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Optimum Design of Electric Scooter for Longer Operating Time

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ABSTRACT: Electric scoter has come to stay as a mobility device with various uses in sporting, transportation and leisure**.** Electric vehicles are proven to be one of the promising solutions to the global environmental problem caused by emission of greenhouse gases from fossil fuels, thus there is need to produce new designs to meet immediate demand. This research work was focused on computer aided design of electric scooter to enhance longer operating time for the 'scot-man' The electric scooter produced was successfully tested and satisfactory performance obtained.

KEYWORDS: Electric, scooter, operating time, transportation.

1.0 INTRODUCTION

The wooden kick scooter, with skate wheels, dates back to sometime in the late 19:th century, about the same time motorized bikes were also arriving on the scene[1]. To answer the question "who invented the electric scooter" is not as straightforward as one would think.A quick search online of who invented it, sometimes answers the name of Arthur Hugo Cecil Gibson, an inventor who developed the Autoped in 1913 and patented it in 1916. It is similar to e-scooters with collapsing stem, and handlebars for better storage.Many thought it was merely a toy for the rich elite but it found use by delivery men, postal workers, and NYC traffic officers amongst others.

The exact date, place and the name of the inventor is unknown .What is known as fact is that on 1st December 1895 Ogden Bolton Jr was granted his first patent for a battery-powered bicycle. It was seen as a modification to the existing electric bicycle.

Figure 1 shows a wooden-kick scooter.

Figure 1: Wooden-kick Scooter [1]

Various electric scooter prototypes saw the light of day. One of them was a company called Myway which started as a garage project in 2009. The gains of electric scooters and particularly stand-up scooters over the gas-powered mopeds are plentiful and evermore people realize this daily. Portability, lightweight, zero emissions, easy to use and handle, perfect last-mile solution, and extremely low cost per mile are some of the benefits of the modern electric scooter. Figure 2 shows the modern electric scooter.

Figure. 2: Modern Electric Scooter [1]

Electric vehicles have gained more attention because of the rising fuel cost and battery development technology. BLDC(Brushless Direct Current) electric motors are being encountered more frequently in electric vehicles due to their high efficiency and robustness.. By using the computational ability and simulation of modern computers and CAE (Computer-Aided Engineering) software, the dynamic responses, dynamic stress distribution and modal tests can be calculated and performed. The existing literature about ePTWs(electric Powered Two wheelers) is presented. One of the first analyses of ePTWs and its usage is presented in [1].In this paper, a broad introduction of the Chinese market, regulatory distinctions of PTWs in China, and industry development is given. A more usage centered analysis of eBikes in Chinese cities is presented by [2], where a survey among bike, eBike and liquefied petroleum gas (LPG) scooter users was conducted. A general overview of the market situation, especially in China, is given by[3] Alongside the market analysis, technological developments and employed technique relevant in this sector are presented , with classifications globally.In order to evaluate the global ePTW market.[4] presented a market analysis and clarified the differences between the markets in Asia, North America, and Europe. The given forecast estimates China and India as the largest markets for low-powered ePTWs in 2018, expectng 12.4 million units to be sold in China and 1.1 million units to be sold in India. One of the first studies about PTW usage in European cities is presented by [5] where the development of PTW usage in the city of Paris, France is analyzed. Findings indicate a rise in travelled passenger-kilometers by 36% between 2000 and 2007, adding to a share in road traffic of up to 17%. Surveying PTW users, the prevailing reason for using PTWs was commuting (>90%), making it the most relevant trip purpose. Another approach to understand usage of PTWs especially in western countries is presented by [6].. By analyzing registered addresses, trip distances were estimated, revealing that Scooters travelled significantly shorter distances than other PTW types. The influence of national and regional policies on the adoption of electric vehicles is analyzed by [7 Therefore, a program to promote and subsidize low-powered ePTWs was commenced in 1998, spending NT$ 1.8 billion, which included tax reductions for manufacturers of ePTWs, subsidies for charging facilities, and rebates for buyers up to 50% of the retail price. However, there were neither bans nor other restrictions on gasoline-powered PTWs..

The main aim of this review paper is to present the idea of harnessingvarious energy and use it in today’s existence of human life. For human being travelling has become vital. This is quite a challenging task, as the performance of the battery in terms of usable capacity and internal resistance, varies over time. In the traditional motor design method, 80% of the area is larger than 80% of the total working area of the motor.

1.1 System Description

The electric scooter comprises of several electrical, mechanical and electronic components which are assembled together to construct a complete model of the system. The electric scooter consists of :

i. **Battery**

The battery is an electrical device that converts chemical energy into electricity. Without battery, electric scooter will not work. Batteries are divided into two types which are rechargeable batteries and disposable batteries (which cannot be charged. Its advantage is it can deliver high electrical current for starting an engine. However, it runs down quickly and need to be charge about 1 hour and 20 minutes. For this electric scooter, two batteries will be used and connected in series to produce larger input supply which is equal to 24V.The battery used in this study is shown in figure 1.Figure 1. SLA Rechargeable Battery (GPP1272)

ii. Motor driver

MD30C is designed to drive medium to high power brushed DC Motor with current capacity up to 80A peak and 30A continuously. AC /DC Rectifier Adapter

It converts the AC source into DC to charge the battery. Adapter for battery power equipment may described as chargers.

iv. Indicating Unit

It includes speed output unit and plugged in charger. It basically contain a monitor type display where the condition of the vehicle shown on the display.

v. Driver controller unit

Table 1 shows the trend in the development of electric scooter.

Table 1: Trend in the development of electric scooter

Author(s) (Year)	Main focus	Included modes	Main conclusion(s) or recommendation(s)
Oeschger, Carroll, and Caulfield (2020)	Knowledge on the integration of micro-mobility and public transport	Micro-mobility and public transport	The effect of integrating micro-mobility and public transport on different elements of society, the environment, and the economy shape the primary knowledge gap.
Liao and Correia (2020)	Usage pattern, estimation, of demand & impacts	Shared e-mobility including electric vehicle, e-bike, e-scooter, & e-cargo bike	The shared e-mobility usage is mainly for short-distance trips. Users are primarily male, middle age, and well-educated with high income.
O'Hern and Estgfaeller (2020)	A summary of research status	Powered micro-mobility including e-bike, e-skateboard, & e-scooter	The findings demonstrate the increase in the trend of micro-mobility since 2012. Several topics such as users' behaviour, planning, policy and health were identified in the literature.
Abduljabbar, Liyanage, and Dia (2021)	Knowledge on micro-mobility from a sustainability standpoint	Micro-mobility including cycling, e-scooter & e-bike	The emerging micro-mobility could tackle mobility challenges such as congestion and accessibility discomfort in the next few years.
Şengül and Mostofi (2021)	Knowledge on micro-mobility from a sustainability standpoint	Micro-mobility, including e-bikes and e-scooters	An overview of micro-mobility is provided, and its impact is classified into four categories: energy consumption, travel behaviour, traffic safety, and environmental impacts.

1.2 Usage of Electric Scooter

It is used in commuting and leisure activities. Shopping and running errands seems to be underrepresented with just 8% and 6% respectively, though.. After all, the Mid survey, a quinquennial nationwide representative survey of traffic behaviour in Germany with several additional regional studies, and the evaluation for Munich [8] in particular, was chosen. Although, the data from this study refers to mobility patterns of persons, while our data refers to mobility data of vehicles, yet it is the most useful dataset available at this time and therefore is incorporated. Business trips only account for 5% of all trips while pickup/drop-off accounts for 7%. Comparing our results with these shares, leisure trips are close to these numbers with 31%. The largest share of trips in this study were commuting trips. Comparing these shares, a prevalence of these trips is apparent.

