International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 06 | June 2021 www.irjet.net p-ISSN: 2395-0072

Basic Approach for Designing a Electric Bicycle

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Abstract – *In todays's world transportation experiences a lot of problem when it comes to adhering to the emission guidelines . IC combustion companies are trying their best to reduce the emissions from the vehicles and many advancements have been made in the fuel industry to come up with a alternative for the hydrocarbon fuel for obtaining nearly zero emission.*
Another alternative to IC combustion transportation is the development of electric vehicle which has nearly zero emission.Developments in this field will surely prove to benefit the environment in all possible ways when it comes to toxic substances.

Key Words: Frame,Chain-Drive,Motor-Controller,Battery, Throttle,Display etc.

1.INTRODUCTION

Developing a Electric Vehicle has a lot of benefit when it comes to carbon emission.Electric Vehicle emits less carbon or carbon based pollutants or we can say that the carbon emissions are nearly zero when the electric energy is being harvested from renewable resources..
This is a basic approach on how to design a Electric Bicycle which includes mainly four subsystems :
1.Frame
2.Transmission (Chain-Drive)
3.Braking System
4.Electrical System (Hub Motor,Battery etc)

1.1 FRAME DESIGN

Frame houses all the important components of the electric bicycle so a designer needs to take into consideration all the factors which influences the failure of the frame and material has to been choosen wisely so as to reduce the overall weight of the bicycle and to reduce the cost as well.
A simple frame is been shown in **Fig(1)**
A general methodology is been followed when designing a frame.

DESIGN METHODOLOGY:-The Design methodology mainly includes three steps :

1.Theoretical Analysis : Theoretical Analysis includes fixing the dimensions of the frame and performing hand calculations to find out the stresses induced due to the loads acting on the frame.

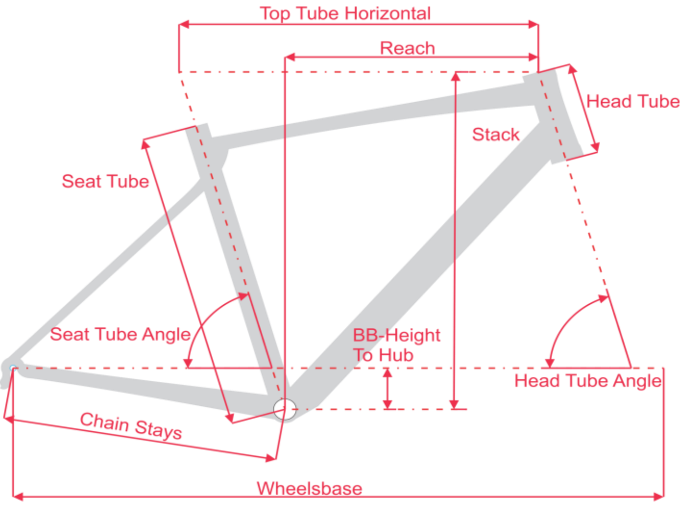
2.Creating 3D Model :A three-dimensional model of the frame is created in **SOLIDWORKS 2018** and then imported in ANSYS Software to verify the theoretical calculations.

3. Finite Element Analysis : Finite element analysis (FEA) is a software based analysis where in the part is been divided into many small elements and the software solves these elements individually and combines the solutions and gives the overall result.

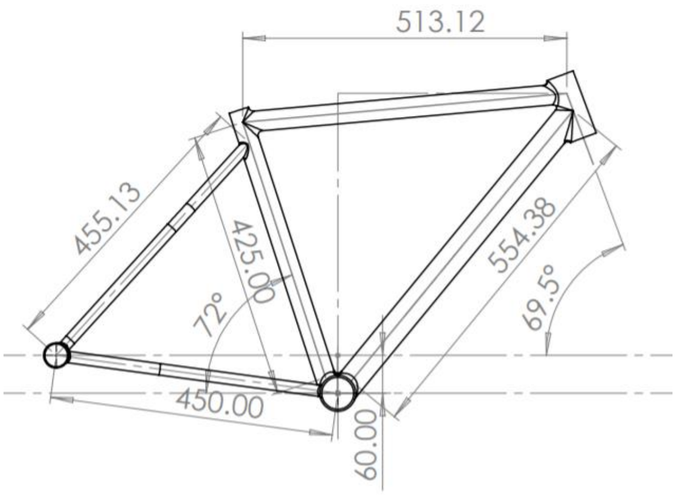
Fig(1)

