Design, Analysis, And Fabrication of Electric Kick Scooter for Indian Road Conditions

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Abstract

The day-by-day rising of carbon emissions and escalating prices of conventional fuels have created much more necessity and attention towards electric propulsion globally as well as in India. As per data collected from the NITI Aayog report, India can save about 64% of passenger mobility energy demand and reduce carbon emissions by up to 37% by the year 2030. There has been a noticeable rise in the use of electrical kick scooters in European countries and the United States, with the prediction of an overall market evaluation of USD 2.5 Billion recorded to grow at the rate of 10.3% CAGR from 2021 to 2028. Despite the soaring demand for electric vehicles and advances in electric vehicle technology, India is still facing some stumbling blocks towards turning it into a complete EV nation. One reason is the high initial investment in electric vehicles.

The objective of our project is to bridge the gap between customer needs in the current scenario and provide a cost-effective micro-mobility option that can convince economical needs and provide portable transport options. By looking at every other option currently available in India, the major mobility options are electric bikes, scooters, and cycles. But due to the high initial investment cost, we chose to design, analyze and fabricate the electric kick scooter. We also analyzed the report on daily average commute travel in major metro cities in India which came out to be 20-25 Kilometres per day. Therefore, by taking into consideration the factors such as projected cost, structural requirement, and availability of resources we aimed to design the electric kick scooter which seems to be the best trade-off to satisfy the basic daily commute needs and load capacity.

Analyzing the Indian drive cycles and requirements, we followed the model-based design approach and sized powertrain on MATLAB and SIMULINK. The frame of the electric kick scooter was designed taking into consideration the ergonomics, and cost-effective use of materials. This electric kick scooter can also be used for private as well as majorly for public sharing commutes to minimize the product utilization cost providing a comfortable riding experience.

Objectives:

- Use of model-based design approach using MATLAB/Simulink
- Make use of drive cycle for powertrain sizing
- Should be able to carry a load of 100 Kg.
- Achieve a range of 25-28 Km in a single charge
- Integration of suspension system to make it sustainable for Indian road conditions.
- Fast charging in a short duration
- Easy foldable and portable design

Methods: The electric kick scooter is modeled and simulated in MATLAB and Simulink and other mechanical components such as the suspension system, mainframe, steering, etc. are designed and analyzed in Solidworks to sustain and perform as expected.
Findings: During the research, we observed the vehicles available in the market had a fixed range of outcomes and limited performance for Indian road conditions which provided an opportunity for us to try and implement an innovative design with economical manufacturing which makes the entire vehicle affordable, without compromising the performance and the aimed goals.
Novelty: The electric kick scooter is designed to adapt to Indian roads and the vehicle is modeled in MATLAB for a better understanding and accurate outcomes. The final manufactured vehicle weighs much less than other vehicles in this domain. The vehicle has suspension which contributes to better handling and provides much easier maneuverability. The vehicle folds down which makes it easier to carry around and fits in small spaces.
Keywords: Carbon emission, Economical Portable transport, Electric propulsion, MATLAB, SIMULINK.

1. Introduction

An electric kick scooter is a vehicle that has to be ridden in a standing position and propelled using an electric hub motor. It is classified under the form of micro-mobility. The scooter is designed in such a way that the deck is made comparatively broad enough to stand for the driver. The first-ever electric kick scooter was made by Autoped at the beginning of 1915. In recent times, electric kick scooters have gained popularity in western countries because of their compactness and they are mainly introduced on sharing platforms by the companies such as Lime and Bird with help of apps allowing users to rent the scooter.

They have hard wheels with a generally foldable chassis made of aluminium. Those scooters are used in entertainment parks, for security patrols, and leisure. They are very much popular in urban areas and used as alternative options for bicycling and walking.

Electric kick scooters are an environment-friendly personal mode of transportation. They can be specifically used for small rides in urban areas. An average adult electrical kick scooter weighs about 20 kg that has a 250-Watt motor powered by a 250 Watt-Hour Lithium-ion battery, and 15 Kilometre range with a top speed under 25 Kmph costing around 30,000 – 40,000 INR.

1.1 Need

The constant rising of carbon emissions and day-by-day escalating prices of conventional fuels are major reasons to look at Electric vehicles as an alternate option. Many western countries have turned themselves towards new EV alternative options. Although advanced developments are taking place, India still is facing some stumbling blocks before turning into a complete EV nation.

According to reports, the daily average commute in India in major cities is around 20-25 Kilometres. Therefore, looking after many considerations and factors, an electric kick scooter proves to be the best trade-off to satisfy the basic daily commute needs and load capacity. The consistently rising rate of fuels and day-by-day worsening levels of pollution have been some of the serious problems in India. According to the 2020 report, 35 cities in India stand among the world's top 50 polluted cities. The average traveling time taken to travel for a distance of 20 km in the city takes around 40 mins to travel due to increasing traffic issues. Therefore, India needs a compact traveling solution that will be non-polluting, consume less energy than conventional energy resources, and will take less time to travel on a daily commute basis.

1.2 Problem Statement

- To design an electric kick scooter with a total driving range of 25-28 km with the capability of propelling a 100 kg load.
- To design a suspension system having a total combined jounce and rebound range of 50 mm while maintaining a minimum ground clearance of 100 mm in all possible dynamic conditions.