2.0 MATERIALS AND METHOD

2.1 The Materials used include: Stainless steel, Iron Pan, High Carbon Chromium Steel, Lithium-ion Battery, Hover board Motor, Rubber,Square inch rectangular mild steel Pipe, Electric Speed controller, Arduino Mega 2560 Micro-controller and Hover boar

2.2 Design Using Cad Software

The design of the electric scooter was carried out using the Solidworks 2023 software on a DELL Latitude E5430 non-pro PC. The process involves creating a concept for the electric scooter and making decisions about the size, shape and features of the vehicle, design calculations and detailed part design [9]. The design also considered the materials that will be used in the construction of the scooter [10]. Figure 3 shows the basic design of electric scooter, while Figures 4,5,6,7,8,9,10,1 and 11 show the various views of the components.

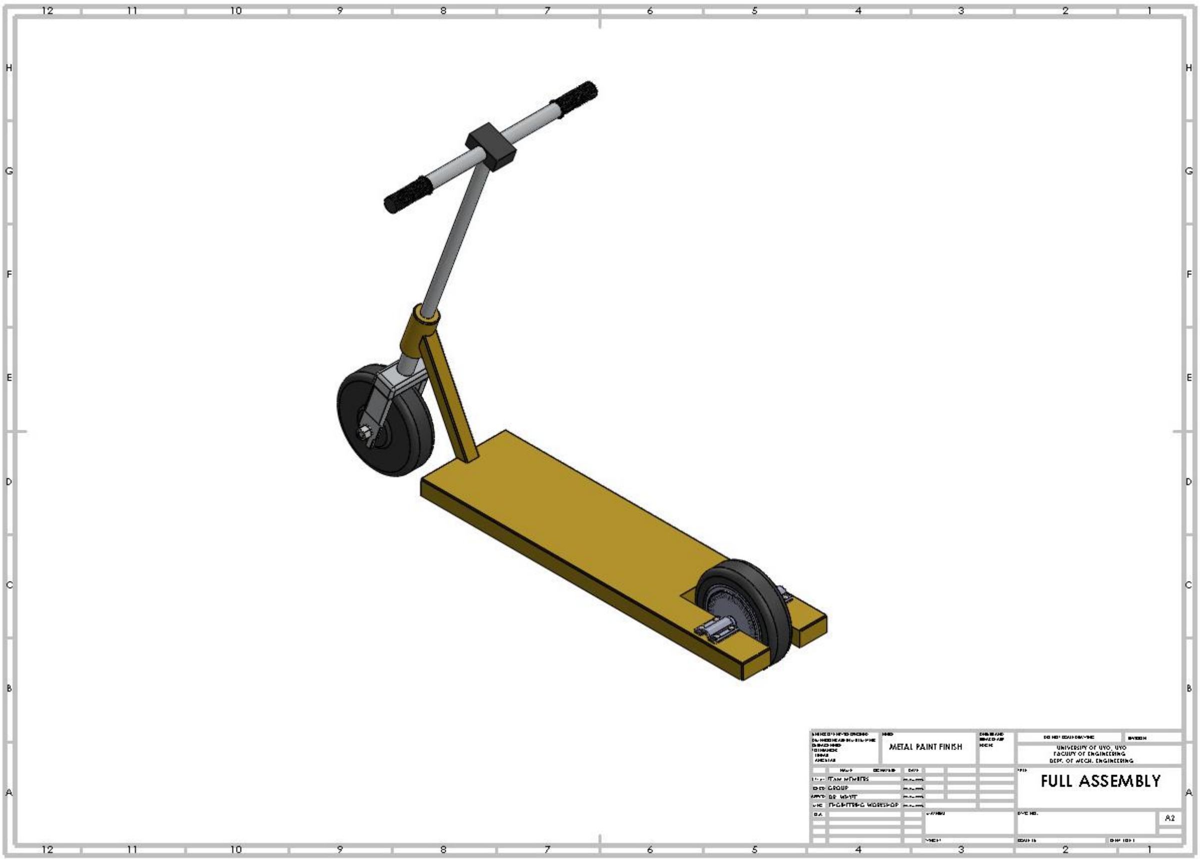

Figure 3: Model of an Electric Scooter

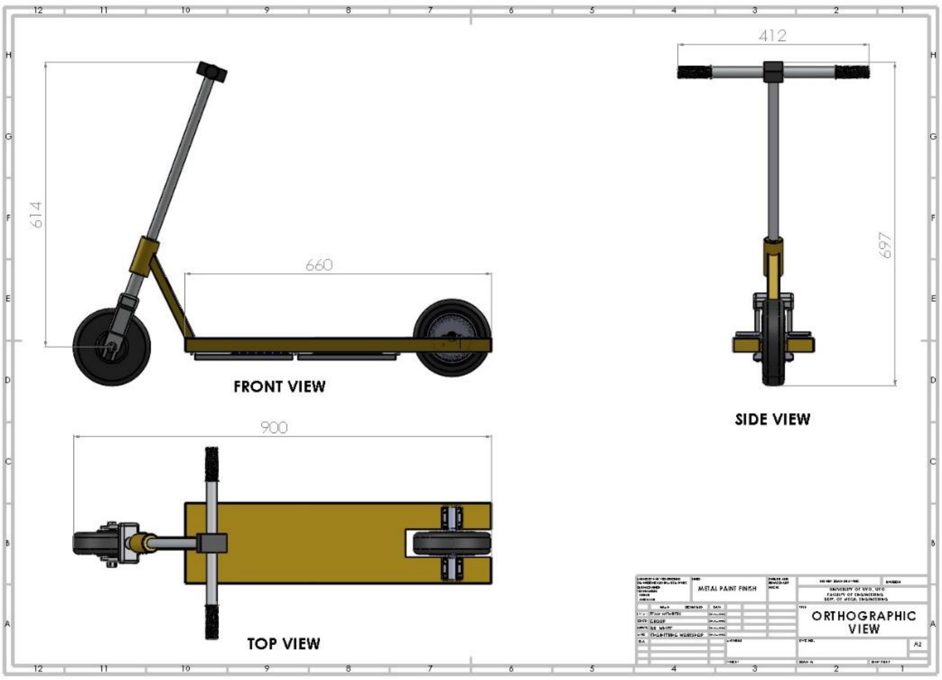

Figure 4: Orthographic view

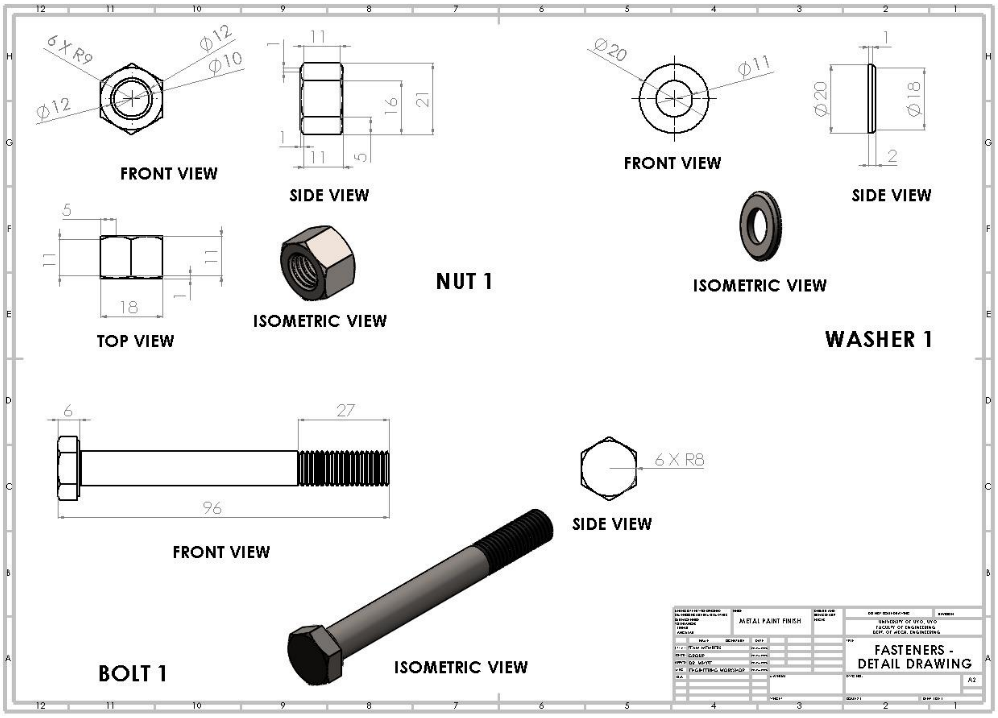

Figure.5: Detailed drawing of the fasteners

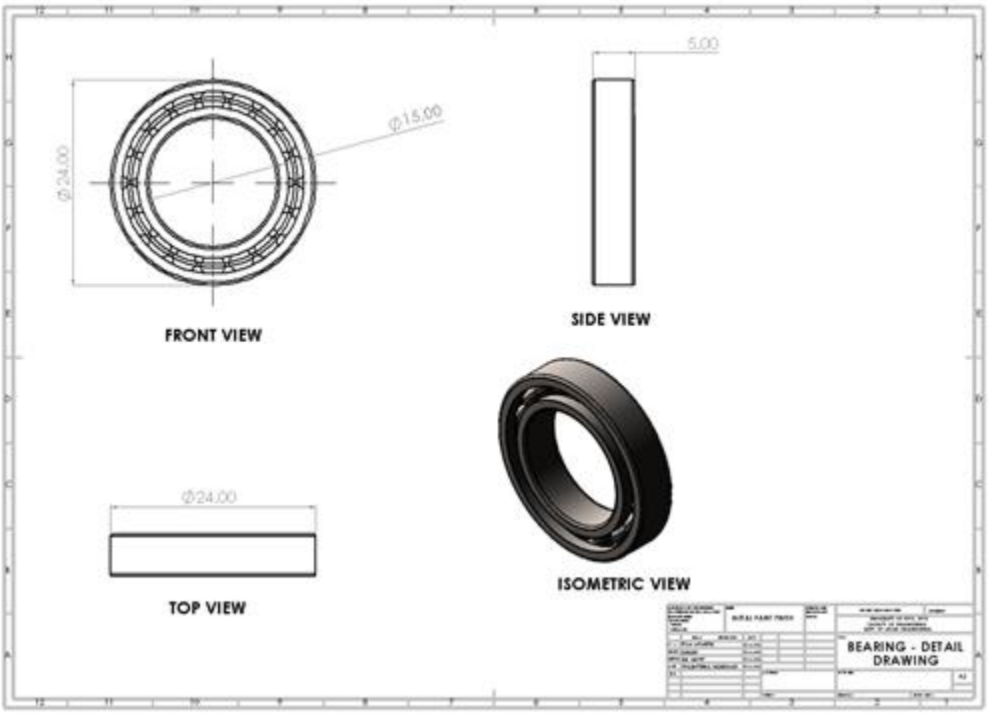

Figure 6: Detailed drawing of the bearing

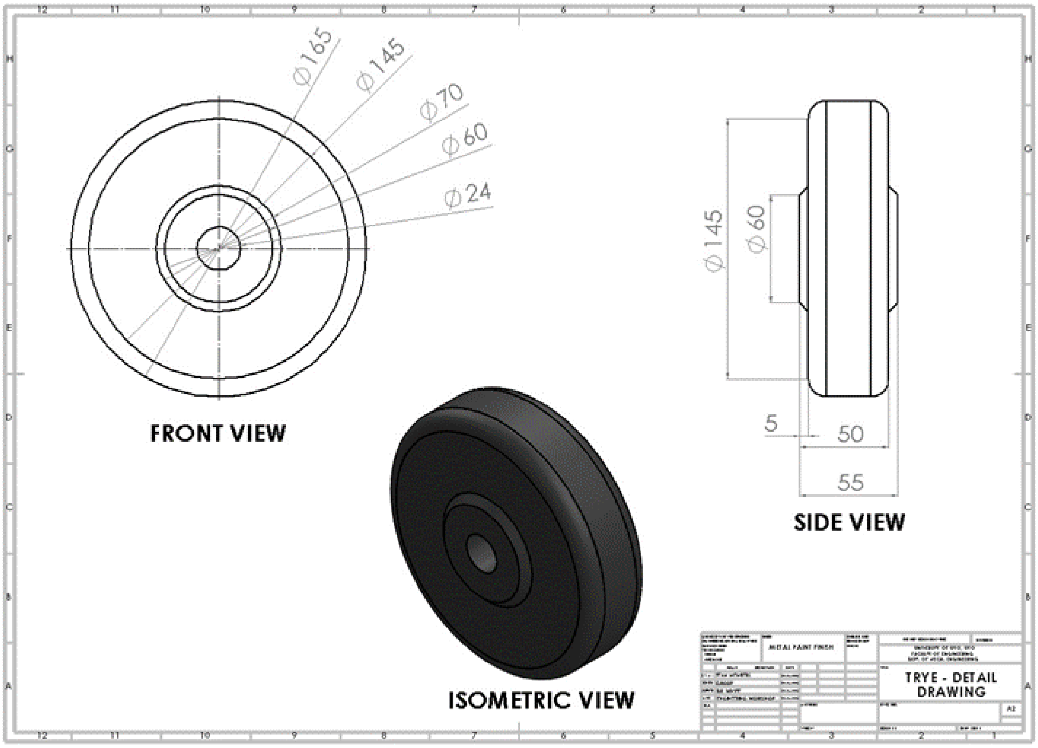

Figure.7: Detailed drawing of the Tyre

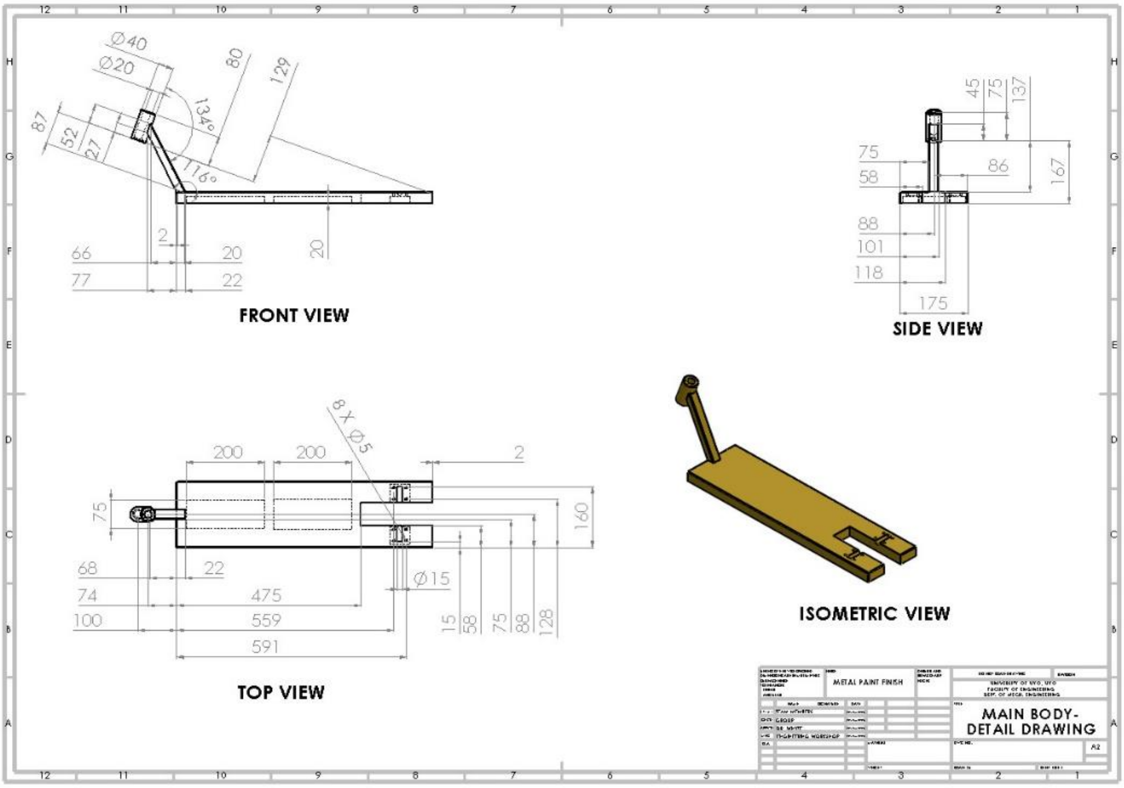

Figure.8: Detailed drawing of the frame

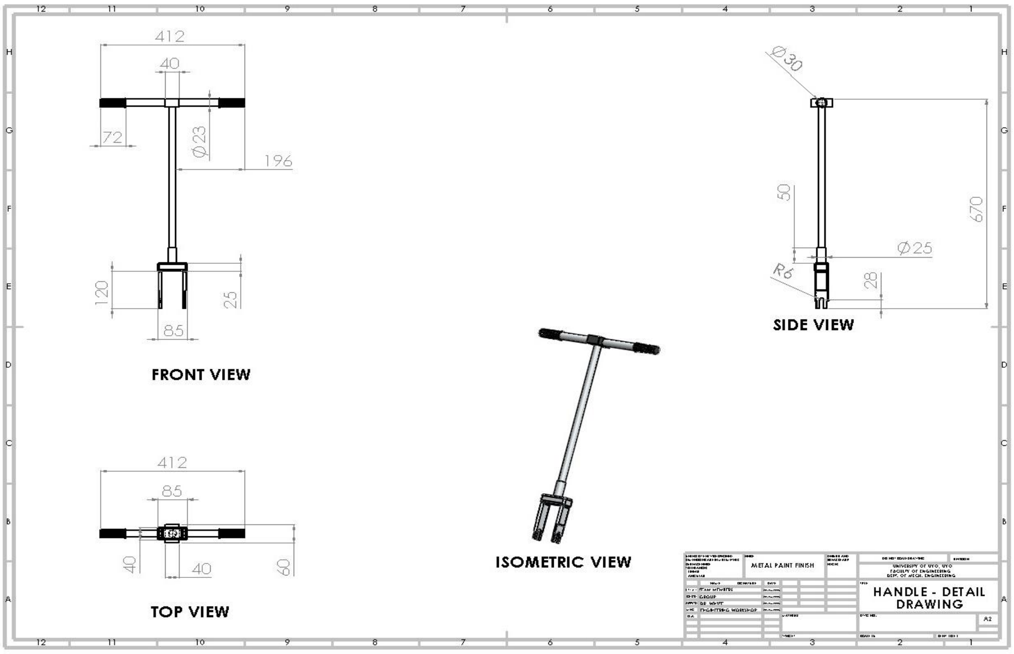

Figure.9: Detailed drawing of the handle (stem)

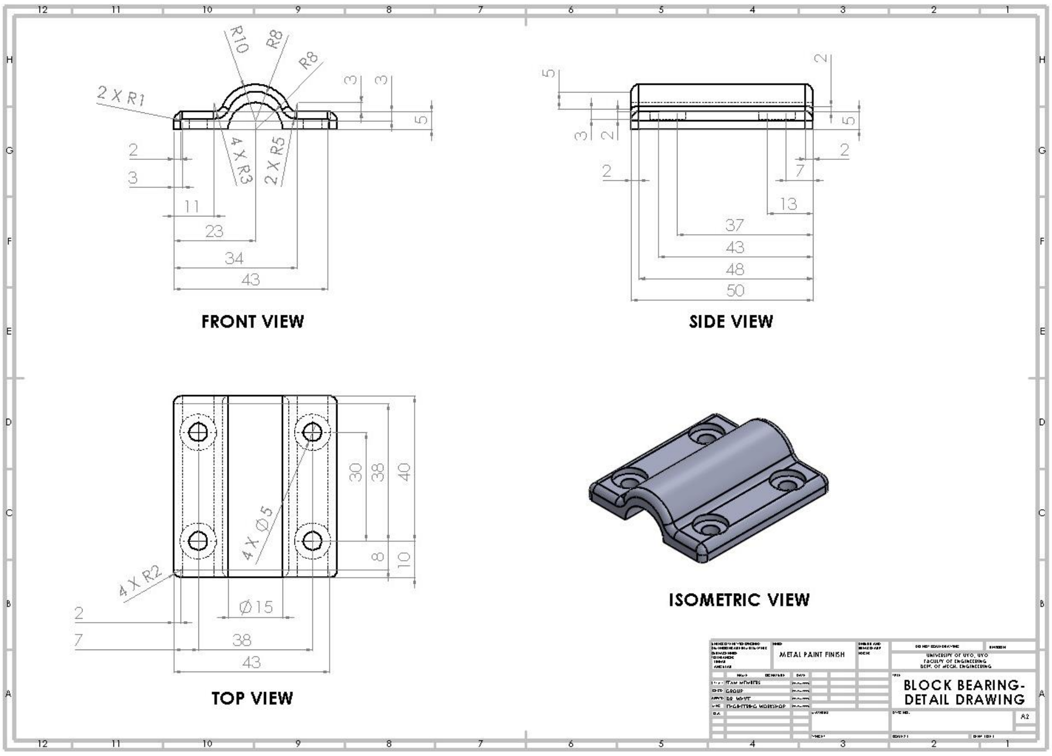

Figure. 10: Detailed drawing of the block bearing

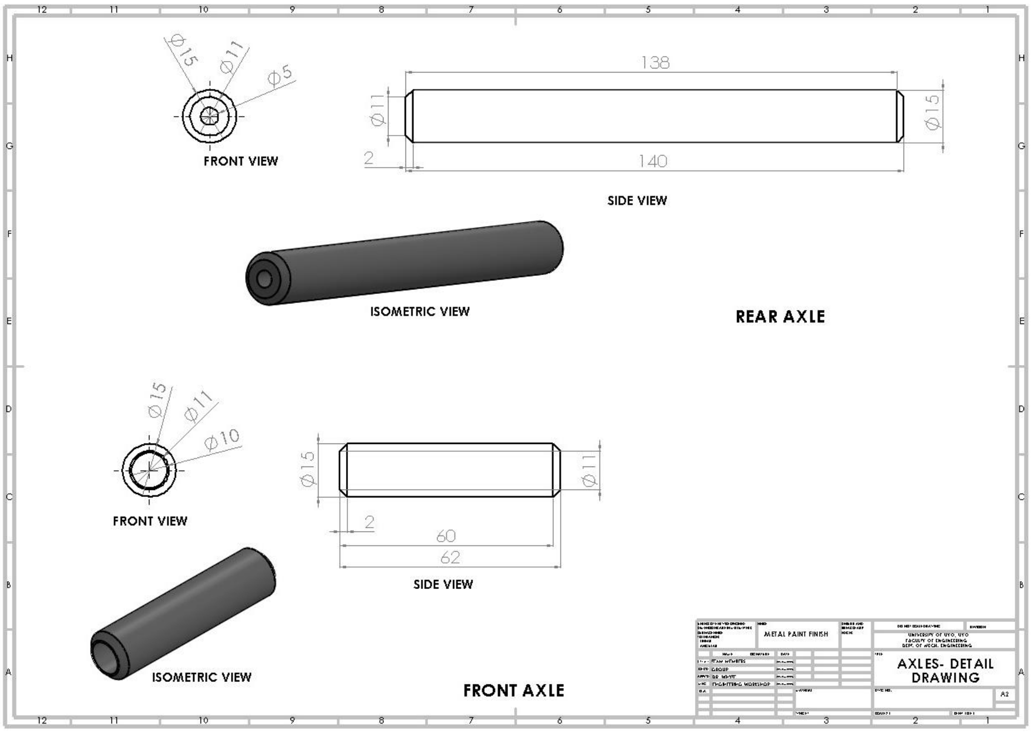

Figure. 11: Detailed drawing of the axles

2.3 Design Criteria

Working through the design of an electric scooter, there are a few things that needs to be fully understood first, like the basic components of the scooter, what kind of power source to be used, the kind of motor, the amount of load it would carry, the distance it would cover etc.Those things are the foundations of the design of this work and need to be decided first, and then we can move on to other details, like the dimension of each component and choosing the right wheels. In this chapter we are going to go through some basic design criteria to get an overall idea about the design of the scooter. Some factors which we took into consideration while designing the electric scooter are;