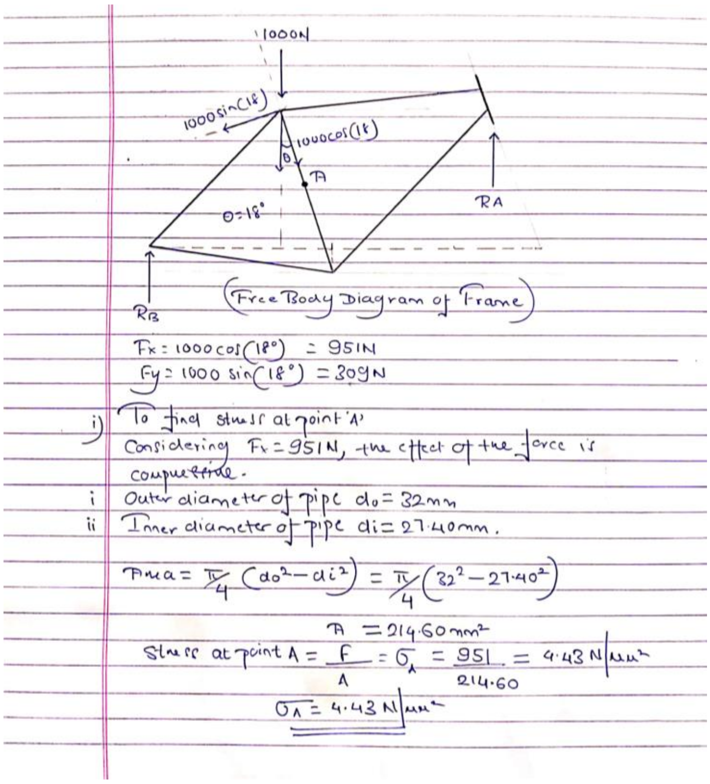
1.2 THEORETICAL ANALYSIS :

Different dimensions of the frame are fixed which are highlighted in the table (1).A simple case is assumed where in the bicycle is at rest and weight of the rider is acting on the bicycle.
1.Weight of the rider = 100kg
2.Height = 5.5 -6ft
The main structural member of the frame is the seat tube which supports the weight of the rider so the stresses are calculated by converting the weight of the rider into force which is then resolved into components so that the force acting on the seat tube directly produces a pure compressive stress and buckling stresses.



Stack	19 in
Reach	15 in
Head Tube	6 in
Seat Tube	17 in
Chain stay	18 in
BB Drop	12 in
Top Tube	21 in
Wheelbase	43 in





The result was verified using ANSYS software.

1.3 MODELING : :A three dimensional model was created using the dimensions in SOLIDWORKS 2018.

1.4 FINITE ELEMENT ANALYSIS :

The material selected for the frame is AISI 4130 alloy steel which contains chromium and molybdenum as strengthing agents. It has low carbon content and can be welded easily. The physical properties of AISI 4130 is given in the table below.

Density (g/cc)	7.85
Ultimate Strength(Mpa)	560
Yield Stength(Mpa)	460
Young's Modulus(Gpa)	210
Bulk Modulus(Gpa)	140
Shear Modulus(Gpa)	80
Poison's Ratio	0.30

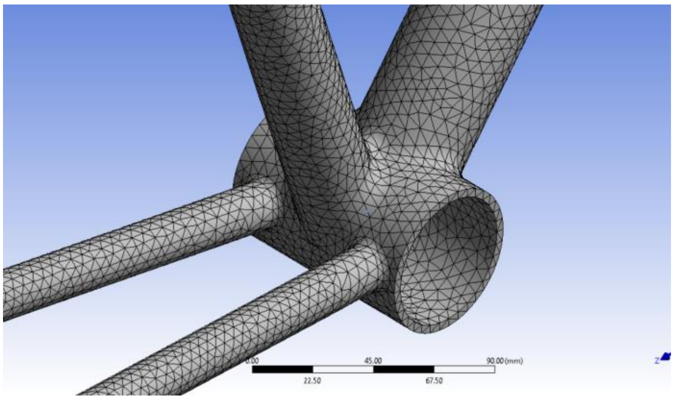
AISI 4130 Steel is a Alloy Structural Steel belong to ASTM A29/A29M Steel Grade standard.

