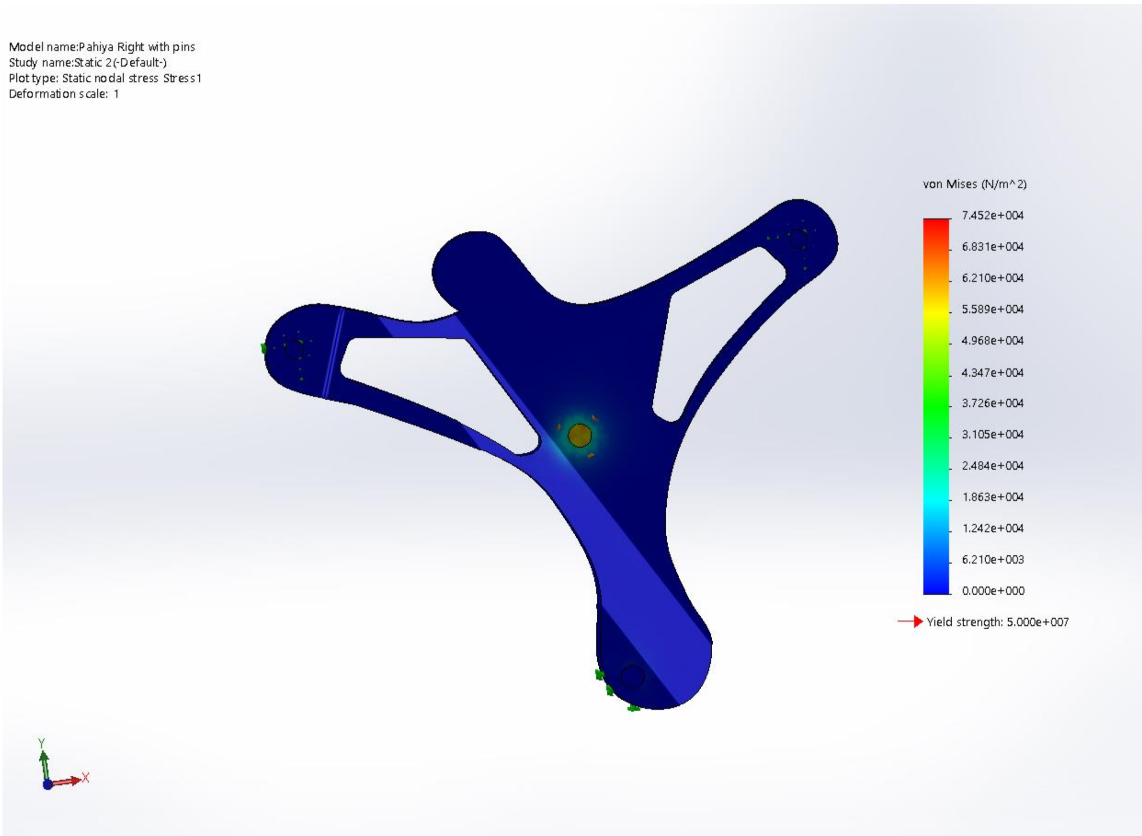

Figure 15. Stress under safe limit

Finally, holes were drilled using milling machines at several points on the aluminum sheet for support of rollers and motor and a central hole for axle that would be supporting the whole wheel assembly on to the bicycle.