1. Portability: Not all, but most electric scooters are portable. It is designed to be a last mile solution to commuters, or a quick and easy run about for short trips close to home or work.
2. Time: In busy cities, time is the issue and these sleek vehicles can help you save a lot of time on the road, hence we selected materials that can enhance the speed of the scooter.
3. Safety: Riding the scooter is easy, with power controlled by a twist grip on the right handlebar. Braking is with the levers on the left and the right, activating a v-brake in front, and a cable operated disc brake at the back of the tyres are proper pneumatic item items, and there is no suspension but with a speed limit of 15kmh on footpaths and 25kmh on cycling and shared paths.
4. Eco-friendly: A viable alternative to the petrol engine car and scooter is without doubt the electric scooter, as it does not produce any form of emission that are harmful to the environment and to the people, and it requires less maintenance than traditional cars or scooter engines as itdoes not have valves, cylinders or carburetor and doesn't need oil changes.
5. Availability of Materials: Materials used in the construction of this scooter were locally sourced for easy production and replaceability incase a part gets damaged.
6. Load carrying factor: The electric scooter was designed to carry just one person at a time with maximum load of 100kg.

2.4 Design Calculations

The major designs were on the mechanical component of the electric scooter, to determine the strength of the material to be used and the various forces acting on the scooter.Figure 12 presents the overall force analysis.

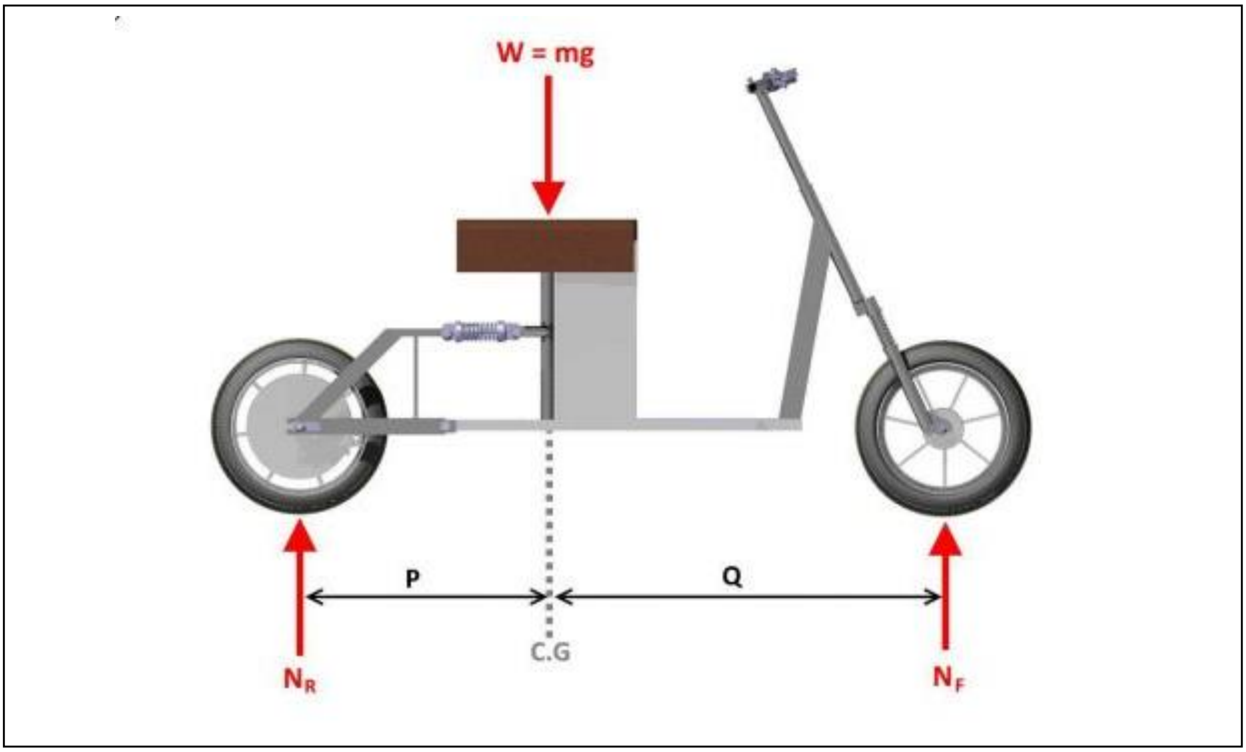

Figure 12: Overall Force Distribution

To calculate the force distribution to the rear and front tyres, a maximum load of 200kg was used. From Equation 1,

W = mg Equation 1

m=200 kg, $g = 9.81\frac{m}{s^2}$

hence

W = 1962N

In terms of dimensions, P = 360mm and Q = 1100.6mm

For static case analysis, the summation of moments at all points and forces in all directions equals to zero.

The force exerted on front tyre, NF; $\sum MR = 0$

NF*(P+Q) – W*(P) = 0 Equation 2

Substituting into Equation 2

NF = W*P/ (P+Q) = 1962*360/ (360+1100.6) = 483.58N

The force exerted on rear tyre,

NR; 84 $\sum FY = 0$ NF + NR – W = 0 Equation 3

Substituting into Equation 3

NR = W – NF = 1962 – 483.58 = 1478.42N 85

Torque = r*F (sinϴ) Equation 4

Where r=0.9m

ϴ= 120°

F= 980.67 N

where r is the length of the scooter, thus

T= 0.90*980*sin 120

= 512.45Nm

Figure 13 shows the steering fork forces

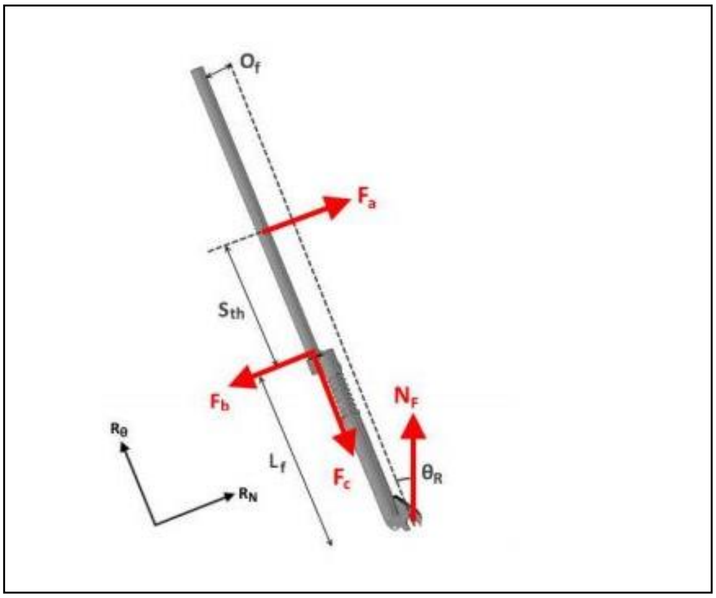

Figure 13:Steering Fork Forces

Fork offset, Of = 50mm Steering throat length, Sth = 275mm Length of fork, Lf = 345mm Rake angle, θR = 25º

$\sum Mb = 0$, Fa(Sth) – NF sin(θR)(Lf) = 0 Equation 5

Substituting into the above Equation

Fa = NF sin(θR)(Lf)/Sth = 483.58 sin(25º)(345)/275 = 210.56N

$\sum FRN = 0$, Fa – Fb + NF cos(θR) = 0 Equation 6

Substituting into Equation 6

Fb = Fa + NF sin (θR)

