Design Report

1. INTRODUCTION

The inspiration to fabricate Effi-cycle was because of its potential to handle various environmental problems and to reduce automobile pollution Effi-cycle is a 3 wheeled hybrid vehicle which runs on both human and electric power. As it doesn't release any harmful gases it promotes the idea of eco-friendly vehicle for daily commuting there by contributing for green mobility. The designing of the vehicle is according to the rules and regulations specified in the SAE-NIS Effi-cycle rulebook 2019. Various static and dynamic were considered and based on analysis results, modifications were made to make the vehicle perfect for use and more efficient. The mechanisms of sub-systems were considered so as to keep the vehicle simple yet efficient in operation to justify the purpose of making the Effi-cycle

2. SELECTION & DESIGN OF SUB-SYSTEMS

2.1. DRIVETRAIN - *HUMAN*

The Human Drive train is a rear wheel drive, which is solely dependent on the chain drive. Each driver is given a discrete pedal station to give inputs. The input is then conveyed to the rear wheel by a mesh of chains and sprockets which are further being barred by a shaft.

A crank of arm length 7 inches is chosen and a crank wheel of 42 (semi- compact) is employed in the crank set. Rear wheel hub is allocated with a 7 speed free wheel (14-34T), providing a assorted sprocket ratios in the drive train, sprockets of 14 teeth are used on intermediate shafts.

CALCUATIONS:

Assuming input rpm given by a human is 60 rpm and that the maximum velocity is attained in 10 seconds.

Maximum Velocity:

Formula:

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

Where,

N_1 → Input rpm T_1→ No. Of teeth (input)

N_2 →Output rpm T_2→ No. Of teeth (output)

From pedal to shaft

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

$$N_2 = \frac{60 \times 42}{14}$$

N_2 = 180 rpm at shaft

From shaft to rear wheel

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

$$N_2 = \frac{28 \times 180}{14}$$

N_2 =360 rpm at rear wheel

Where,

$V_{\max}$ is the Maximum velocity of the vehicle

R is the Radius of rear wheel

W is the angular velocity

N_3 is the speed at rear wheel

$$V_{\max} = R \times W$$

$$V_{\max} = \frac{0.33 \times 2\Pi \times N_3}{60}$$

$$V_{\max} = \frac{0.33 \times 2\Pi \times 360}{60}$$

$$V_{\max} = 12.44 m/s = 44.7 kmph$$

Therefore, the maximum velocity of the vehicle in Human Drive is 44.7Kmph.

Acceleration:

Let v→Final velocity

u→ Initial velocity

a→acceleration

t→ time taken to reach maximum velocity

By Equation of Motion,

v=u+at

but

u = 0 m/s

v= $V_{\max}$

assume t=10 sec, i.e., maximum velocity is achieved in 10 sec

$$a = \frac{V_{\max}}{t}$$

$$a = 1.24 m/s^2$$

$$a_{\max} = a - \mu_r g$$

(μ_r is Coefficient of rolling friction)

$$= 1.24 - 0.005 \times 9..81$$

$$a_{\max} = 1.19 m/s^2$$

Therefore the Maximum Acceleration in the vehicle in Human Drive is 1.19 m/s^2.

Gradeability:

On inclined planes,

$$\theta = \sin^{-1}\left(\frac{a}{g}\right)$$

$$= \sin^{-1}\left(\frac{1.19}{9.81}\right)$$

=6.96°

Therefore the Maximum Gradeability of the vehicle in Human Drive is 6.96°.