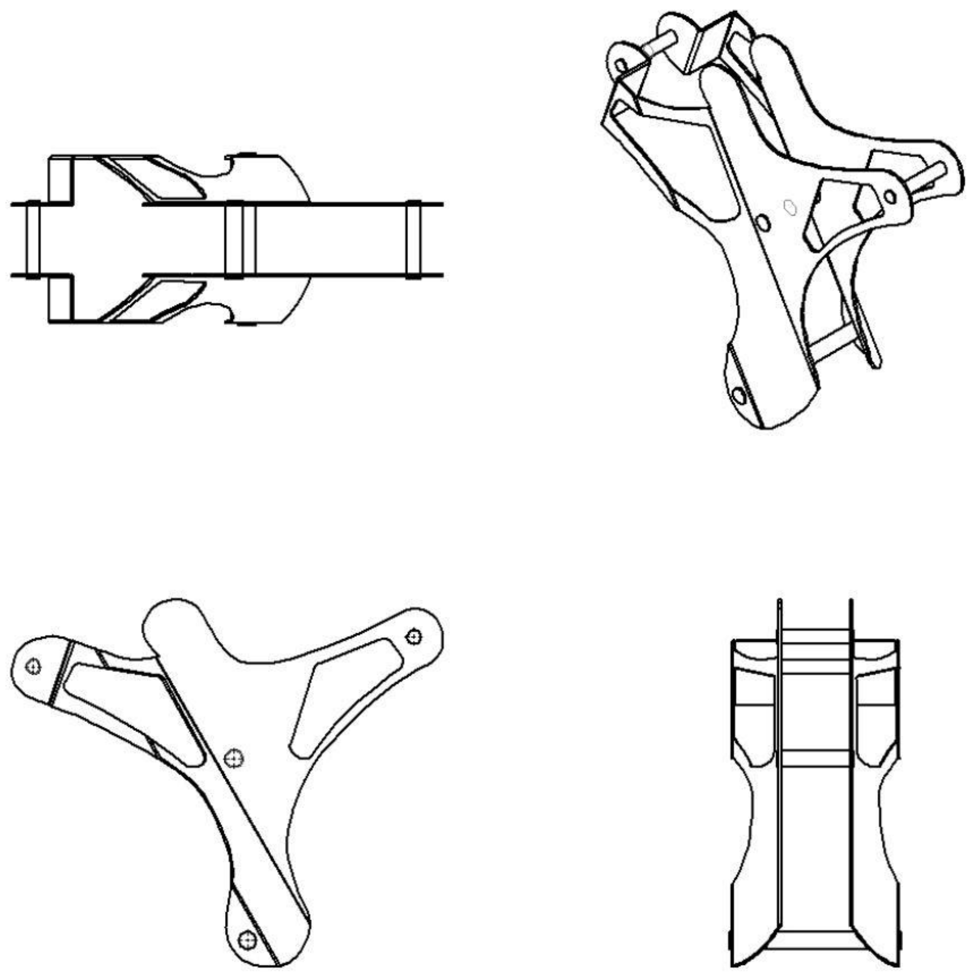

Figure 16. 2D drawing of CAD model

CHAPTER 4: COMPONENTS

There are several steps for the development of our wheel. After our literature review and design, we move towards converting our design into reality that is the fabrication of the prototype.

Figure 17. Components used for electric wheel

4.1 Wheel

700c rim strip has been selected for our prototype. It will be used without spokes whereas its internal surface will be roughened to provide enough friction for the motor to drive it.

4.2 Material Selection

For the fabrication of the frame, there were several options under the consideration: Aluminum, mild steel and fiber glass. Strength to weight ratios have been compared against each other which shoes that aluminum is the best for our prototype.

After proper dimensioning and manufacturing of aluminum frame following components were assembled.

4.2.1 Roller Mechanism

Aluminum body has three contact points on the rim surface. One of them is the motor contact point and the other two comprised of frictionless rollers that are tightened to surface of rim. Through our stress analysis using designing software we came to know that these two points were under the east loading and they were just meant to support the circular motion of rim over the frame, for that because we used nylon as the parent material for manufacturing of roller which was cheap and easily available in the market, also it fulfilled the support requirements of the roller.

These rollers were to be supported on a rod that was to act as axle for the rollers. After simulation running and testing we observed the same diameter for such rod to be 8mm to carry the part of load that was targeted at wheel assembly. We selected medium based on the outer rod diameter i.e. 8mm. Grooves were made in rollers to fix these bearings.

One of the rollers was fixed at its spot on to the frame but other one was made adjustable by use of a lifting mechanism. This roller helped to assemble and fix the aluminum frame inside the wheel's rim.

4.2.2 Bearings

We used ball bearings enclosed in a ring. Based on the diameter of axle which was 8mm we choose the bearing with internal diameter of 8mm and external diameter of 22mm and fixed them at contact point of roller and axle for smooth and frictionless rotation.

4.3 Motor

We used brushless DC motor of 500 watts to carry the load of bicycle and rider forward in a front wheel drive. The motor was out runner and was fixed at the bottom contact point of frame on the rim surface to avoid any shear on aluminum surface due to weight of the motor.

Rubber was used at contact points of motor and rim to increase gripping force between them and to avoid slipping of motor. Through this motor we achieved the speed of about 25 km/hr on the bicycle.