MACHINABILITY - AISI 4130 steel can be easily machined.

MESHING :

Meshing is the process in the which the component is been broken down into many elements of differents shapes and sizes and the software solves these elements individually by taking into consideration the boundary conditions and combines all the solutions and gives the overall result.

Creating a suitable mesh requires a lot of practice because if finer the mesh is, the result obtained are nearer to accurate values and vice versa.

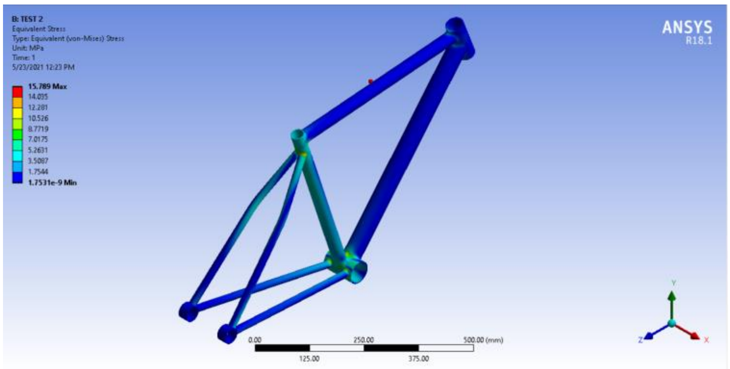


BOUNDARY CONDITIONS :

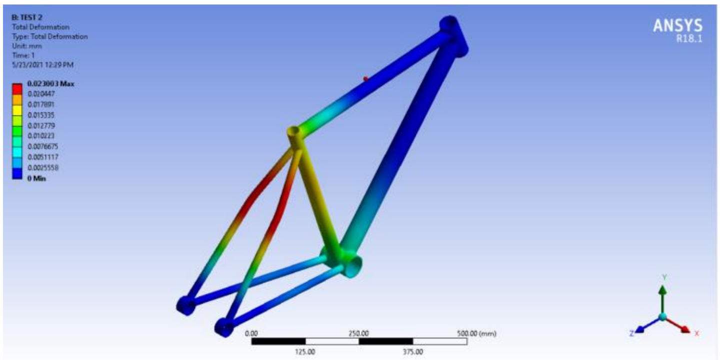
Fixed supports are assigned to the rear dropouts and head tube and a force of 951N is applied at the top of seat tube and direction along the seat tube and is evaluated for Stress(Equivalent Von Mises) and Total Deformation.

RESULT :

--Equivalent Stress(Von-Mises)
--Total Deformation



Equivalent Stress(Von-Mises)



Total Deformation

Maximum Stress (Mpa)	15.789
Total Deformation (mm)	0.023003
Stress at point A (Mpa)	3.5087-5.2631

2. CHAIN DRIVE :

Chain drive is the main component in bicycle when it comes to power transmission. It transmits power from the driver shaft to the drive shaft with the help of roller chain. A suitable chain has to be choosen in order to meet the requirements of the hub motor, so as to transmit power without any failure of the roller chain.

Motor Power Calculations.

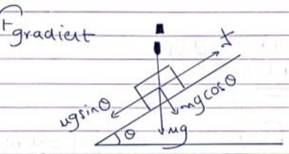
$F_{total} = F_{rolling} + F_{gradient} + F_{aero\ drag}$

1) $F_{rolling} = C_r m a$

C_r = coefficient of rolling resistance
m = mass of vehicle
a = acceleration due to gravity
$C_r = 0.004$ (Bicycle on asphalt road)

$= (0.004)(110)(9.81)$
$= 4.31N$

2) $F_{gradient}$



$F_{gradient} = mg\sin\theta$

For flat road $\theta = 0°$

$= (110)(9.81)\sin(0)$
$F = 0N$

3) $F_{aero\ drag} = 0.5(\rho v^2 C_d A_f)$

ρ = density of air $(kg/m^3) = 1.225\ kg/m^3$
v = velocity of vehicle $(m/s) = 25 km/hr$
C_d = Coefficient of air resistance = 0.9
A_f = Frontal Area (m^2)

$v = 25 km/hr$
$= 6.94 m/s$

$= 0.5(1.225 \times (6.94)^2 \times 0.9 \times 0.3696)$
$= 9.81N$

$A_f = l \times b \times$ (Adjusting Value) For bike = 70%

$F_{total} = 4.31 + 0 + 9.81$
$= 14.12N$

Power (w) = $F \times v$ v = velocity of the bike
$= (14.12)(6.94)$
$= 97.99W \simeq 100W$

Required Power = 100W

Calculations to find the suitable roller chain for the given power output of the Hub motor.