Gear Ratio:

Gear No.	1	2	3	4	5	6	7
Teeth No. on rear wheel	34	24	22	20	18	16	14
Gear ratio (shaft to Wheel)	1.2R	0.85R	0.78 R	0.71 R	0.64 R	0.57 R	0.5 R

For example:

Gare ratio is 1.2R,

it represents that for every 1 rotation of intermediate shaft there is 1.2 rotation of rear wheel. Vehicle reaches 100 meters in…

By the equation of motion

$$s = uT + \frac{1}{2}aT^2$$

$$s = \frac{1}{2}aT^2$$

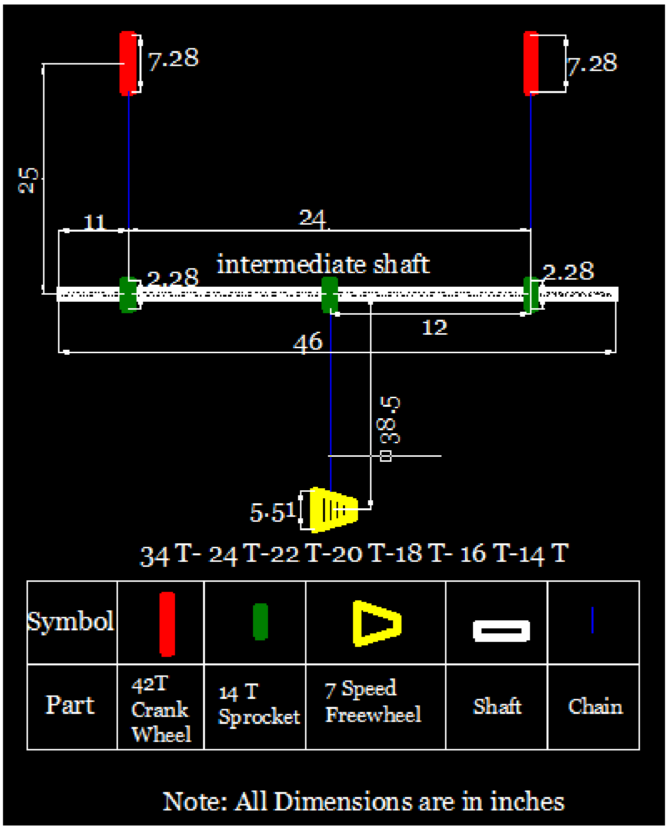
$$T = \sqrt{\frac{2s}{a}}$$

$$T = \sqrt{\frac{2 \times 100}{1.19}}$$

$$T = 12.96 \sec$$

In human drive Vehicle covers 100 meters in 12.96 seconds

CAD Model image of Human drive Train:



2.2. DRIVE TRAIN - *ELECTRIC*

Specifications of battery are as follows:

SPECIFICATION	VALUE
Type	li-ion battery
Dimensions	360mmx180mmx65mm
Power Rating	48V,35Amph
Run Time	1hours
Charging Time	6hours
Charger Rating	48V
Weight	12kg

The motor is provided by Vikson India. The specification of motor is as follows:

SPECIFICATION	VALUE
Dimensions	223mmx171mmx146mm
Power	Rated-600watts,peak-1400watts
Current	Rated-13A,Peak-32A
Voltage	48V
Rated RPM	500
Torque	Rated-10Nm,Peak-400% of rated power for 10sec.
Efficiency	~80% on full load and full RPM
Weight	Controller-0.55kg,Motor-4.60kg

The Controller is of Vikson India. The specifications of Controller are as follows:

SPECIFICATION	VALUE
Rated voltage	48V DC
Handle voltage	0.9-4.3
Rated current	35±1A

The motor is powered by battery and is linked to the shaft by a chain.

CALCULATIONS:

Formula:

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

Where,

$N_1 \rightarrow$ Input rpm $T_1 \rightarrow$ No. Of teeth (input)

$N_2 \rightarrow$ Output rpm $T_2 \rightarrow$ No. Of teeth (output)

From Motor to Shaft

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

$$N_2 = \frac{500 \times 14}{52}$$

N_2 = 134 rpm at shaft

From shaft to rear wheel

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}$$

$$N_2 = \frac{134 \times 28}{14}$$

N_2 = 268 rpm at rear wheel

Where,

$V_{\max}$ is the Maximum velocity of the vehicle

R is the Radius of rear wheel

W is the angular velocity

N_3 is the speed at rear wheel

$$V_{\max} = R \times W$$

$$V_{\max} = \frac{0.33 \times 2\Pi \times N_3}{60}$$

$$V_{\max} = \frac{0.33 \times 2\Pi \times 268}{60}$$

$$V_{\max} = 9.26 m/s = 33.34 kmph$$

Therefore, the Maximum Velocity of the vehicle in Electric Drive is 33.34 Kmph.