2. Methodology

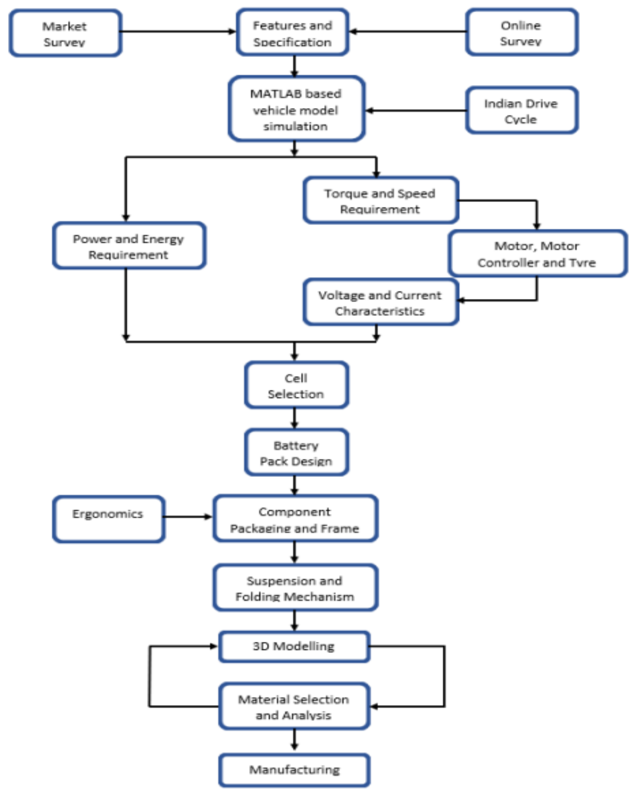

Figure 2.1 Methodology flowchart

2.1 Market Survey

Before deciding on the design parameters and the objectives of the electric kick scooter a thorough market survey was carried out. The global electric kick scooter market was evaluated at 2.5 billion USD in 2020 and a 10.3 % CAGR from the year 2021 to 2028. Many western countries such as France, Germany, the United Kingdom, and Spain have observed a large acceptance of the eco-friendly and maintenance-free electric kick scooter culture. The need for smaller parking spaces, especially for countries like India, inexpensive transport costs, the ease of exercise in the traffic-congested metropolitan cities in India, and the rising focus on eco-friendly alternatives of transport have surged the demand and support for an electric kick scooter.

Table 2.2 Electric kick scooter market survey

Sr no.	Country name	Bike name	carrying capacity(kg)	Weight	Motor specifications	Tire dia.(inch	Mileage (km)	Charging time	capacity and other	speed(kmph)	Price(INR)
1	INDIA	Hover board India: eco electric scooter	15-120	11 kg	250 W	8	15-18	5 hours	7.8Ah	25	38000
2	CHINA	MI electric scooter M365	100		Max tourque: 16 NmMot	8.5 inflatab	Above 20	5.5 hours	250 Wh18650	25	54990
3	CHINA	Jasion ES electric foldable scooter	120	10.4 kg	300W DC Brushless Front Whe	6" solid fro	40-50	4-5 hours	Battery Capacity:	30	40908
4	INDIA	U-BOARD	25-100	-	250W		30	5 hrs	18650 mAh high-ca	25	47997
5	EUROPE	Egret eight v2	100	14	350W with max output o	8	30	00% and 2h	36 V, 10.4 Ah	27.3	65401
6	EUROPE	Inokim light 2	100	13	350W base / 650W peak	8.5	24-35	4 to 5 hrs	LG Li-ion 36V 10.4A	35	73107
7	EUROPE	SXT light plus V	125	11.2	Brushless Hub motormax	Solid rubbe	40	3 hrs	10.5 Ah378 wh	20	78395
8	CHINA	E-TWOW/E-Wheels Booster Plus s+	100	11	500W motor(Brushless D	-	35	with 3 A ch	Li-ion battery v	35	51153
9	CHINA	Marsoul Electric scooter	100	17.2	Single drive 48v 501-1000	9		4 to 6 hrs	8.8 Ah	31-40km/h	27808
10	CHINA	P10 Electric scooter	150	17	Rated power: 350wmax p	10	35 to 45	5 to 6	DC36V10AH lithiur	25	22990
11	CHINA	PXID C1 electric kick scooter	120	20	500W motor(Brushless D	10	80 to 90	6	Removable Lithium	25	28540

An overall market survey of major and widely used electric kick scooter companies was done to identify all general specifications included. Around 10-11 major companies such as MI, U-Board, SXT light plus-V, etc. were listed. All general and common features were listed as follows:

- Range: 30-40 Kilometres
- Max speed: up to 30 Km/hr.
- Battery Capacity: 36 V 10Ah
- Battery Type: Lithium-Ion
- Motor power output: 250W- 500W
- Motor Type: BLDC hub motor
- 3-step foldable system
- Frame material: Aluminium Alloy
- Price Range: 50k- 60k INR

Our project aims to minimize the production cost along with providing as close features as other Electric Kick Scooter brands in the market. Therefore, the design was kept with very little complexity and optimum sturdiness.

2.2 Drive Cycle

The drive cycle is representative of the road. It is a series of data points representing the speed of a vehicle versus time. They are produced by different countries and organizations to assess the performance of vehicles in various ways such as battery consumption, electric vehicle autonomy, and polluting emissions [21].

The Indian drive cycles are developed by taking into consideration various parameters which are affected by traffic and road conditions such as duration of acceleration, deceleration, maximum speed, cruise and idle time, and the number of stops per Km. Considering all these parameters the Indian drive cycle was referenced to get the overall energy consumption and other parameters required to design the electric powertrain system in MATLAB/SIMULINK [22].

