Design, Development and Testing of Convertible Bicycle

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Abstract: **The global threat of depletion of fossil fuels is a major concern due to fuel prices are rising steadily day by day. In addition to it, the pollution due to vehicles in metro cities & urban areas is increasing continuously. However, adoption of traditional bicycle is low due to more fatigue required in cycling. This paper delineates the design, fabrication and testing of human powered bicycle as a potential answer to this need. The primary purpose of this vehicle is to make a convertible bicycle is enable a trade-off in speed, effort, fatigue and comfort to make it more popular and safer. Innovation is to design a convertible (movable) frame by applying two four bar linkages for achieving upright mode and recumbent mode as per rider need. Advanced techniques of finite element analysis have been used to test the design of this model. A prototype was fabricated and tested to ensure the safety of the rider.**

Keywords: **Human power, speed, convertible, safety.**

1. INTRODUCTION

Standard of living of people is on a rise, the pressure on the fossil fuel resources is increasing alarmingly. Transportation being the backbone to a nation provides accessibility to widespread resources and far-flung markets. But it has many serious effects such as traffic congestion, safety, global warming and depletion of non-renewable sources of energy. In India, the average fuel consumption is around 3,292,000 barrels per day and is ranked fourth in the list of countries with largest fuel consumption per day [1]. The consumption rate will soon result in depletion of these resources and a major threat to the world. Many countries and organisations such as UNO has become highly concerned towards this problem and promoting 'GO GREEN' initiative. The paper is inspired from such an idea to enhance eco-friendly environment. It reveals the design of a *Convertible Bicycle* which will relieve this pressure on fossil fuels. The use of bicycle is obsolete nowadays due to its unrevised models and drawbacks.

It is an initiative to revive the era of bicycles in the present world with innovative changes in the existing traditional upright bicycle to motivate people to use it again. The vehicle is made to provide an alternative to the two-wheelers consuming fuel and replace them for long and short distances with reasonable cost. The problems with the existing traditional bicycle are:

- Only one mode of driving is available to the driver
- No safety system exists for rider.
- Uncomfortable seat.
- Much of the rider effort gets lost due to aerodynamic drag.
- Traditional bicycle design lacks the aesthetic considerations that result into disinterest of the younger generation and de-motivation for their use.

The proposed design is going to overcome above mentioned problems in the mode of comfort, aerodynamic drag and safety associated with a traditional upright bicycle and enhance eco-friendly environment.

2. DESIGN OBJECTIVE

The objective of this design is human powered convertible bicycle which can run of maximum speed is not exceeding 24 km per hour [2], which is able to

- Switch between two modes of driving, i.e., upright mode and recumbent mode.
- Become to stoppable mode at the earliest with the help of power brakes.
- Reduces the aerodynamic drag and attain higher speed by using fairing.
- Maintain driver safety with rollover protection system and seat belt.
- Motivate people of all age to use bicycle rather than motor vehicle.
- Enhance and help in creating eco-friendly environment.
- Provide better ergonomic design for long distance in recumbent mode.

3. DESIGN CONSIDERATIONS

We considered three general bicycle configurations for the rider.

- Upright mode
- Recumbent mode
- Prone mode

In an upright configuration a rider sits in the conventional position whereas in a recumbent configuration, the rider sits reclined with feet extending forward. In another configuration known as prone, rider lies with face down and head pointed in the direction of travel. In the prone position, the rider feels discomfort in a long drive and is difficult to ride. An upright bicycle design requires the rider to remain in the most vertical of positions with the greatest amount of body area susceptible to drag forces. But due to its ease in driving, it is desirable in vehicle. On the other hand, human comfort is a major issue of upright bicycle so its need the recumbent mode also.

4. DESIGN OVERVIEW

4.1 Design Overview of Convertible Bicycle

The design of convertible bicycle allows the rider to transform between recumbent and upright modes during a ride. A four-bar linkage, as a main frame of the bicycle is used to achieve the transformation between both modes. A main frame four-bar linkage is connected to another four-bar linkage consisting two supporting tubes and the seat. This allows the seat to arrange its position during transformation modes. The vehicle comprises of roll over protection system (RPS) to ensure the safety of the rider in case of side impact and rolling down of the vehicle. A seven-gear transmission system is applied in order to obtain good tractive effort with a positive drive. The proposed design is exhibited in Figure.1

Front view Side view

Top view Three dimensional view

Fig.1: Different views of proposed design

4.2 Special Features

4.2.1 Hydraulic Piston Arrangement

The transformation is initiated by a hydraulic piston attached to the rear seat tube. This piston is acted like a locking device for both four-bar linkages. The movement of piston is controlled by a lever which is attached below the seat as shown in Figure.2.