Acceleration:

$$p = \frac{w}{t} = \frac{\frac{1}{2} \times m \times v^2}{t}$$

P→Peak power of motor

w→ work done = change in kinetic energy

t→time taken to reach Maximum Velocity

$$t = \frac{\frac{1}{2} \times 280 \times (9^2)}{1400}$$

t =8.1 sec

Therefore, time taken to reach Maximum Velocity is 7.65 sec.

v→Final velocity

u→ Initial velocity

a→acceleration

t→ time taken to reach maximum velocity

By Equation of Motion,

v=u+at

but ,

u = 0 m/s

v= $V_{\max}$

t = 8.1 sec

$$a = \frac{9.26}{8.1} = 1.14 \text{ m/s}^2$$

$$a_{\max} = a - \mu_r g$$

(μ_r is Coefficient of rolling friction)

$$a_{\max} = 1.14 - 0.005 \times 9.81$$

$$= 1.1 \text{ m/s}^2$$

Therefore ,the Maximum Acceleration of the vehicle in Electric Drive is 1.16 m/s^2.

Gradeability:

On inclined planes,

$$\theta = \sin^{-1}\left(\frac{a}{g}\right)$$

$$= \sin^{-1}\left(\frac{1.1}{9.81}\right) = 6.4°$$

Therefore the Maximum Gradeability of the vehicle in Electric Drive is 6.4°

Gear Ratio:

Gear No.	1	2	3	4	5	6	7
Teeth No. on rear wheel	34	24	22	20	18	16	14
Gear ratio (shaft to Wheel)	1. 2R	0.85 R	0.78 R	0.71 R	0.64 R	0.57 R	0.5 R

For example:

Gear ratio is 1.2R,

it represents that for every 1 rotation of intermediate shaft there is 1.2 rotation of rear wheel.

Vehicle reaches 100 meters in…

By the equation of motion

$$s = uT + \frac{1}{2}aT^2$$

$$s = \frac{1}{2}aT^2$$

$$T = \sqrt{\frac{2s}{a}}$$

$$T = \sqrt{\frac{2 \times 100}{1.1}}$$

$$T = 13.48\sec$$

In electric drive, Vehicle covers 100 meters in 13.48 seconds

BATTERY RUNTIME:

$$Batteryruntime = \frac{Energyinbattery}{LoadPowerontheBattery}$$

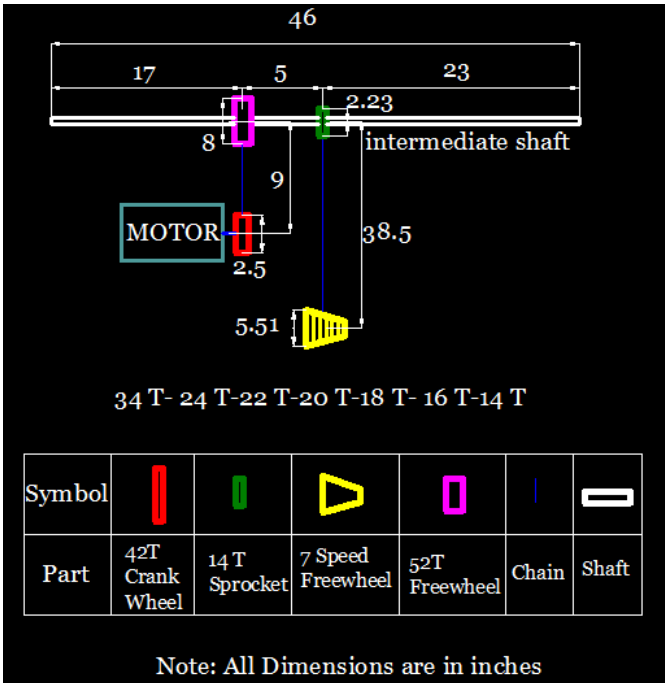
$$= \frac{35Ah \times 48V}{600W}$$

$$= \frac{1680Wh}{600W}$$

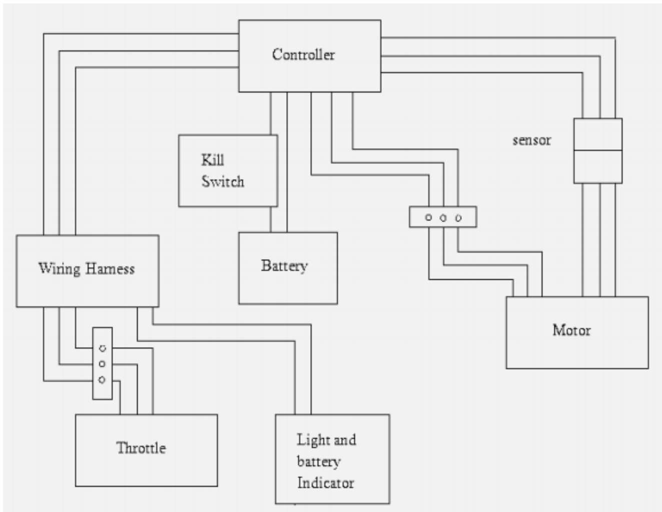
$$= 2.8h$$

Therefore Battery runtime is 2.8hours

CAD Model image of Electric drive Train:



The Circuit Diagram of Electric Drive is as follows:



2.3. Drive Train - *Hybrid*

Vehicle reaches 100 meters in…

By the equation of motion

$$s = uT + \frac{1}{2}aT^2$$

$$s = \frac{1}{2} a T^2$$

$$T = \sqrt{\frac{2s}{a}}$$

$$T = \sqrt{\frac{2 \times 100}{1.19}}$$

$$T = 12.96 \sec$$

In hybrid drive, Vehicle covers 100 meters in 12.96 seconds

1. Maximum Average Velocity = $\frac{33.34 + 43.7}{2}$ = $38.52 Kmph$

2. Maximum Average Acceleration = $\frac{1.1 + 1.9}{2} = 1.5 m/s^2$

3. Maximum Average Gradeability = $\frac{6.4 + 6.96}{2} = 6.68^0$

4. Reaches 0-100 meters in 12.96 seconds

2.4. STEERING

The steering considerations while designing the steering were

a) Minimum Turning Radius

b) Lesser cost ,Lesser Weight

c) More efficient and easy to handle

Keeping in mind all these aspects, the chosen steering design includes Direct Knuckle steering. This steering which we have used in our vehicle is one of the most economical, in which it includes handle which can be operated with one hand and it is placed towards right side of the driver which is the most economical position.

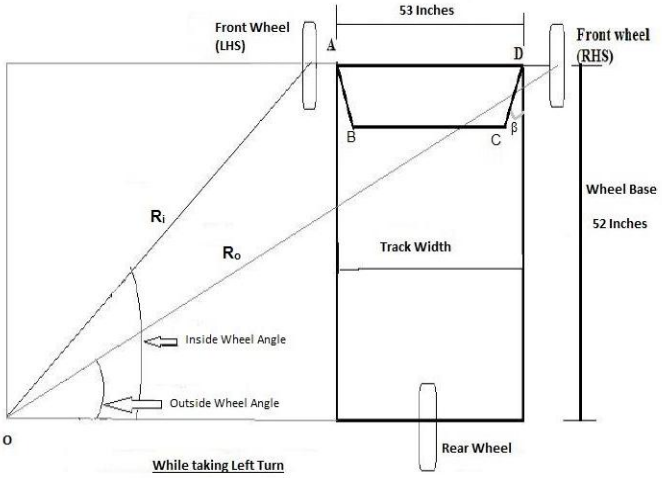
Direct steering is employed because there is no urge requirement of rack and pinion steering system. The entire requirements are fulfilled by using this mechanism.