2.3 Modelling on MATLAB/SIMULINK

All the design parameters were found on MATLAB/SIMULINK by developing a vehicle model integrated with the drive cycle. Similarly, it was carried out for motor and battery pack characteristics. All the results such as Torque-Speed, Voltage-Speed, Torque-Current, and Power-Distance characteristics were obtained and integrated to form a complete model-based design of the electric kick scooter.

2.4 Motor Selection

Amongst the various types of motors, the BLDC motor was selected as it has lower control complexities and better efficiency than others. The selection of motor parameters was based on the output of the vehicle model developed on MATLAB/SIMULINK

We found that most of the electric kick scooters were using a tire diameter of 8 inches. By considering the Indian road conditions, a 10-inch diameter BLDC hub motor was found to be an ideal choice [16].

2.5 Battery Modeling

The lithium-Ion battery type was selected because of its high energy density compared to its weight. Various battery parameters such as voltage and current discharge versus time were determined from the result obtained from the drive cycle simulation. Also, it was designed by taking into consideration the power output required to drive the scooter up to a specified range. The oversizing of the battery was avoided for safety purposes of rider, weight, and compact packing [14].

2.6 CAD and Analysis

After determining the various inputs and based on the results the component sizing was finalized followed by its computer-aided design and finite element analysis. Considering all the aspects and load capacity the electric kick scooter frame was designed with minimal complexity that is foldable and portable.

3. Design and Analysis

3.1 Motor Selection

The two available options to choose the type of motors were AC motor and DC motor. Around all the battery sources of the electric vehicles in the current market were lithium-ion technology. All the portable batteries which are currently in use in the market provide the DC supply. The inverter is needed to convert the DC power supply to get it in AC form. It unnecessarily increases the weight and complexity of the battery and the controller design. Also, it adds weight to the mechanical structure of the scooter which makes the electric kick scooter heavier than the general or affordable expectations of the current customer in the market.

Also, the DC motor has easier speed control than the AC motor which puts the DC motor choice first. DC motors have always been on the top when it comes to good linear characteristics, excellent performance, strong overload capacity, and variable speed motion control. Therefore, In the end, a Brushless wheel hub DC motor was chosen with the following specifications.

Table 3.1 Motor Specifications

Company	Yalu Motors
Rated Power	350 Watt
Rated Voltage	24 V
Speed	400-1000 RPM
Efficiency	83%
Certification	CE, CCC, ROHS
Speed	12-28 Km/hr
Diameter	254mm with tire
Weight	4.5 Kg
Load Weight	80 - 150 Kg

3.3 MATLAB and Simulink Model:

After calculation of the overall power requirement for the electric kick scooter, motor, vehicle body, and battery parameters were finalized using the model-based design method on MATLAB and Simulink. Simulink enables users to design our system with a multidomain model and simulate it before moving to hardware. The primary aim was to estimate the battery state of charge and range for an electric kick scooter. The following block model diagram was simulated on the Simulink software.

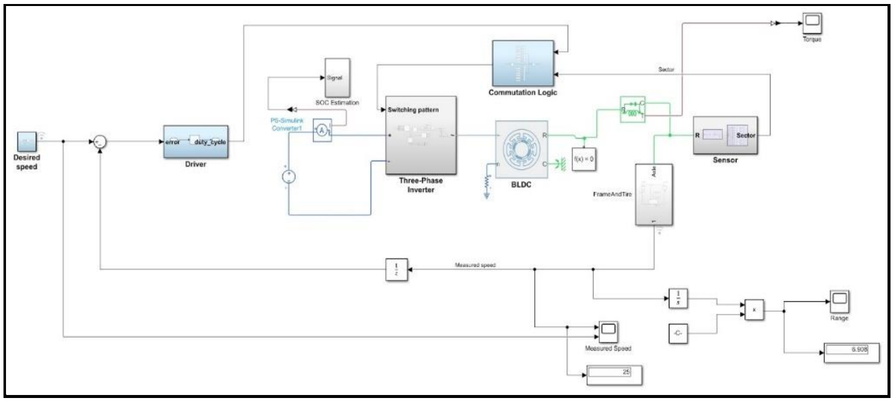

Figure 3.2 Electric Kick Scooter Simulink Model

The simulation was carried out with a drive cycle input for power computation. The vehicle body block provided by the Simulink takes into account the forces due to air drag, gradient, CG height above the ground, Rider mass, and vehicle mass including the front and rear tires.[7]
The values of variables taken were as follows,

Table 3.3 Electric Kick Scooter MATLAB Model Variables

Vehicle Mass	20 kg
Rider Mass	80 kg
Air Drag coefficient	0.4
Frontal Area	1 m^2
Battery Voltage	24 V
Rated current	12.5 A
Rolling Resistance	0.002
Tire Diameter	10 inches

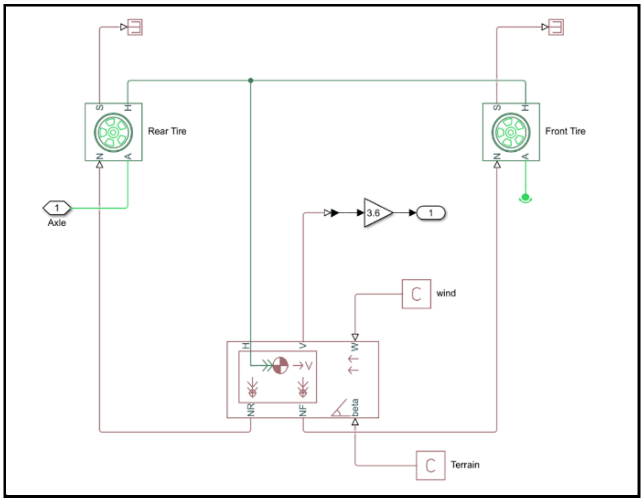

Figure 3.4 Vehicle Body and Frame

3.4 Battery Sizing

Terminology:

- Nominal Voltage (V): The reference voltage of the battery, also known as the "normal voltage" of the battery.
- Cut–off voltage (V): It is the voltage at which a battery is considered fully discharged, beyond which further discharge could cause harm. It is this voltage that generally defines the "empty" state of the battery.
- C rate- The C rate is the measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means the discharge current will discharge the entire battery in 1 hour.[13]
- State of Charge (SoC) is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points (0% = empty; 100% = full).
- Nominal Capacity of the battery: The nominal capacity (Q_N) is defined as the amount of charge delivered by a fully charged battery under specified conditions of temperature and load. Capacity is calculated by multiplying the discharge current (in Amps) by the discharge time (in hours) and decreases with increasing C-rate.[1]

Assumptions:

1) P-300W
2) Battery voltage-24V
3)V = 25km/hr. = 6.944m/s
4) Range - 25km

Calculations:

The energy required to be supplied by Battery per kilometer is:

$$\frac{Wh}{Km} = \frac{P}{Range} = \frac{300}{25} = 12\frac{Wh}{Km}$$

To supply this amount of energy, the capacity of the battery per kilometer should be

$$\frac{Ah}{Km} = \frac{\frac{Wh}{hr}}{V} = \frac{12}{24} = 0.5\frac{Ah}{hr}$$

Hence, for the 25 km range, the capacity of the battery is:

$$Ah=\frac{Ah}{Km}*Km=0.5*25=12.5Ah$$

Charging time -

According to the formula:

$$T1=\frac{(Ah*Cp)}{A}$$

Where,
T1= Charging Time
Ah= Battery Capacity
Cp= Charging Efficiency
A= Ampere of Charging
(Lithium Battery Charging Coefficient is generally 90%⟻0.9)

$$T1=\frac{12.5*0.9}{5}$$
$$=2.25$$

About 2 hours and 15 minutes are needed to charge the 24V,12.5 Ah Lithium-Ion battery.
From the above calculations, a 24 V,12.5Ah battery is selected for this application
As the Lithium-Ion battery has a high energy density and better longevity compared to other batteries like lead-acid batteries. Therefore, it was ideal to opt for lithium-ion batteries.

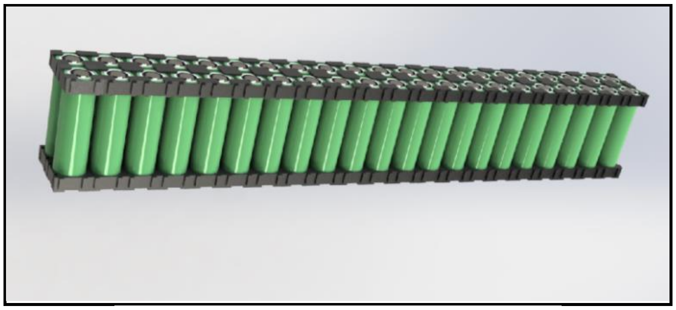
Figure 3.5 Lithium-ion Battery Pack 7s6p

The Battery is designed and assembled by using 18650 Rechargeable Lithium-Ion cells.
Its technical specifications are as follows:

1. Nominal Voltage of cell- 3.7V.
2. Nominal Capacity- 2.4mAh.
3. Operating temperature- Charge 0 ^{o}C to 45 ^{o}C Discharge 20 ^{o}C to 60 ^{o}C
4. Weight- Approximate 49 g
5. Discharge current- 3C

Lithium-ion cells are susceptible to various fire hazard accidents. Utmost safety has to be taken while operating the battery. The battery should not be directly exposed to sunlight. The use of a powerful charger or fast charger may decrease life or might damage the cells of the battery. The Battery must be stored in a cool and dry place.[15]

3.5 Battery Management System (BMS):

For better management of battery power usage and continuous monitoring of the battery pack so that to ensure the safety of the device, batteries, and the User itself the BMS is integrated with the vehicles. Therefore, after studying and understanding it was decided to use a BMS of 24 V, 7S in the vehicle.

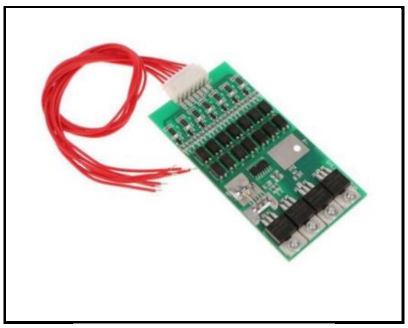
Figure 3.6 BMS of 24 V

3.6 Simulations and Analysis

After running the simulations for 360 seconds the values of the state of charge, distance, and power consumption of the electric kick scooter were obtained using a data inspector. The values of the total distance traveled by the electric kick scooter were estimated using the obtained values from the simulations.

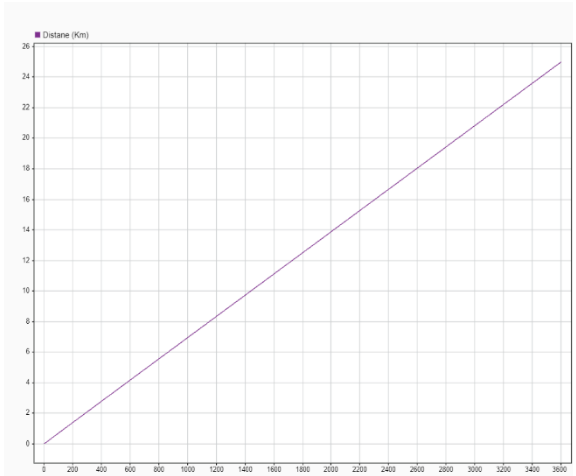

Figure 3.7 Distance Vs Time

From the above graph, we can see that the total distance traveled by the vehicle in 360 seconds is 2.464 kilometers with the state of charge dropping to around 84 % from the 95% initial state of charge.