= 210.56 + 483.58 sin(25º) = 395.62N

$\sum FR\theta = 0$, Fc – NF sin(θR) = 0 Equation 7

Substituting, we have

Fc = NF cos(θR) = 483.58 cos(25º) = 446.77

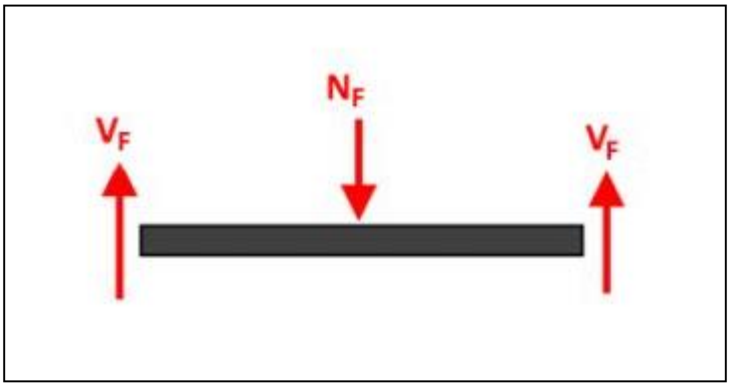

Figure 13:Front tyre axle diameter

The minimum size of the front tyre axle diameter, Maximum Shear Stress Theory is used with the maximum force NF acting in double shear.

To calculate shear force acting on the rear tyre axle;

$\sum F = 0$, NF – 2VF = 0 Equation 8

Substituting

VF = NF/2 = 483.58 /2 giving 241.79N

Yield strength of A36 steel, Sy = 250MPa

Maximum shear stress according MSST, τmax with factor of safety, n of 10;

τmax = Sy/2n Equation 9

Substituting into Equation 9

= 250*106 /2*10 = 12.5MPa

To relate with area of the cylindrical shaped axle and minimum diameter required;

τmax = VR/A = 4VR/ πd2 d Equation 10

Making Substitution

= (4VR/ πτmax) 0.5

= (4*241.79/π*12.5*106) 0.5 = 4.963mm

The minimum diameter for the bolt connection on each shock absorber is 4.963mm. According to the maximum loading, the connection is safe.

Figure 14 presents the front tyre diameter.

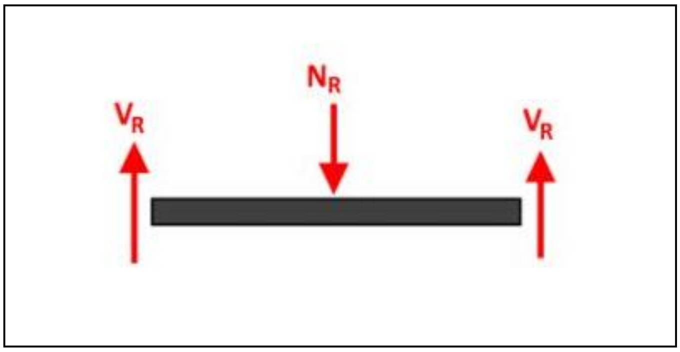

Figure 14: Rear tyre axle diameter

To calculate the minimum size of the rear tyre axle diameter, Maximum Shear Stress Theory is used with the maximum force NR acting in double shear. The shear force acting on the rear tyre axle, is given as:

$\sum F = 0$, NR – 2VR = 0 VR = NR/2 Equation 11

Substituting

= 1478.42/2 = 739.21N

Yield strength of A36 steel, Sy = 250MPa

Maximum shear stress according MSST, τmax with factor of safety, n of 10;

τmax = Sy/2n Equation 9

Making substitution,

= 250*106 /2*10 = 12.5MPa

To relate with area of the cylindrical shaped axle and minimum diameter required;

τmax = VR/A = 4VR/ πd2 d Equation 10

Putting values

= (4VR/ πτmax) 0.5

= (4*739.21/π*12.5*106) 0.5 = 8.677mm

The minimum diameter for the bolt connection on each shock absorber is given as :8.6777mm. However, the standard specification of the found rear tyre axle pre-assembled with hub motor has a connection diameter of 14mm.

Hence, according to the maximum loading, the connection is safe. Figure 15 shows rear support connector bolt diameter and thickness.

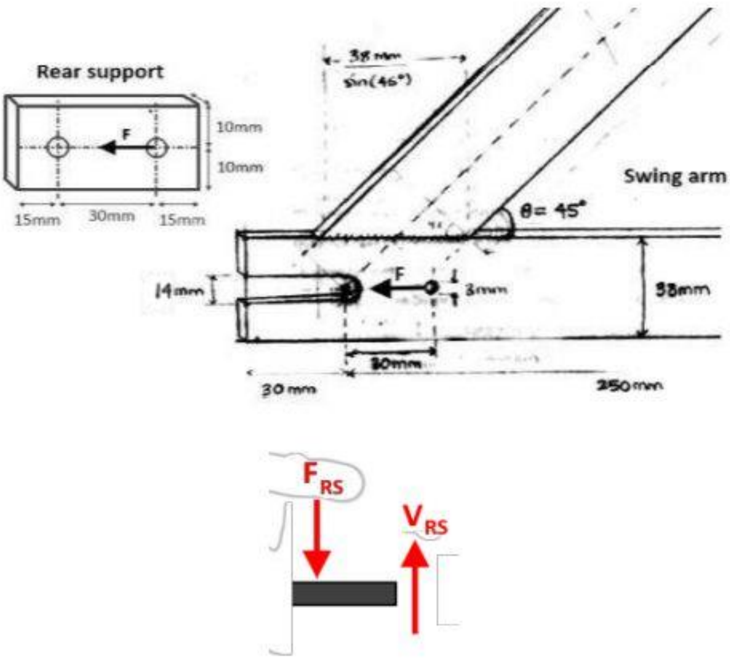

Figure 15: Rear support connector bolt diameter and thickness

To calculate the minimum size of the rear support connection bolts, Maximum Shear Stress Theory is used with the maximum force FRS for each of the rear supports, equivalent to half of the force acting on the rear tyre, NR. It is a single shear force.

To calculate shear force on the bolt; $\sum F = 0$

FRS – VRS = 0 Equation 12

Making substitution

VRS = FRS = NR/2 = 1478.42/2

= 739.21N Minimum yield strength of bolt from Property Class 4.8, Sy = 340MPa Maximum shear stress according MSST, τmax with factor of safety, n of 1.5;

τmax = Sy/2n

Equation 9

Substituting values

= 340*106 /2*1.5 90 = 113.33MPa

To relate with area of the cylindrical shaped bolt and minimum diameter required;

τmax = VRS/A = 4VRS/πd2 d

Equation 10

Substituting

= (4VRS/πτmax) 0.5

= (4*739.21/π*113.33*106) 0.5 = 2.882mm

The minimum diameter for the bolt connection on each shock absorber is 3mm. Figure 16 the swing axel diameter.