(1)

Motor specifications

1. Type :- Brushless
2. Rated Power :- 250W
3. Rated RPM :- 170RPM
4. Rated voltage :- 36V
5. Rated Output Torque :- 45N-m

Given :-

1. No. of teeth on smaller sprocket = $18T_1$
2. No. of teeth on larger sprocket = $52T_2$

Velocity Ratio = $\frac{52}{18} = 2.888$

Design Power = Rated Power x Service Factor
$S.F = K_1 \times K_2 \times K_3$

1) Load factor $(K_1) = 1.25$ (for variable load with mild shock)
2) Lubrication factor $(K_2) = 1.5$ (periodic lubrication)
3) Rating factor $(K_3) = 1$ (8 hours per day)

$D.P = 250 \times 1.25 \times 1.5 \times 1$
$= 468.75W$ or $0.468 kW$

(2)

From Table 21.4 (R.S Khurmi)
As the nearest RPM to 170 is 200, choosing smaller sprocket RPM to 200

For 200RPM :- ISO chain No:- "08B"
Power rating :- 1.18kW (single strand)

From Table (21.1) (R.S Khurmi) Chain characteristics for "08B"

- pitch = 12.70mm (p)
- Roller diameter (d_1) mm = 8.51mm
- width between inner plates (b_1) mm = 7.75mm

Breaking load from Table (21.1) (R.S Khurmi)
w_B = 17.8kN
= 17.8kN

Pitch circle diameter of smaller sprocket =
$d_1 = p\ cosec\left(\frac{180}{T_1}\right) = 12.70 \times cosec\left(\frac{180}{18}\right)$
$d_1 = 73.13mm$ or 0.073m

Pitch circle diameter of larger sprocket
$d_2 = p\ cosec\left(\frac{180}{T_2}\right) = 12.70\ cosec\left(\frac{180}{52}\right)$
$d_2 = 210.33mm$ or $0.210m$

(3)

Pitch line velocity of smaller sprocket

$$v_1 = \frac{\pi d_1 N_1}{60} = \frac{\pi (0.073)(200)}{60}$$

$$v_1 = 0.764 \text{ m/s}$$

Total load on the Chain

$$w = \frac{\text{Rated Power}}{\text{Pitch line velocity}}$$

$$= \frac{250}{0.764} = 327.22\text{N or } 0.327\text{KN}$$

$$\text{Factor of safety} = \frac{17.8 \times 10^3}{327.22} = 54.29$$

We know that the centre distance between sprockets is

$$x = 457.2\text{mm}$$

To accomodate initial sag, centre distance is reduced by 2 to 5mm

$$x = 457.2 - 5$$
$$= 452.2\text{mm}$$

$$\text{No. of chain links } (K) = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left(\frac{T_2 - T_1}{2\pi}\right)^2 \frac{p}{x}$$

$$= \frac{18+52}{2} + \frac{2(452.2)}{12.70} + \left(\frac{52-18}{2\times\pi}\right)^2 \frac{12.70}{452.2}$$

$$K = 35 + 71.21 + 0.82 = 107.03 \text{ or } 107$$

$$\text{length of chain} = K \times p = 107 \times 12.70 = 1358.9\text{mm or } 1.358\text{m}$$

3. BRAKING CALCULATIONS :

Brakes are used to stop the bicycle,due to the friction between the rubbing surfaces the bicycle comes to a hault,the happens by applying force on the caliper pistion which pushes the brake pad against the rotor so as to make contact with the rotor to produce the friction effect..