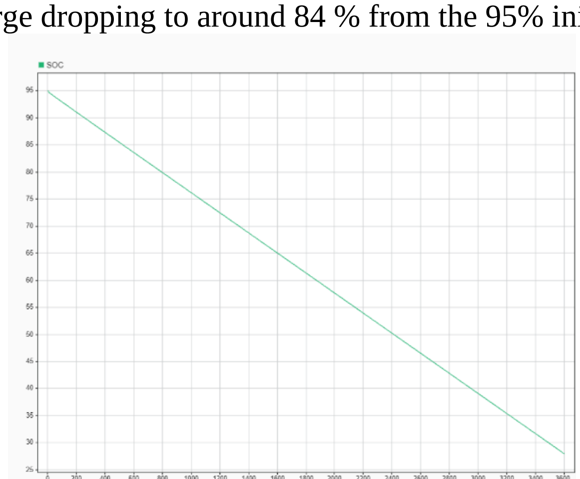

Figure 3.8 SOC Vs Time

Therefore, the total travel range for 3600 seconds was estimated to be 24.64 Kilometres from the simulations. Also, it was found that the peak power consumption for the drive cycle was near 500 Watts with a mean power consumption of 300 Watts.

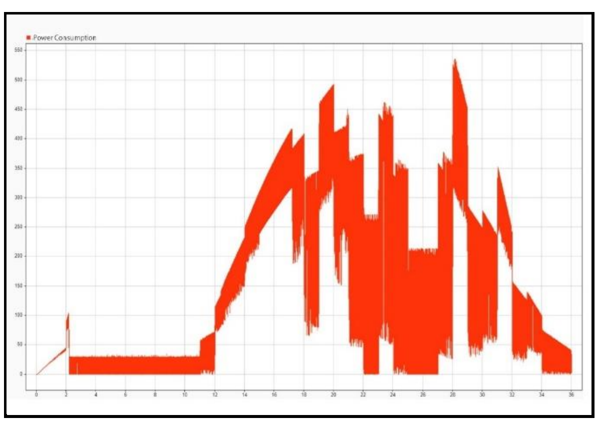

Figure 3.9 Power Consumption

3.7 Suspension Geometry

After the procurement of the hub motor, dummy wheel, motor controller, battery pack, and damper, we were able to determine the optimum space needed for the platform for a comfortable riding experience and hence started with 2D alterations of the platform and suspension geometry as shown in the sketch below. The scooter was designed taking into consideration the Indian roads, which lead us to keep the combined jounce and rebound of the suspension system to a minimum of 40 mm with a minimum ground clearance of 100 mm in all conditions.

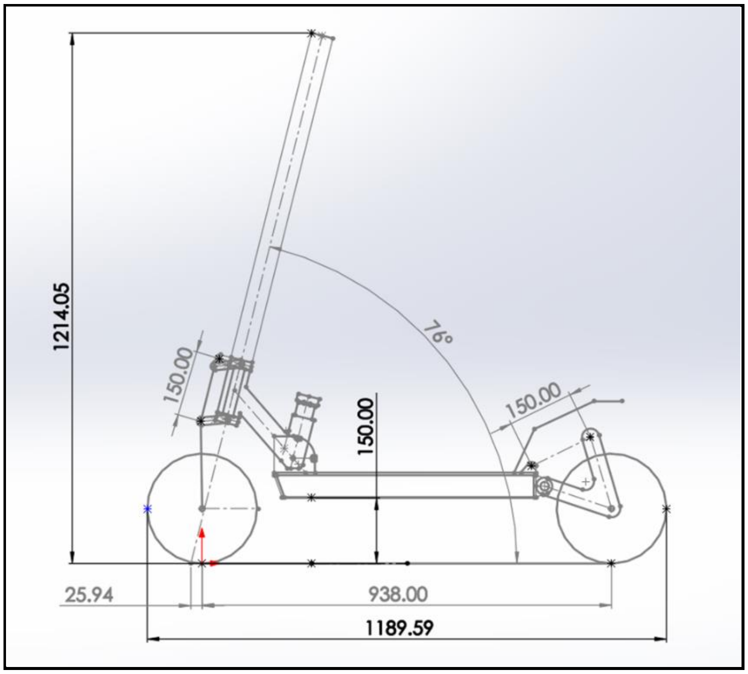

Figure 3.10 Final Suspension Geometry Parameters

Table 3.11 Suspension Geometry Parameters

Wheelbase	938 mm
Caster angle	14 deg
Front spring motion ratio	0.967
Rear spring motion ratio	2.898
Mechanical trail	25.94 mm

3.8 Frame

After developing the sketch, we were able to find the hard points and link lengths. The platform was designed to sufficiently place the battery along with the motor controller below the platform. Also, the platform was designed in the slot and insert system to fix the position of side plates and brackets. The platform is adequate for the driver to stand comfortably. Considering the portability of the vehicle, it is made compact and as light as possible. Since we wanted our Electric kick scooter to be easily mobile, Aluminium 6061 T6 material was selected. All the parts are designed in such a way that, when welding takes place, the parts will themselves act as Jigs and fixtures. Hence reducing the errors while welding with increased accuracy.