STEERING GEOMETRY:

The Ackermann Geometry has been used as it prevents slipping of wheels while taking turn in low speed vehicles. According to Ackermann steering geometry, the outer wheels move faster than the inner wheels. Therefore the correct equation for steering is

$$\cot \emptyset - \cot \theta = \frac{b}{l}$$

Where Φ = outer wheel angle, θ = inner wheel angle, b = track width, L = wheelbase



CALCULATION OF TURNING RADIUS:

The relation between turning angle, wheel base and turning radius is

$$\sin(Outer\ wheel\ turning\ angle) = \frac{Wheel\ base}{Outer\ wheel\ turning\ radius}$$

Substituting the values

Wheelbase = 55 = 1.39 m and

Turning angle = 30degrees

Turning radius = 1.39/sin (35)

Turning radius = 2.64m.

From the relation Cot Φ – Cot θ = b /l

We get inner wheel turning angle=54.55 Degrees

$$\sin(inner\ wheel\ turning\ angle) = \frac{wheel\ base}{Inner\ wheel\ turning\ radius}$$

Inner wheel turning radius=1.32/sin (54.55)

Inner wheel turning radius=1.62 m

CALCULATION OF CRITICAL VELOCITY:

According to Newton's 1st Law of motion, a body moving in a straight line will continue in a straight line unless acted on by an external force. A body moving on a circular path with constant speed will have a changing velocity (directional speed) due to the body's changing direction.

This velocity change with time, called centripetal acceleration, has a radial direction toward the center of the circular movement and is given by the following equation:

$$a = V^2/R$$

Where V= velocity (m/s)

R = Radius of Turn (m)

a = Centripetal acceleration

Since Newton's second law tells us that a force has to act on the body to produce acceleration. Therefore,

F = m a

Where m = mass of vehicle

a = centripetal acceleration

F = Centripetal Force

$$\text{Therefore, } F = m v^2/R$$

Now, the lateral force on a vehicle moving in a circular motion on a pavement surface is produced by the frictional force between the tires and the roadway as follows:

$$F = \mu N$$

Where, N=Normal Reaction

$$\text{Therefore } F = \mu mg$$

Condition for a vehicle to not to slip-Centripetal force should not exceed the Frictional force. Therefore, equating both the forces will give the critical velocity which should not be exceeded.

$$m v^2/R = \mu mg$$

Solving the equation will give,

Critical velocity , $V_{critical} = (\mu gR)^{0.5}$

Where μ=0.6

G=gravitational constant=9.81m/s^2

R= turning radius=2.64 m

Therefore we get critical velocity = 3.94 m/
This is 14.19 kmph, a desirable critical velocity of vehicle.

Steering Parameters:

Track Width	53 inch
Wheel Base	52 inch
Steering Angle	30
Turning Radius	2.64m
Critical Velocity	3.94 ms^{-1}
Wheel Diameter	18 inch
Steering ratio	1:1

2.4. SUSPENSION

Suspension is a mandatory system to be provided for better bump impact resilience, riders' comfort, stability and, therefore, a sound ride/travel on Indian urban roads. Keeping in view the above mentioned aspects and to account for the dynamic weight distribution of the vehicle, we have opted to install both rear and front suspension.

Front Suspension

We had the following options for a front suspension:

1. Double wish bone

2. Suspension forks (Double forks)

3. Lefty (Single fork)

a. Double wishbone mounting is quite complex and is heavier compared to other options. Therefore, this option was rejected.

b. Lefty has a single fork only. The advantages it has over its double fork counterpart is that, it consumes less space, and is lighter. But this option was eliminated too due to unavailability of the product in our local market, and huge price if ordered from outside the state.

c. Suspension forks(double) are easier to mount, less complex in maintenance and repair, are convenient for welding extra parts/rods if required, cheap and are easily available in our local market.

Therefore keeping into account the cost, weight, availability, maintenance and complexity we have decided to use suspension forks(double), as our front suspension system.