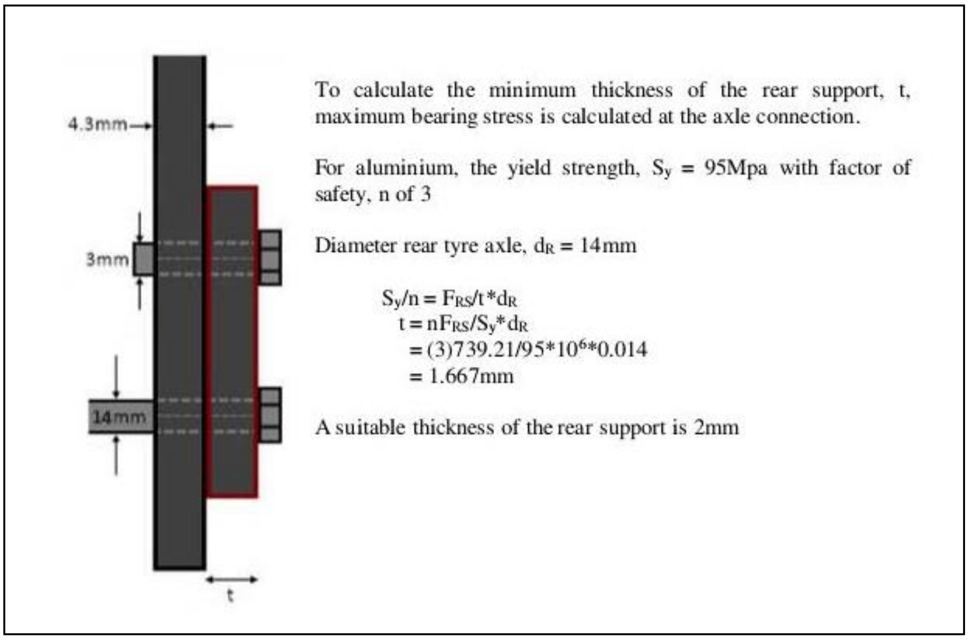

Figure 16: Swing arm axle diameter

To calculate the minimum size of the swing arm connector axle, Maximum Shear Stress Theory is used with the maximum force FSA acting in double shear.

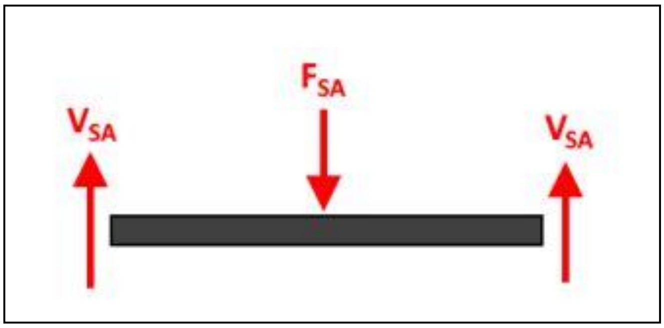

Figure 17: Shear force acting on swing

To calculate shear force acting on the swing arm axle;

$\sum F = 0$ FSA – 2VSA = 0 Equation 13

Substituting,

VSA = FSA/2 = 3044.253/2 = 1522.123N

Yield strength of A36 steel, Sy = 250MPa

Maximum shear stress according MSST, τmax with factor of safety, n of 5;

$\tau max = Sy/2n$ Equation 9

$= 250*106 /2*5 = 25MPa$

To relate with area of the cylindrical shaped axle and minimum diameter required;

$\tau max = VSA/A = 4VSA/\pi d2$ d

Equation 10

$= (4VSA/\pi\tau max)$ 0.5

$= (4*1522.1233/\pi*25*106)$ 0.5 = 8.805mm

A suitable diameter of the swing arm axle is 10mm.

Figure 18 is the shock absorber bolt diameter

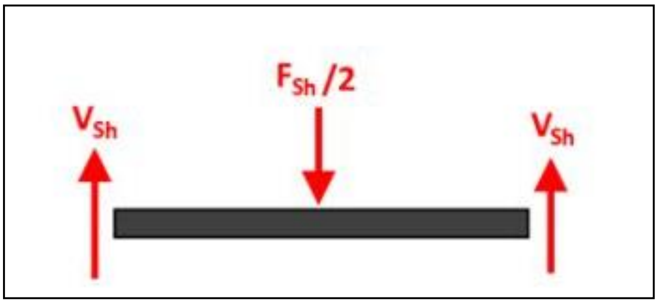

Figure 18: Shock absorber bolt diameter

To calculate the minimum size of the shock absorber connection bolts, Maximum Shear Stress Theory is also used with the maximum force FSh acting in double shear. For the use of two shock absorbers, the force FSh will be divided by two for each shock absorber. To calculate shear force acting on the shock absorber bolt:

$\sum F = 0$ FSh/2 – 2VSh = 0 Equation 13

Substituting

VSh = FSh/4 = 2661.156/4 = 665.289N

Minimum yield strength of bolt from Property Class 4.6, Sy = 240MPa

Maximum shear stress according MSST, τmax with factor of safety, n of 5;

$\tau max = Sy/2n$ Equation 9

$= 240*106 /2*5 = 24MPa$

To relate with area of the cylindrical shaped axle and minimum diameter required;

$\tau max = VSh/A = 4VSh/\pi d2$ d Equation 10

$= (4VSh/\pi\tau max)$ 0.5

$= (4*665.289/\pi*24*106)$ 0.5 = 5.941mm

The minimum diameter for the bolt connection on each shock absorber is 5.941mm.

However, the standard specification for the found shock absorbers has a connection diameter of 10mm. Hence, according to the maximum loading, the connection is safe using M10 x 30mm Property Class 4.6.

Figure 19 is the trail calculations

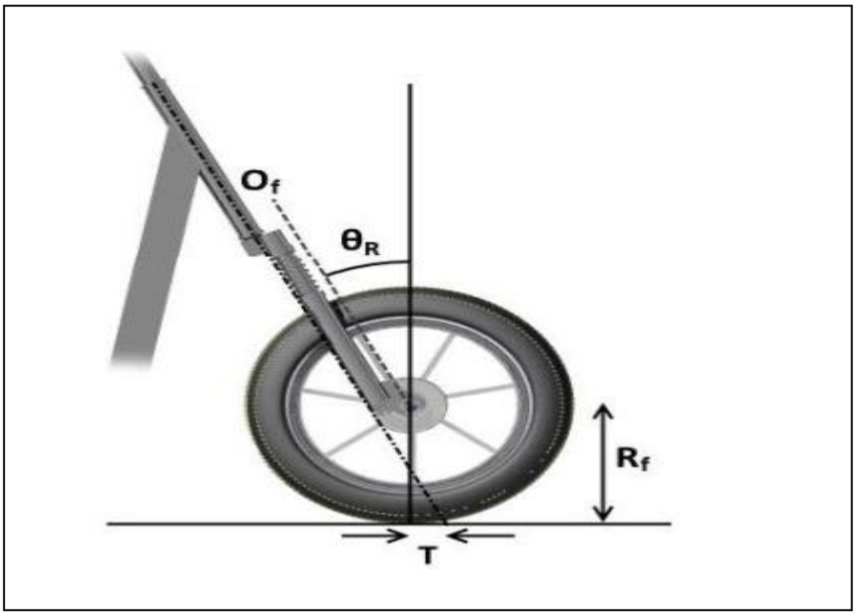

Figure 19: Trail Calculations

Trail is defined as the distance between the contact points of the front tyre with the imaginary line extended from the steering axis.

$$Trail, T = Rf \sin \theta R - Of \cos\theta R$$
Equation 14

where;
Radius of front tyre, Rf = 210mm
Rake angle, θR = 25º
Fork offset, Of = 50mm

The trail is calculated to be 42.8mm from Equation 14

2.5 Materials Selection

Following the results from the analysis based on computations, the appropriate materials for the machine components design were selected. Table 2 shows the calculated values and properties of the materials.

Table 2: Materials Selection

Mechanical Components					
Component	Material	Tensile Modulus (Young's Modulus of Elasticity, E) (GPa)	Ultimate Tensile Stress, σu (MPa)	Yield Strength σy (Mpa)	Selection Criteria
Deck	Aluminium Composite Panel	69	110	95	1. Light weight 2. Durable and robost 3. Rigid 4. Cost effective
Frame	Mild steel square pipe	200	400	250	1. High tensile strength 2. High impact strength 3. Good ductility and weldability
Stem	Iron Pipe	210	262	130	It can easily be shaped and formed
Bolt, nuts wahers	Stainless Steel	193	515	205	1. Corrosion resistance 2. High tensile strength 3. Temperature resistance 4. Very durable

Electrical Components			
Component	Materials	Specification	Selection
Battery	Lithium ion		1.charge faster 2. Last longer 3. high power density
Suspension	Pneumatic tires	Special features: 8x 1, ¼ Aluminium alloy hub material type: Aluminium alloy hub. Item weight: 0.4kg Item diameter: 8inch	1. Better shock absorption then suspension 2. Large damping effect
Motor	BLDC Motor (Brushless Direct Current)	Capacity: 350W Max load bearing capacity: 100kg	1. \High efficiency 2. High dynamic response

			3. High speedranges 4. Long operating life
Brake	Electric Brake		1. Fast response time 2. Precise tension control
Micro controller	Arduino UNO Board	Length:68,6mm Width: 53,4mm	1. Very adaptable 2. 2. It's cheap. 3. There is a lot of documentation about it, so the sensors would be easily incorporated.