Two transform from:

- Recumbent to upright mode: The rider needs to shift his weight on pedal, and pull the lever of piston, and then the hydraulic piston allows this transformation.
- Upright to recumbent: The rider needs to shift his weight on seat, and pull the lever of piston, and then the hydraulic piston allows this transformation

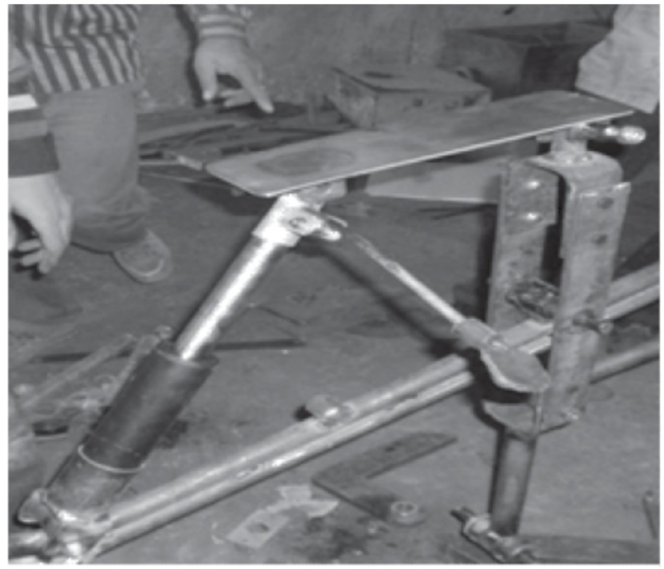

Fig 2: Piston with lever for conversion

4.2.2 Compound Gear System

The other special feature is the varying wheelbase due to change of driving mode. The wheelbase increases in recumbent mode and decreases in upright mode. Hence, the problem of chain length variation arises. To overcome this situation, compound gearing is used as shown in Figure.3.This is accomplished by using two different chain loops.

- First from front sprocket to compound sprocket.
- Other from compound sprocket to rear sprocket. The two compound sprockets have equal number of teeth so that the gear ratio does not change and the wheelbase can be varied easily.

Fig 3: Compound gearing mechanism

5. DESIGN CALCULATION

5.1 Frame design

For the frame, alloy steel AISI 4130 is used with specifications as mentioned in Table.1 [3]. AISI 4130 alloy steel contains chromium and molybdenum played role as strengthening agents. It has low carbon content, and hence it can be welded easily. Complete safety and aerodynamics is considered while fabricating the frame. The frontal area of the frame is minimized in order to reduce aerodynamic drag. Each sharp corner is smoothened to ensure safety of the rider.

Table 1: Specification of AISI 4130

S.No.	Physical Properties of AISI 4130	Numeric value
1	Density	7.85 g/cm^3
2	Melting point	1430°C
3	Ultimate Tensile Strength	560 MPa
4	Specific Heat	477 J/kg-K
5	Thermal Conductivity (100^o C)	42.7 W/mK
6	Modulus of Elasticity	190-210 GPa
7	Bulk Modulus	140 GPa
8	Shear Modulus	80 GPa
9	Impact Strength Izod	61.7 J

5.2 Power Transmission System

Like the traditional bicycles have a rear wheel drive, the current design also has the same drive to gain its advantages. From the front sprocket, power is transmitted to the compound sprocket with no variation in gear ratio followed by the rear sprocket. The vehicle have a seven cassette gear-shifting mechanism with different sizes of driven sprockets is known as rear sprocket to obtain higher speed or torque, when required. The bicycle comprises of 26 inch driving and driven wheels.

5.2.1. Maximum and Minimum Speed of Pedalling for Maximum Speed of Vehicle

We use the relation N=60V/πD with N being RPM of the driving wheel with diameter D to calculate V which is the maximum velocity corresponding to the RPM 'N', neglecting frictional and other losses. For achieving speed of 24 km/hour (6.67m/s), the design iterations reveal following data as Figure.4[4]:

Diameter of the driven (rear) wheel D=26 inch = 0.65m R.P.M of rear wheel: N = (60*6.67) / (3.14*0.65) =

196 rpm.. (1) As all rear sprockets are fixed on the same axle, hence rpm of all rear sprockets will be same.