Specifications:

1. Length of the whole setup (From start of the free rod to the mounting points):

2. Maximum compressible length:42mm

3. Diameter of the free rod(piston):2.5 cm

4. Suitable for wheel size ≤ 20 inch B.S.D(Bead seat diameter)

Rear Suspension

Coil over suspension system is very simple to build, as it consists of simply joined structures with springs mounted on a joint, connected to the chassis. The springs used are of constant rate, which are easily available in the market, are lighter and cheaper. Therefore the Coil-Over suspension is preferred.

Specifications:

Spring Rate of one spring	450 Lbs/inch=78.8 N/mm^2
Wire diameter	8mm
Pitch(average)	19mm
Number of Coils	6
Maximum spring travel	42mm
Number of Springs used	2

Analysis of the rear suspension:-

Assumptions made:

a. The rods used are assumed to be straight lines.

b.40% of the weight {280kgs, (Vehicle weight (120 kg) + Driver, Co-Driver weights (80-80kgs))} is acting on the rear wheel.

c. The springs are replaced with rigid rods, for ease, though it doesn't make any significant difference.

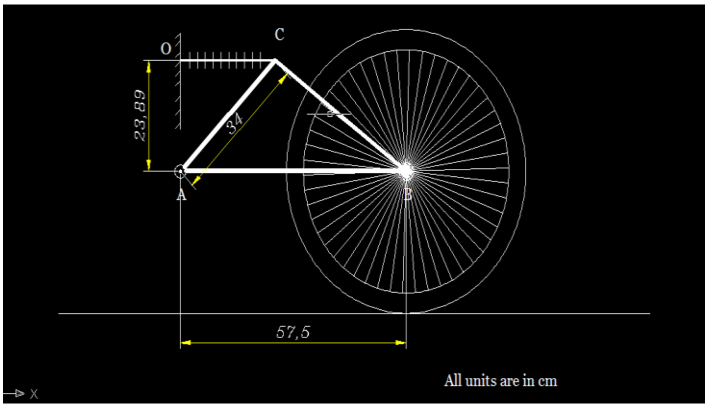
d. One end of the spring is attached to a chassis member, which is assumed to be a rigid, motionless wall.

Calculations:

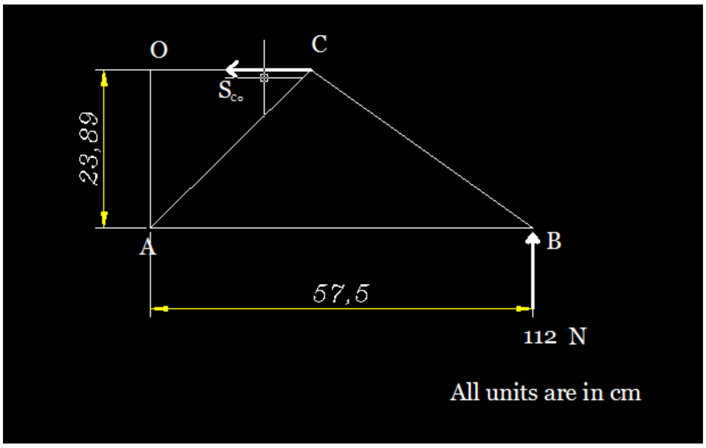
1."A" is the pivot (hinge), can rotate in the XY-Plane defined.

2. The vehicle is in static condition with the drivers on.

Schematic diagram of the suspension system:



Free Body Diagram (FBD):



Dimensions and angles:

AB = 57.5 cm

AC = 34 cm

BC = 41 cm

Angle CAB=44.65 Degrees

Angle OAC=45.35 Degrees =β

OA = AC x cos (β)

34 x cos (45.35)

=23.89 cm

As we assumed that 40% of the weight is on the rear wheel,

40% of 280 kgs=112 kgs

Therefore, the reaction from the ground, on the wheel is 112 x9.81=1098.72 = R_W.

The axial force on the member OC be S_{CO}

Now, taking moments about po int A.