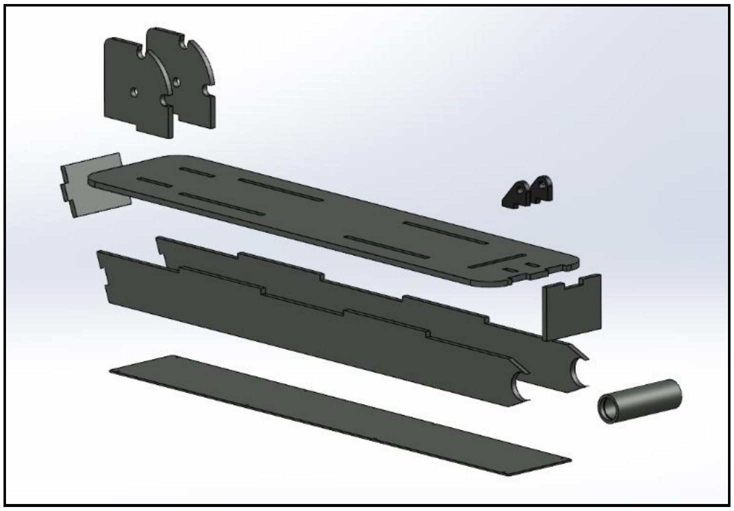

Figure 3.12 exploded View of Frame

3.9 Finite Element Analysis:

FEA Simulation generally represents the key behavior and characteristics of the parts under certain loads and forces. The Finite Element Analysis of the parts is done on SOLIDWORKS. The stress and deformation analysis are done using this software. The analysis of the Frame, Rocker, Fork, and Folding mechanism square bar is performed [11].

Main Frame:

Main Frame is the main component of the Scooter onto which wheels and other components are fitted. The material selected for the mainframe is Aluminium 6061 T6. The frame was supported with two fixed supports one at the rear suspension bearing housing and one at the front folding pivot point. A load of 3000 N was applied at the center of the platform simulating human load [6].