$N_1 = N_2 = N$

Diameter of driving sprocket (D_3) =10 inch= 0.254 m Diameter of rear sprocket 2(D_2) = 6 inch =0.152 m Diameter of rear sprocket 1(D_1) = 4 inch =0.101 m

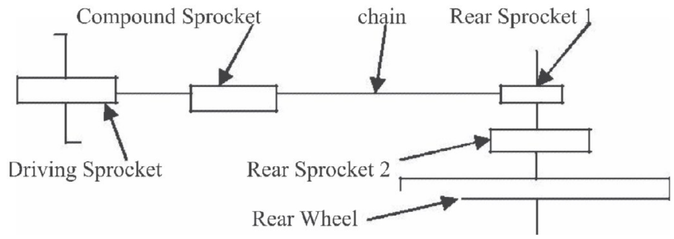

Fig.4.Power Transmission Gear Train

R.P.M of driving sprocket 2 = N_3 when chain is on 6 inch sprocket.

R.P.M of driving sprocket 1= $N_{3'}$ when chain is on 4 inch sprocket.

5.2.2 Determining the length of chain

With reference to the specifications of chain as shown in Table.2 we calculate the number of links [5] and the length of chain in alignment with the theory of power transmission through belts, ropes and chain.

Table 2: Physical Specification of Chain [4]

S.No.	Terms Used in Chain	Specification
1	Pitch of Chain	.012m
2	Centre Distance (Cassette and Crank Set) ©	1.78m
3	No of teeth on larger (front) sprocket T_2	44
4	No of teeth on smaller (rear sprocket T_1)	29

The length of chain is always expressed in terms of the number of links or $L = L_n * P$

Where L=length of chain (mm) L_n=no of links in the chain

The number of links in the chain is determined by the following relationship [4]:Where

T_1= No. of teeth on front sprocket

T_2= No. of teeth on rear sprocket

C= Distance between sprockets (m)

P = Pitch of chain = 0.012 m

By putting these values in above equations,

Case 1: When calculating length of chain from front sprocket to compound sprocket:

P=0.012 m; T_1 = 48; T_2 = 48 (No of teeth on front and compound sprocket)

C=C_1= Centre distance between crank and compound gear = 0.55 m

No. of links, $L_n = \left(\frac{48+48}{2}\right) + \left(\frac{2*0.55}{0.012}\right) + \left(\frac{48-48}{2.\pi}\right)^2 * \left(\frac{0.012}{0.55}\right)$

L_n = 140 ....(4)

So length of chain from front sprocket to compound

Case 2.When calculating length of chain from compound gear to rear sprocket:

P=0.012 m; T_1 = 48; T_2 = 14 (No of teeth on compound sprocket and rear sprocket 1)

C= C_2 = Centre distance between compound gear and rear sprocket = 0.93 m

No. of links, Ln= $\left(\frac{48+14}{2}\right)+\left(\frac{2*0.93}{1.2}\right)+\left(\frac{48-14}{2.\pi}\right)^2*\left(\frac{1.2}{93}\right)$

L_n = 187.. (6)

Length of chain from compound gear to rear sprocket, L_2 = 187 * 0.012 = 2.24 m

Total length of chain, L= L_1+ L_2 = 1.68 +2.24

= 3.92 m... (7)

5.2.3. Determining the corresponding force to be applied at pedal

Considering the first loading condition total tractive effort required on the rear wheel of the tricycle is calculated [6].

- Gross weight of the convertible bicycle
- Desired maximum speed of the bicycle(V_{max})= 24 km/hr=6.67m/s
- Desired acceleration time (t_a) = 10 sec 4
- Gradient (α)=0^o
- Coefficient of rolling resistance between tire and road C_{rr} =0.017 (contact surface asphalt)

  Total force on pedal

$$F = \frac{F_R r_w}{r_c} x \frac{r_1}{r_2} \qquad (8)$$

Where

F = total force applied on pedal in N F_R= total tractive force in N

r_w = radius of rear wheel in mm =325 mm r_c = length of crank arm in mm = 180 mm