R_W x AB + S_{CO} x OA = 0

1098.72 x 57.5 + S_{CO} x 23.89 = 0

S_{CO} x 23.89 = - 1098.72 x 57.5

S_{CO} = - 1098.72 x 57.5 / 23.89

S_{CO} = - 2644.470N

As we are using two springs of spring constant =78.8 N/mm^2 , the effective spring constant is 157.6 N/ mm^2.

k_{eff} = 157.6 N/ mm^2

We know that any spring satisfies the below equation

F = k x X, where F s the axial force; k, the effective spring constant; X is the compression in the spring.

From the calculations above the axial force F = -S_{CO} = 269.56 N (As spring's restoring force is opposite to that of the axial force)

X = F/k_{eff}

X = 2644.470 / 157.6

X = 16 mm

Here X is the compression in the spring when an axial force of 269.56 N or 112 N of reaction force is applied.

We know that the maximum possible compression in the spring, X_{max} = 42 mm

F_{max} = k_{eff} x X_{max}

F_{max} = 157.6 x 42 = 6619.2 N=6.6 KN

The relation between Axial force on spring(F) and Reaction force on the wheel is linear, therefore

$$\frac{F}{F_{\max}} = \frac{R_T}{R_{T\max}}$$

2644.470 / 6619.2 = 1098.72 / $R_{T\max}$

$$R_{T\max} = \frac{6619.2 \text{ x} 1098.72}{2644.47} = 2750.134 \text{ N}$$

Therefore, a maximum of 2750 N of reaction force is the safety limit.

<u>Analysis of the suspension system if the vehicle is thrown from a height</u>

<u>Assumptions made:</u>

1. When the vehicle is thrown from a height H_{max}, 40% of the reaction force acts on the rear wheel. It is same as assuming that

Calculations:

$$\text{F} = \text{m}\frac{\Delta v}{\Delta t}$$

$\Delta v = v_2 - v_1 = \sqrt{2gH_{\max}} - 0 = \sqrt{2gH_{\max}}$

Δt =Reaction time=0.5 seconds (Assumption)

F=2750.224 N

m = 40% of M=120 kgs

m = 48 kgs

$$\text{F} = \text{m}\frac{\sqrt{2gH_{\max}}}{\Delta t}$$

$$\text{F}^2 = \text{m}^2\frac{2gH_{\max}}{\Delta t^2}$$

$$H_{\max} = \frac{\text{F}^2.\Delta t^2}{\text{m}^2.2g}$$

$$H_{\max} = \frac{2750.224^2 \text{ x } 0.5^2}{48^2 \text{x2x9.81}} = 41.82m$$

Therefore, the suspension springs are safe if vehicle is thrown from a height of 41.82 m.

2.5. WHEELS & TYRES

Front - wheel Rim Diameter = 18 inches

Wheel dia =20 inches

Rear - Wheel Rim Diameter = 24 inches

Wheel Diameter = 26 inches

The Rear Wheel is chosen to have a larger Diameter than the front wheel for bearing more power, suck up the shocks and also to achieve better ergonomics.

The power absorbed is disseminated to suspension to render traction in all kind of surfaces.

2.6. BRAKING SYSTEM

Mechanical disc brakes are being used on all three wheels .Dual pull lever is used for the front wheels (one brake lever-dual cable pulls). They have high heat dissipation capacity as it has many holes on the disc.

Brake Specification: Independent disc with lever actuation.

Disc brakes are used over cantilever brakes for the following reasons:

1. Disc brakes have much higher mechanical advantage. This makes it easier to stop with less hand effort.

2. Disc brakes even grab better when wet.

3. Disc brakes do not wear out the rim.

4. They are lighter and cheaper also mounting and maintenance is easy.

5. They have high durability also.

6. Moreover Rubber pads need frequent replacement.

CALCULATIONS:

Maximum speed (v) = 30kmph= 8.33m/s

Vehicle mass (m) = 270kg

Rotor radius(r) = 80mm

Front Wheel radius(R) = 9inches= 0.228m

Coefficient of friction between rotor/disc and brake pad (u) =0.5

Area of brake pad (A) =370mm^2

Pressure (P) =3.8pa

Number of contact surfaces (n) =2(since they are two brake pads)

The force exerted by the brake pad on the rotor (Clamping force) will be

$$F_C = PA = (3.8x10^{6})(370x10^{-6}) = 1406N$$

The braking torque at the disc will be

$$T_d = nuF_C r = (2)(0.5)(1406)(80x10^{3}) = 112.48Nm$$

Since the disc is fixed to the wheel hub, Torque at the disc is equal to the torque of the wheel i.e.