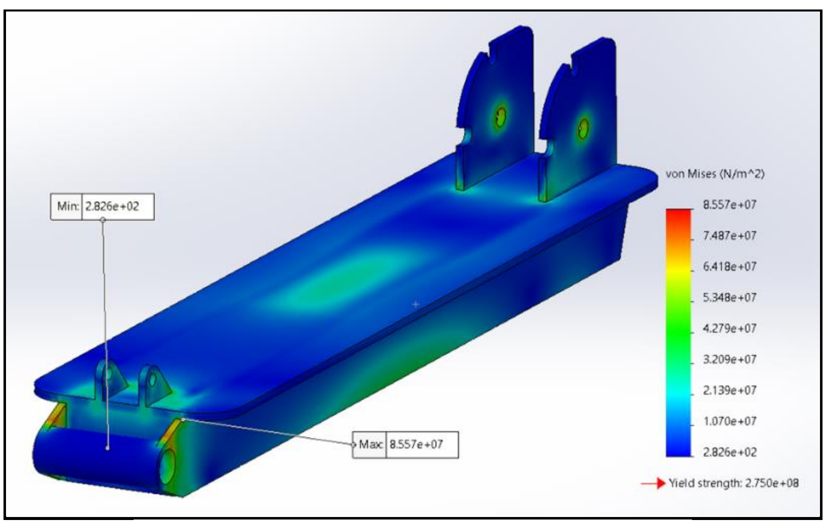

Figure 3.13 Mainframe Equivalent von Mises Stress

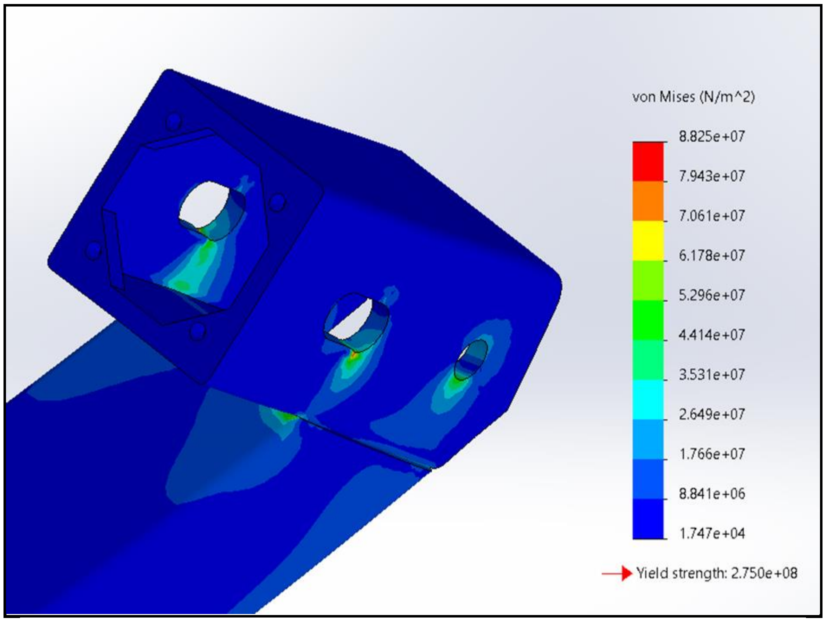

Figure 3.14 Folding Mechanism Square Bar Equivalent Von Mises Stress

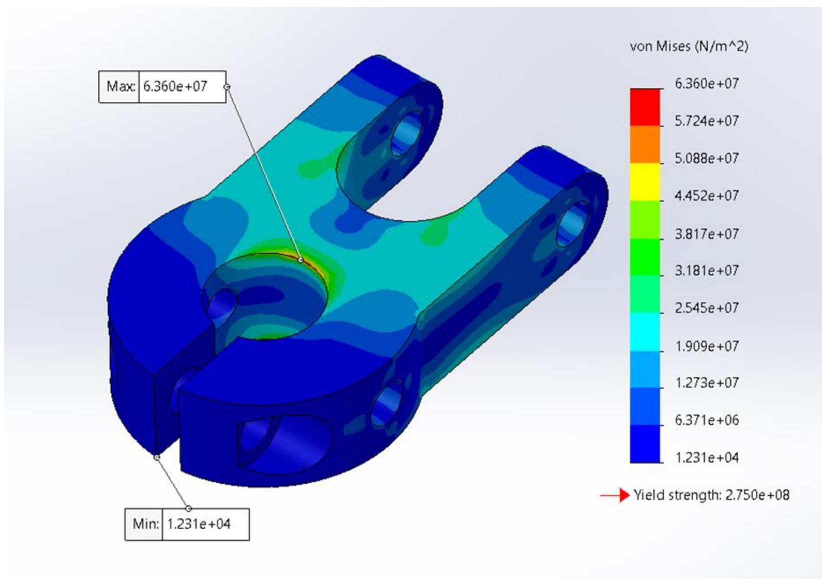

Figure 3.15 Front Damper Bracket Equivalent Von Mises Stress

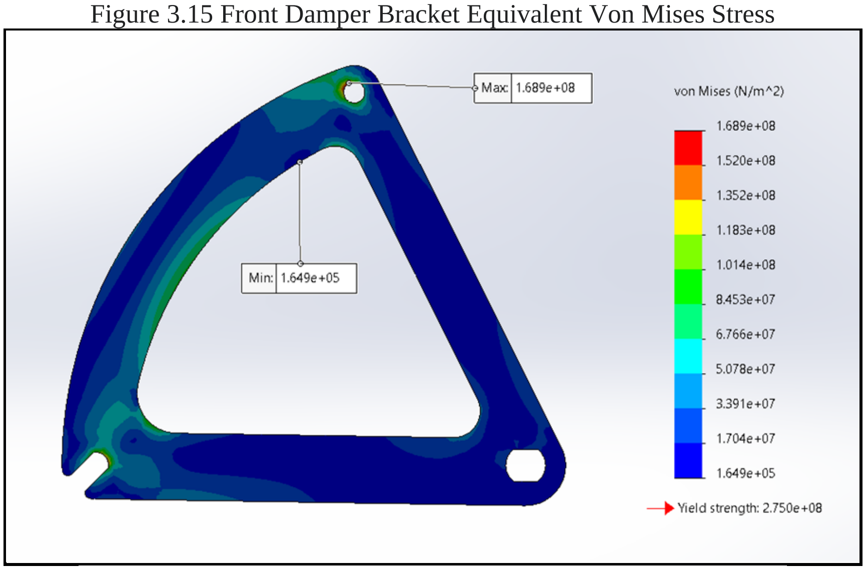

Figure 3.16 Rear Suspension Rocker Equivalent Von Mises Stress

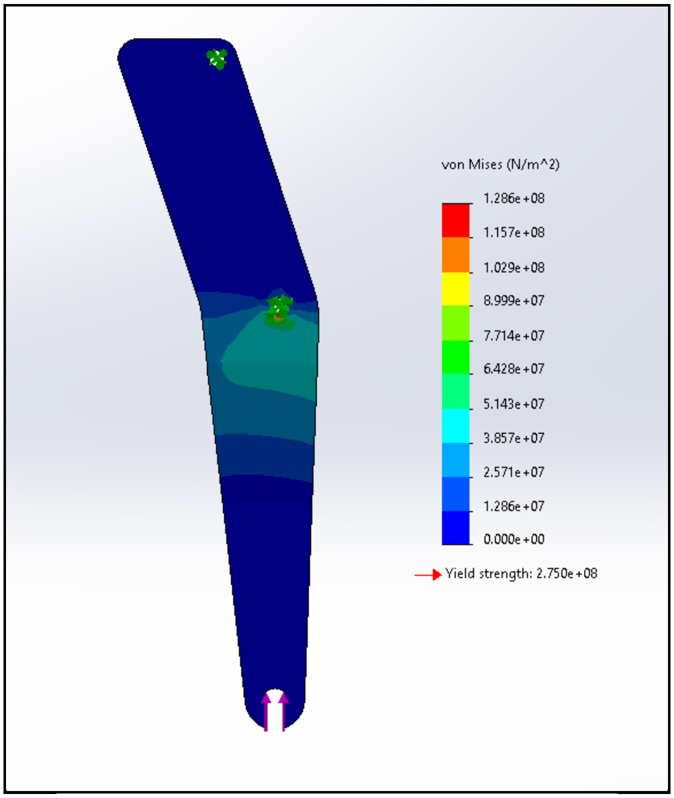

Figure 3.17 Front Fork Equivalent Von Mises Stress

Table 3.18 Factors of Safety

Part Name	Factor of Safety
Main Frame	3.2
Folding mechanism square bar	3.1
Front Damper Bracket	4.3
Rear Rocker Plate	1.6
Front Forks	2.13
Avg. Factor of Safety	2.86

Thus, after integration, all the data and performing all the simulations as well as finite element analysis, 3D computer-aided drawings of all the components were made and assembled in Solidworks. For optimizing all the components to reduce the weight of the vehicle, many iterations were done and the best ones were finalized. The following picture shows the complete developed computer-aided drawing of the electric kick scooter assembly.