Components of Hydraulic DiscBrake :
1.Master Cylinder
2.Brake Lines
3.Caliper
4.Brake Pads
5.Disc Rotor

The reasons for using Hydraulic DiscBrake for electric bike is that it produces a high braking capacity,less maintainance and highly reliable…

i) Speed of bicycle = 25 km/hr = 6.94 m/s

ii) Weight of the bicycle including rider = 110kg

$$K.E = \frac{1}{2} mv^2 = \frac{1}{2}(110)(694)^2 = 2648.99\text{N}$$

a)
$$\text{Stopping distance} = \frac{v^2}{2\mu g} = \frac{(694)^2}{2(0.3)(9.81)}$$

$$d = 8.18\text{m}$$
$$= 8.18\text{m}$$

b) Deceleration

$$v^2 = u^2 + 2as$$
$$0 = (694)^2 + 2a(8.18)$$
$$a = -2.94 \text{ m/s}^2$$

c) Stopping time

$$v = u + at$$
$$0 = 6.94 + (-2.94) \times t$$
$$t = 2.36 \text{ sec}$$

$$\text{Braking force} = \frac{K.E}{a} = \frac{2648.99}{8.18} = 323.83\text{N}$$

$$\text{Braking torque} = F \times r = 323.83 \times 0.33 =$$
$$= 106.86 \text{ N-m}$$

Brake lever force applied by the rider = 300N

Master cylinder dia = d_{mc} = 14mm

$$P_{mc} = \frac{300}{\frac{\pi}{4} \times 14^2} = 1.94 \text{ N/mm}^2$$

Caliper piston dia = 25mm

$$F_p = 1.94 \times \left(\frac{\pi}{4}(25)^2\right)$$
$$= 952.29\text{N}$$

Braking torque

$$T = 2\mu F_p \times r$$

r = radius of brake rotor
μ = Coefficient of friction between brake pad and rotor

$$= 2(0.5)(952.29)\left(\frac{0.250}{2}\right)$$

$$= 119.03 \text{ N-m.}$$

Since the obtained braking torque is greater than the required braking torque the bicycle stops at a distance of 8.18m with a deceleration of 2.94 m/s² and with a time of 2.36 sec

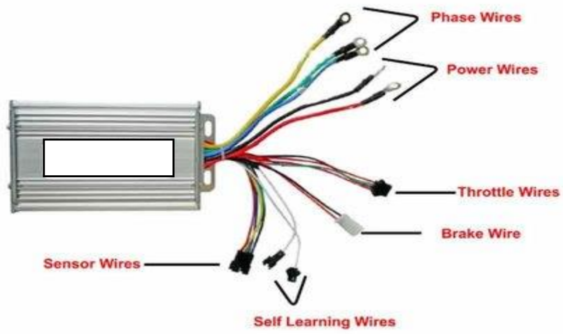
4. ELECTRICAL SYSTEM :

MOTOR :

The electric motor is what causes the bicycle to move forward, the electrical energy coming from the battery is converted into mechanical energy(rotational motion).A BLDC Motor is selected as the hub motor because of it excellent specifications and design. A BLDC is a brushless DC motor where in the carbon brushes are not used to make the electric contact in order to deliver or harvest electric energy. Bicycle Hub motors are specifically designed for electric bicycle so as to perfectly fit in the bicycle along which the wheel spokes, Different motors are available in the market which produces different powers. The electric motor is been selected by taking into consideration various factors which influences the power of the motor. Some of them are rolling resistance, gradient force and aerodynamic drag force.

MOTOR CONTROLLER :

The motor controller is a device which is used to control the speed of the motor in reponse to the throttle. When the throttle is held, due to change in the voltage the motor starts rotating the wheel which causes the bicycle to move forward. The motor controller also has many appilcations apart from controlling the motor. Miscellaneous componets of the electric bike can be connected to the motor controller such as the bicycle lights, sensors if used, brake, display unit etc



THROTTLE :

A throttle is a regulating device which is used to control the speed of the electric bicycle. The throttle is connected to the motor controller which responds when is throttle is being held or released. Throttle regulates the voltage to control the motor speed. There are different types of throttle and the one which is being used in electric bicycle is the Twist Grip Throttle.

BATTERY :

The Battery is the source of electric energy in the electric bicycle which supplies electrical energy in-order to run the motor. There are different types of rechargeable battery available

1.Lead Acid Battery
2.Lithium Battery
Among these two Lithium battery is highly preferred because of its compact size,high energy storage and stable power output.

DISPLAY :

Display unit displays the information about the speed of the vehicle,charge left in the battery,the voltage and current.

3. CONCLUSIONS :

Developments in the electric bicycle will benefit the environment in cases of pollution.Electric bicycles are cheaper than their electric motorcycle counterparts and the kilometers per charge is high making it suitable for daily errands and chores.

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BIOGRAPHIES

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