$T_w = T_d$ i.e. $F_f R$ = 112.48 Nm

F_f (0.228) = 112.48 Nm

F_f= 492.03 N

Where F_f=braking force on front wheels

Similarly, the braking force on rear wheel= 370N

Therefore, average braking force, B_r= 431.01N

Vehicle wheel base (L) =51.9in= 1.32m

Centre of gravity height (h) = 19.6in=0.5m

Distance of COG to front axle(X) = 14in=0.355m

Coefficient of friction between wheel and road(u')= 0.7

The deceleration of the vehicle during braking is

$$d = (Lu'F_f)/(m(LX-uh))$$

$$= (1.32)(0.7)(492.03)/(270)(1.32*0.355-0.5*0.5)$$

$$D = 7.7m/s^2$$

The stopping distance of the vehicle at the maximum Speed will be

$$S = V^2/2d = (8.33)^2/2*7.7$$

$$S = 4.50m$$

The stopping distance of the vehicle at 24kmph is

$$S = (6.66)^2/2*7.7$$

$$= 2.88m$$

Braking Force	431.01N
Braking Torque	112.48Nm
Deceleration	7.7m/s^2
Stopping distance	4.05m

2.7. Seats

The seating system is devised to such a degree that it proffers enormous safety and comfort to the driver.

Both the seats are" apart each are having a clearance of " from the chassis verge making sure that the driver's body is completely defended inside the chassis.

The seat base is inclined at an angle of 15 to the horizontal. The seat back and seat base are mutually perpendicular.

The seat back angle is hence taken as 105 (90+15) for satisfying the facets of comfort, rideability and visibility.

The dimensions of the seat base, seat back for both the seats are as follows:

Seat Base: 15 * 18 in^2

Seat Back: 20 * 14 in^2

The seats are deployed at an elevation of 21" from ground and are rigid.

The seats are fabricated by placing a cushion of 2" on a support to withstand the weight of the drivers.

Sitting space for both the riders is 40 inches.

No adjustment mechanism has been made for seats.

Seating configuration, details of adjustment systems provide in the seat (slider, recliner, lifters etc), head restraints, and seat height for riders, seat back angle, seat design and features etc should be mentioned in detail. Method of manufacturing of seat to be indicated; if fabricated in-house.

3. SAFETY FEATURES OF VEHICLE

Firstly, to ensure safety due to the design of the chassis, impact analysis for different conditions, i.e., front impact, side impact, rear impact and roll over impact have been carried out and factor of safety values were calculated. This indicated that the vehicle isn't affected and the drivers will be safe during impact. Seat belts are provided.

A front fairing that runs all over till the upper end of the chassis safeguards the drivers from any frontal effects.

As mentioned in the rulebook, the seat and the drivers' body is completely inside the chassis and comfortable clearance has been provided.

All safety provision for drivers, collision safety mechanism for occupants etc, electrical safety etc,

4. ERGONOMICS & COMFORT FEATURES

The vehicle is ergonomically formulated for an adult driver of normal height and weight.

The front fairing augments comfort to the riders and the chassis design bestows a good line of sight.

The seats are semi- recumbently delineated, conducive to ensure that no fatigue ensues even after driving for a long distance.

The pedaling locale is meticulously determined to withdraw maximum power with minimum exhaustion of the rider.

APPENDIX-1 : PICTORIAL PRESENTATIONS

Sub System: Braking

SubSystem: Braking

SubSystem: Drive train