Total Tractive Force (F_R) = R_R+G_R+F_{AR}

Rolling Resistance (R_R) = W*C_{rr} = 1400*0.017 = 23.8N

Accelerating Resistance (F_{AR}) = W*(V_{max} –V_{min})/gt_a

= [1400*(6.67-0)]/ (9.81*10) = 95.2N

r_1 = radius of front sprocket (mm) =10 inch/2= 127 mm r_2 = radius of rear sprocket in mm = 6 inch/2 =76.2 mm Where p is the pitch of chain in (mm)

Force at pedal

$$F=\frac{119.2*325\ 127}{180 * 76.2}$$

F=358.70 N..(11)

5.2.4. Mechanical Advantage

M.A = Output Force/Input Force F/F_R = 358.70/119 = 3

5.3 Design for Safety

Rollover Protection System: All vehicles must include a rollover protection system (RPS) that protects a rider during running of vehicle from an accident [7]. Functionally, the RPS must:

- Absorb sufficient energy in a severe accident to minimize risk of injury.
- Prevent significant body contact with the ground after an accident by falling (vehicle resting on its side) or rollover (vehicle inverted).
- Provide adequate abrasion resistance to protect against sliding across the ground.

Self locking safety belt has been used to provide maximum safety especially when driver feels any impact during riding, it has been self locked. The design also incorporates a reflector which provides the safe riding in nights as well as a ringing bell.

6. ANALYSIS

Structural Analysis of Frame

The major points of concern in design were the linkages and joints stiffness. For checking stability of the frame, geometry was being imported into ANSYS from Pro-Engineer and analysis was done using structural model. For safety of rider, we took factor of safety=3 by assuming total weight of vehicle including rider weight not to exceed 660 lbs (300 kg) as shown in Figure.5. After few amendments in the design, a successful analysis of frame was done with sustainable bending. The material of steel 4130 had generated maximum stress of 524.95 MPa at the centre joint [8]. However the reason of bearing high stress is taking the factor of safety as 3.

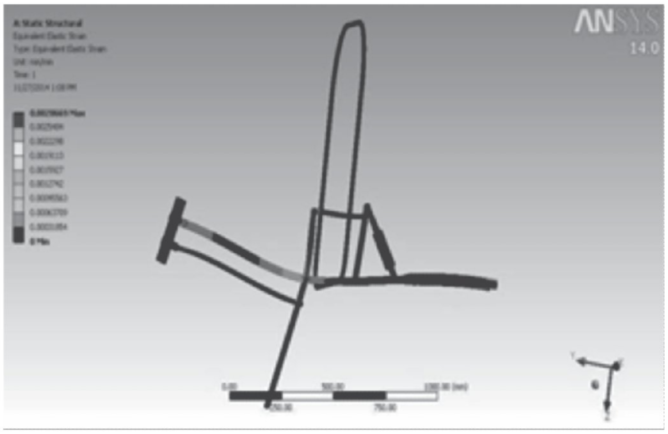

Fig 5: The equivalent stress for frame

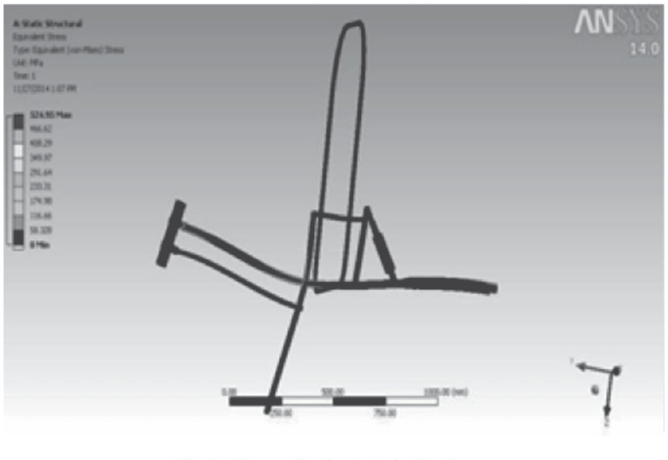

Fig 6: The equivalent strain for frame

7. FABRICATION

The fabrication process is the beginning of the actual project process which involves a transition from virtual design to the real world physical object. It is a lengthy and creative process which involves the practical application of sound engineering principles. The fabrication process started with the fabrication of frame as per design followed by welding of RPS over it. Metal Inert Gas (MIG) Welding is used during the whole fabrication process as it provides a high strength welded joint which can sustain dynamic and impact loading efficiently as compared to electric arc welding as shown in figure7.