Figure 20 shows the exploded view of the electric scooter.

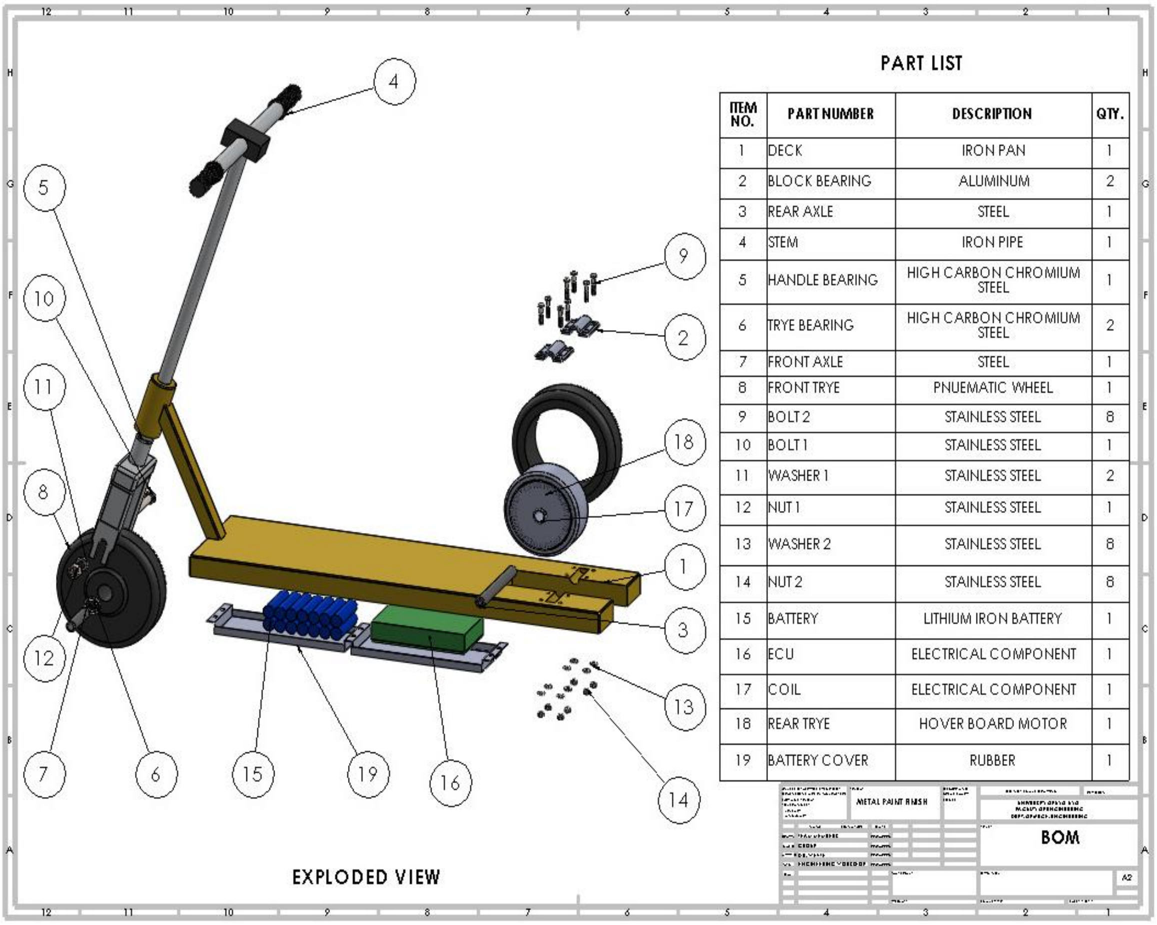

Figure: 20 Material selection drawing

2.6 Production Process

I. Frame Construct: The frame was made of square inch rectangular pipe (steel) and iron pan welded together to provide the scooter with qualities such as light weight, durability and strength to support the weight of the rider. The frame was constructed using welding and bonding technique, take one rectangular pipe, cut it in half then connect them in the middle to get U shape. Cut out one side in the shape of a motor. On one side we drilled 8mm hole and on the other cut out frame for motor shaft. The hole and cut out must be in level with the frame and the motor shaft.

II. Battery Installation: After the frame is constructed, the next step is to install the battery. The battery is typically located under the footrest or in the stem of the electric scooter. The battery type used here is the lithium ion battery. Figure 21 is the lithium battery and Figure 22 the hover board motor used.

Figure 21:Lithium-ion Battery

III. **Motor Installation:**Once the battery is installedthe motor will be mounted onto the frame. The motoris typically located in the rear wheel up or in thefront wheel up. The motor used is thehoverboard motor with the following specifications

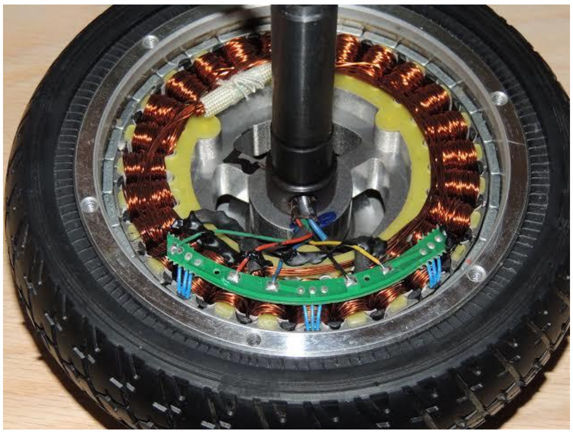

Figure 22: Hover board Motor

IV. **Wiring:** Wiring of the electric scooter is a critical component of the manufacturing process. The wiring connects the battery, motor and other components of the scooter. The wiring was properly installed to ensure the safety and performance of the scooter. Figures 23 a and 23 b indicate the electric speed controller and the micro-controller employe

Figure 23 (a):Electric Speed Controller

Figure 23 (b): Micro-Controller

V. **Assembly:** Once all the components are installed, the electric scooter is assembled. This includes attaching the handle bars, wheel and brakes. The scooter will then be tested to ensure that all the components are functioning properly.

VI. Quality Assurance and Testing: The scooter will be tested for safety, durability and overall performance. Any issues or defects will be addressed before the scooter is released for sale

3.0 RESULTS AND DISCUSSION

3.1 Result

The electric scooter designed and produced had the listed features in Table 2

Table 2: Operational Test

1. Duration of the battery	1hr
2. Maximum speed	15km/hr
3. Performance	Relatively well
4. Battery charge cycle	2000 charge cycle

Figure 23 (a):Electric Scooter (Current Progress)

Figure 23 (b): Fixing of Electrical Components

3.2 Discussion

With the increase in demand for more eco-friendly vehicles, the design and production of electric vehicles holds greater benefits for the university community and country at large. Also with the increase in the price of transportation as a result of the increase in the price of fuel, electric scooter can serve as a perfect alternative to commuters.

The electric scooter produced here has added other features and will undoubtedly form some contributions to its development.

4.0 CONCLUSION

The use of electric scooters as an alternative means of transportation will help to reduce the cost of transportation in urban areas and reduce the over reliance on cars and motorcycles.The electric scooter can carry a maximum load of 100kg efficiently.The electric scooter is a more eco-friendly means of transportation as it produces little or no form of pollution.Further works be carried out to develop an electric scooter that has a longer battery life, greater speed and efficiency

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