Specification of the motor in this kit

Rim size:	20"~28"
Spoke hole:	12G,36Holes,Diameter 3.2~3.4mm
Voltage:	48V
Rated power:	500W
Efficiency (%)	≥80%
Cable side :	Right
Magnet rate:	16Poles
Reduction gear ratio:	1:5.3
Fork size:	138mm
Inside speed sensor:	1
Hall sensor:	With
Free wheel:	Cassette9-10S
Brake:	Disc brake/V-brake
Classification of waterproof:	IP54
Weight:	3.9Kg

Figure 18. Specifications of the motor

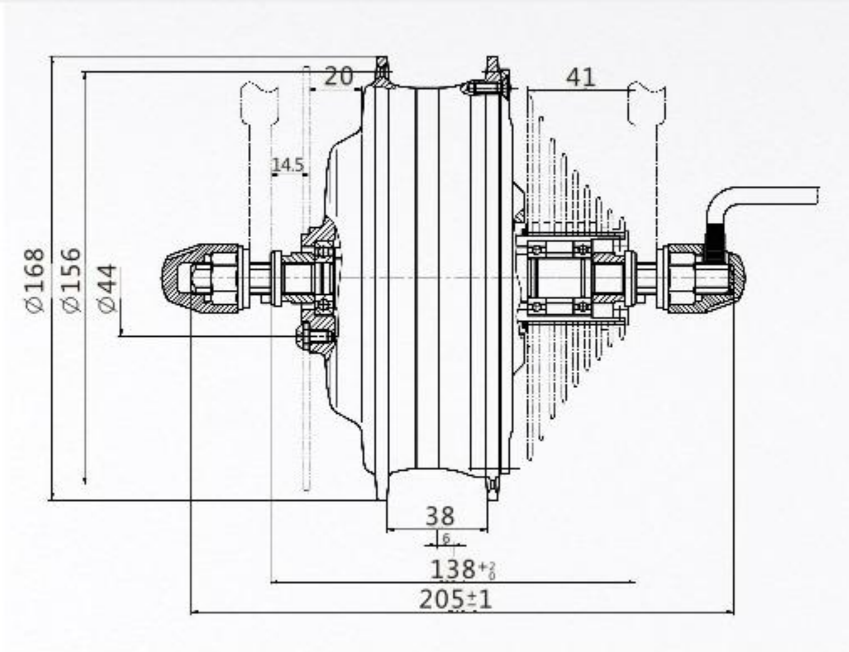

Figure 19. Dimensions of motor

Figure 20. Side view of motor

4.3.1 Motor Controller

Motor controller that was used came along the motor, designed specifically to work for this 500-watt brushless DC motor. It had several purposes like controlling speed of motor by giving you choice to move between 5 different gear ratios.

Name	48v22a 9 mosfets block wave controller
Type	Hub Motor Controller
Max current	22A
Mosfet	9 pcs
Voltage	48V

It also senses the temperature of the motor and displays it on a screen to avoid any accident or damage owing to high temperature. Moreover, speed of bicycle and remaining battery power are displayed on the screen, all controlled by the controller.

Controller also plays its part in electronic brakes that are used, by shutting down the motor whenever brakes are applied so that to assist in braking.

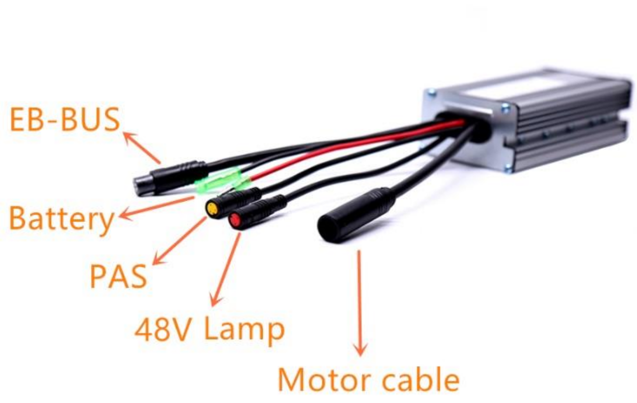

Figure 21. Wiring coming out of controller

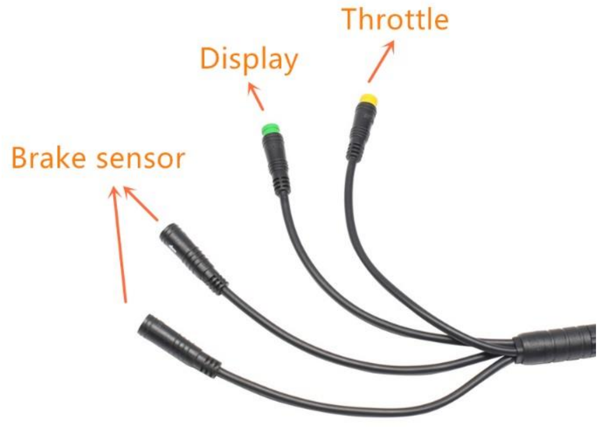

Figure 22. Connections of extended wiring

4.4 Thumb Throttle

A thumb throttle will be attached to the handle for the ease of use. It will help to increase the motor speed as required.