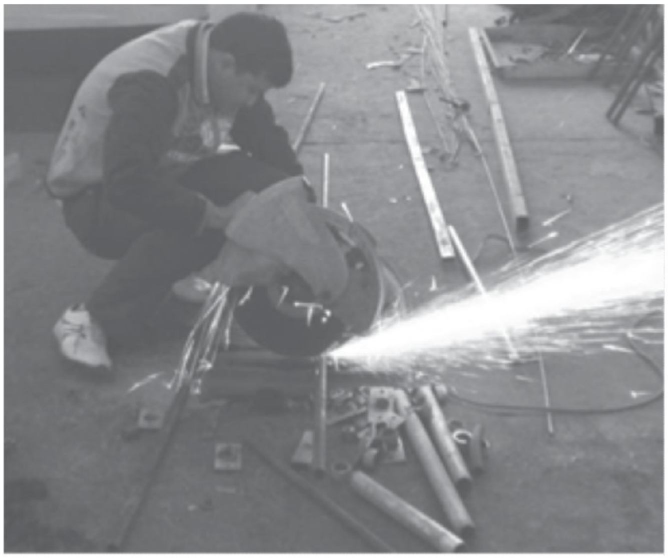

Fig 7: Fabrication of Frame

8. TESTING

8.1 Rollover Protection System (RPS) Testing

The RPS was tested as stated by prescribed safety rules and regulation hand book [5]. The roll protection system must be able to support a load of 600lbf applied to the top of the roll bar, directed downward at an angle of 12° from the vertical and a side load of 300lbf applied horizontally to the side of the roll bar at shoulder height. The roll bar is acceptable if there is no indication of permanent deformation, fracture, or delaminating on either the roll bar or the vehicle frame. The maximum elastic deformation is such that it does not come into physical contact with the driver's helmet, head or body.

Table 3: Results of Load Testing for RPS

Content	Maximum Value	Actual Value
Top Loading	750 lbf	600 lbf
Side Loading	750 lbf	300 lbf
Deflection in Top Loading	2 inches	0.75 inches
Deflection in Side Loading	1.5 inches	0.6 inches

Experiments were performed to measure the elastic deformation of the roll bar protection system in the top and side directions.

8.2 Frame Testing-

It is important to determine whether the frame material is correct and in compliance to our design requirement. This can be done by applying three times more load than the weight of an average human being in order to counter the effect of gravitational forces and bumping of vehicle on road.

8.3 Testing of Convertible Bicycle:

The fabricated bicycle was tested for performance in accordance to the guidelines of ASME for their human powered vehicle competition [5]. A test track of approximately 2 km lap length with level & inclined portions was prepared. The bicycle was driven by a team of 5 riders individually and sequentially. The limitation on each rider was to ride the trike for at least 7 km, or for 30 minutes, whichever was earlier. The results of the performance testing are summarized below:

- No of riders: 5
- No of riders who completed their ride without undue stress: 5
- Maximum speed achieved: 36 km/hr
- Maximum upward incline: 15 degrees
- Maximum distance driven by one rider (without any fatigue): 8 km
- Vehicle Weight – 40 kg
- Turning Radius – 3.65 meters
- Braking Time – 10 Seconds or Less in 6 meters as the stopping distance.

The fabricated prototype was thus found to be satisfactory in performance.

9. CONCLUSION

The Convertible Bicycle is a step to revive the use of bicycles in the routine life of the people. It enhances eco-friendly environment and is also a potential solution to the problem of massive fuel consumption by automobile across the globe. It can be easily and comfortably used in the city traffic as well as for long distance tours by professionals. The physical testing and riding for

30 km has proved its reliability, usability, endurance as well as safety & stability. The Prototype was participated in ASME HPVC India 2015 organised at DTU, New Delhi and was:-

- Awarded the Novelty Award for Unique Design.
- Secured the 10th position across India comprising of Design, Drag and Endurance events (Human Powered Vehicle India -2015, 2015).

The design can be further modified by adding solar powered drive, which will decrease the fatigue caused. The cost aspects can be taken into consideration and economies of scale may be employed to reduce the unit cost of the bicycle. There are definite possibilities of obtaining the patents of the design and launching a commercially viable product after ratifying the minor problems. The idea might change the world scenario and help in sustainable development.

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