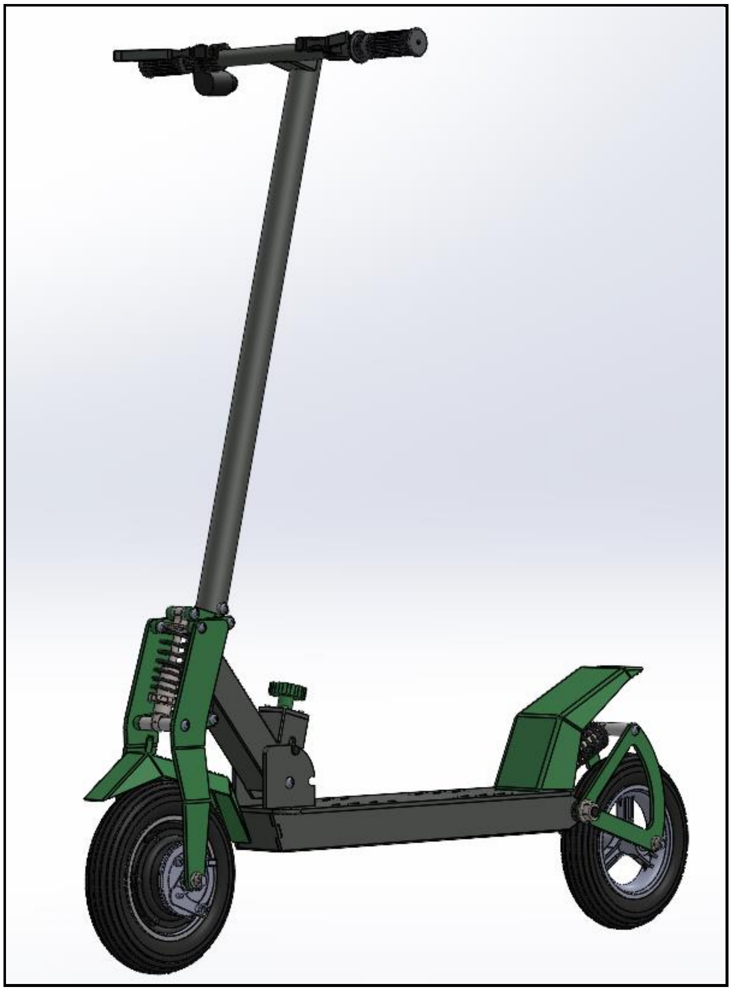

Figure 3.19 Final Computer-Aided Design

4. Results and Discussion

The electric Kick Scooter has been tested at its full capacity to validate the design and check whether the objectives are achieved. The scooter was ridden in the safe environment of Nanded City situated in Pune, taking into consideration the different human weights ranging between 50 to 100 kgs. The testing was carried out on a track of 3.7 Km to and fro. It was found that the scooter is well suited to handle typical Indian road conditions. The battery was charged to its full capacity 4 hours before testing.

Testing Parameters	**Values**
Driver weight	75 kg
Battery Voltage Before Testing	29 Volt (100 %)
Tire Pressure	30 PSI
Ambient Temperature	35 Degree Celsius
Total Distance Travelled	27.2 Km
Maximum Speed	27 Kmph
Testing Duration	2 Hours

Table 4.1 Testing Data

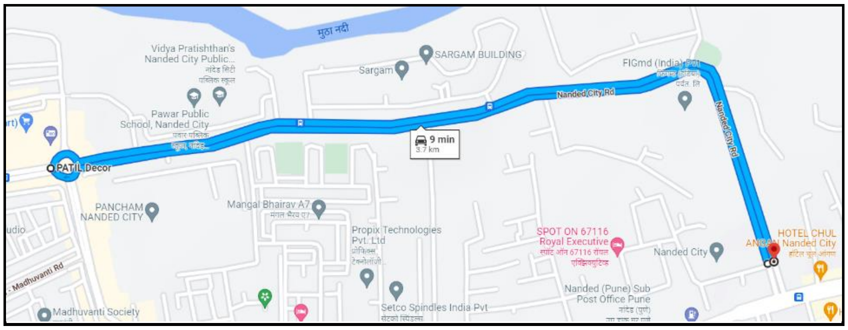

Figure 4.2 Testing Map

Figure 4.3 Vehicle Testing

Figure 4.4 Folded view

5. Conclusion

The team was relatively successful in achieving the objectives it set out to execute. The Electric Kick Scooter suspension is well-tuned and designed taking into consideration the poor Indian urban roads. The single-stage foldable mechanism included in the electric kick scooter can enable individuals to move even quicker in the course of traffic where it is reported that an average time spent during peak traffic hours is double the true travel time. Besides, the use of lightweight aluminium material has made allowances for every gender and fellow above 14 years of age making it the most effortless driveable vehicle.

After thoroughly conducting the market survey as well as product survey, we were able to get the particulars from the customer's point of view. It helped us decide what are the various features people are insisting on as per their requirements. Since we had project budget constraints, every feature could not be involved but the electric scooter is adaptable for any future changes.

During the survey, we also came to know about the various subsidies and the initiatives taken by the Indian Government under mission 2030 to create the desired environment for such eco-friendly and maintenance-free micro-mobility alternatives. Although the electric kick scooter culture is not yet developed in countries such as India due to the substandard state of the road, by bringing such reasonable, compact, lightweight, and conveyable alternative options for high investment vehicles, we can hope to see the change in adaptability in coming years.

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