4.5 Battery

We used the lithium-ion battery mainly because of its low weight and high performance. A 36v 10 Ah rechargeable battery was used with an integrated BMS. It directed the power to the motor to drive it. The dimensions of the battery are 76*110*390 mm (thickness*width*length) which will fit in the aluminum frame. As battery, controller, motor and all components were to be assembled in front wheel, so it was crucial to consider the weight of each component.

This battery can be fully recharged in 4 hours through any common electrical household socket and on a single charge it can take bike to almost 30 kilometers without paddling and almost to 50 kilometers when bike is paddle assisted.

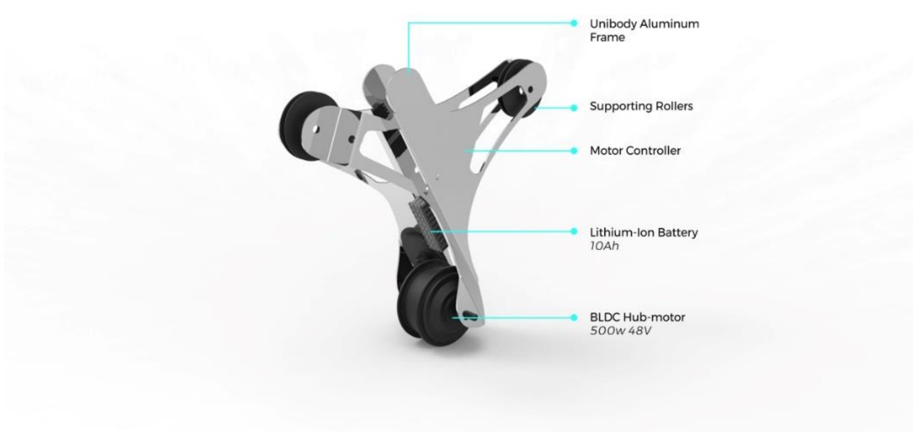

Figure 23. Final assembly of the wheel

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1 Objective:

From this project we intend to achieve our goal of converting a simple bicycle to electric by just replacing the front wheel with the electric wheel. Wheel has simple joining mechanism and can be attached and detached from bicycle within duration of a minute. It has all components necessary to make a bicycle electrical, assembled in a single front wheel, and can bring revolutionary changes in economics in market of electrical and hybrid bicycles because it provides a very cheap solution to high prices of commonly made electric bicycle.

5.2 Overview:

Modern technology made it possible to use a system of mechanical and electrical components for purpose of building an electric bicycle tire and assembling it in an aesthetically sound, portable wheel assembly.

5.3 Attainments:

By implementing this technology in field of electric bicycles we have attained many mile stones and some of them are listed below

1. It has hybrid characteristics which means that it can either be used with or without electrical power and thus it leaves room for exercising athletes to make a use of this technology for their exercising purpose as well
2. Its portable design makes it very easy to replace or recharge and to be attached with any common bicycle in order to make it electric instead of dealing with whole clumsy assemblies used in other common electric bicycles
3. Control system has made it energy efficient, through which it can be maintained at an optimum speed so that only minimum and necessary amount of energy is used in the process.

4. Mechanism includes control system for brakes as well which operates by shutting down the motor whenever brakes are applied and thus not affecting the braking action by adding power to the wheel.

5.4 Challenges:

1. Our first challenge was to design an aesthetically pleasing assembly which had to replace the whole electric bicycle with a single wheel.
2. Second challenge was to control the working of motor under various conditions and circumstances like response of motor at high or too low speed and response of motor when brakes are applied.
3. Next challenge as to make it energy efficient and user friendly which comes by making a design which can be carried easily to any place and can be attached to any common bicycle.

5.5 Skills Gained:

We gained the knowledge and skills about

1. Technologies and analyzing techniques which can be used to realize such a project which takes into account many electrical and mechanical components
2. Software and simulation methods used to check the working of our prototype and to integrate various electromechanical components with the help of computers
3. Project management techniques, including dealing with economics of electrical bicycles because the design we purposed not only does makes common bicycle electrical but also do it with minimum budget as compared to electrical bicycles generally available in market.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Recommendations:

Though our project has covered the basic requirements of converting a simple bicycle to electrical, however there always remain, some room for improvements including

1. Making design more energy efficient by introducing regenerative braking system and also by methods of recharging batteries during simple paddling of the bicycle and thus such a system would do great for exercising purpose as well by requiring more exertion than usual from rider.
2. Reducing weight of the wheel assembly will help in reducing the power consumption as well as make the tire more user friendly and easy to be carried anywhere without any difficulty.
3. Solar panel introduction in design can help recharging the batteries through solar energy during daytime rides and thus would be great step in making it more energy efficient.
4. Modified design of such a portable electric wheel can be applied in wheel chairs to make them electrical or hybrid and may find its use in many other mechanically driven systems.

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