Design and Development of Hybrid Electrical Folding Bicycle

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Abstract: **The global threat of depletion of fossil fuels is a major concern. In addition, 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. Today the use of Electrical Folding Bicycle can help in reducing air pollution, enhancing the mobility of the elderly and lame and, when used by the able bodied, can prove a practical substitute for many car trips of less than 10 km. This paper delineates the design, fabrication and testing of an efficient electrical folding bicycle having high strength and light weight as a potential answer to this need. The primary purpose of this vehicle is to fold by reducing to 50% volumetric area for easy transportation. To operate the bicycle by electric d.c. motor running by led acid dry battery which would be charged by the electric current and transport its rider from one location to other in a single charge with 5 hours back-up time. Innovation is to design a foldable frame of Al6061 by joining four different folding joints for achieving folding and opening in hybrid mode as per rider's need. Advanced techniques of modelling and Finite Element Analysis (FEA) have been used to test the design of this model. A prototype was fabricated and tested to ensure the safety of the rider.**

Key Words: **Hybrid, electric folding bicycle, compact.**

1. INTRODUCTION

Transportation plays a key role in overall development of the society, both economically and socially, by extending accessibility of resources and markets. Nevertheless, it has many spillover effects such as traffic congestion, safety, global warming and depletion of non- renewable sources of energy. In India, there are presently close to 18 million petrolpowered two wheelers and about 1.5 million petrol and diesel powered three wheelers besides a large number of four wheelers [1]. All these vehicles are consuming natural resources which will be depleted in the coming times. This paper, therefore, discusses the design of an electrical folding bicycle which does not depend on fossil fuels. It has a simple design delivering high performance, is easy to maintain and is safe. It is therefore capable of replacing fuelled vehicles for some applications, contributing towards environmental sustainability. An electric folding bicycle is a bicycle with an integrated electric motor which can be used for propulsion and use rechargeable batteries and the lighter varieties can travel up to short distances. Today the use of electrical folding bicycle can help in reducing air pollution, enhancing the mobility of the elderly and lame and, when used by the able bodied, can provide a practical substitute for many car trips of less than 10 km. Basically the idea of this bicycle is to promote the green environment potential for reducing greenhouse gas emissions, air pollution, petrol consumption and traffic congestion in cities [2] and to launch this concept for the Jaipur Metro stations meant for use in transportation from home to metro station and metro station to home.

2. OBJECTIVES

The objective of the design is to design an electrical folding bicycle in consideration of maximum speed of 30 km/hr with 350 watts of silent electric power, which is capable of:-

- Promote the green environment by reducing the fuel consumption.
- Meant for use in transportation from home to metro station and metro station to home.
- Short rides up to 3-5km per ride per charge of battery with 4-5 hours back-up capacity.
- Light in weight commensurate with adequate durability
- Work on hybrid mode which is not available in Indian market i.e pedal operated as well as electrically operated [3].
- Easily foldable with compactness in size as like in suitcase form.
- Good aesthetic look to attract the youngsters towards bicycle.

3. SCOPE OF WORK

The scope of work consists of the following:

- Selection of the project
- An initial literature study to learn about the electrical folding bicycle
- Selection of mechanism and material to test
- Designing the vehicle on NX-CAD
- Virtual Testing on static structural analysis on ANSYS and Test results
- Fabrication and testing of vehicle

4. DESIGN OVERVIEW

This design enables the driver to have a comfortable ride at all times as the body weight is distributed comfortably over a large area supported by back and buttocks. It can also have an option of adjustable seat to enable adoption of a comfortable position by individual rider. The proposed design is exhibited in Fig. 1 in normal mode and in Fig. 2 in folded mode.

Fig.1 Electric folding bicycle in normal mode

Fig.2 Electric folding bicycle in folded mode

The next step of the product development process is to prepare a complete list of requirements of the electrical folding bicycle as mentioned earlier in the 'objective' and setting up of initial specification.

- Maximum speed = 25 km/hrs.
- Charge time = 3-3.5 hrs.
- Tyre size =16 inch
- Target weight of vehicle = 10 kg
- Cost of vehicle = Rs.25000 to Rs.30000
- Battery = Discharging time up to 3-3.5 hrs.
- Motor =capable to ride bicycle with rider of weight 80 kg

4.1 Design calculation

The calculations are a very essential part of our vehicle that will show how our design is efficient and better. These calculations include Braking analysis and various other parameters of the vehicle. Initial Specifications:

Frame design

Steel, has good ultimate strength, with much lower yield strength. This is good, since it means that a steel frame will bend well before it breaks, reducing the chance of a disastrous crash. Steel used for bicycle frame has pretty good elasticity. Steel's only drawback is its relatively high weight. To overcome this effect to select the aluminium 6061 for the frames of the bicycle. By using this material the weight of the cycle will be reduced and simultaneously good elasticity can be achieved. The aluminium alloys are having lower specific gravity, higher corrosion resistance, higher thermalconductivity than carbon alloys whereas the carbon alloys are having higerh ductility and easy machinability than aluminium alloys [4].The various properties of carbon steel 4130 and aluminium 6061 [5] are as shown in table1.

Table.1 Comparison of Carbon Steel 4130 and Aluminium 6061

Property	CarbonSteel 4130	Aluminium 6061
Young's Modulus (MPa)	2.10E+05	69000
Poisson's Ratio	0.29	0.33
Bulk Modulus (MPa)	1.67E+05	67647
Shear Modulus (MPa)	81395	25940
Tensile Yield Strength (MPa)	460	270
Tensile Ultimate Strength (MPa)	560	310
Density (kg mm^-3)	7.85E-06	2.70E-06

4.1.1 Determining the length of chain

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

Table 2: Physical Specification of Chain [9]

S.No.	Terms Used in Chain	Specification
1	Pitch of Chain (P)	.012m
2	No of teeth on larger (front) sprocket T_2	44
3	No of teeth on smaller (rear sprocket $T_{1)}$	29

The length of chain is expressed in terms of thenumber 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 [9]:

$$L_n = \left(\frac{T1 + T2}{2}\right) + \left(\frac{2 * C}{P}\right) + \left(\frac{T1 - T2}{2.\pi}\right)^2 * \left(\frac{P}{C}\right) \quad (1)$$

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, 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) and $C=C_1$=Centre distance betweencrank and compound gear = 0.55 m, we find that the the number of links is,

$$L_n = \left(\frac{48 + 48}{2}\right) + \left(\frac{2 * 0.55}{0.012}\right) + \left(\frac{48-48}{2.\pi}\right)^2 * \left(\frac{0.012}{0.55}\right)$$

$L_n = 140$

So length of chain from front sprocket to compound gear,

$L_1 = 140 * 0.012 = 1.68$ m (2)

4.1.1 Braking analysis

This calculation was performed using 100 kg as the weight of the vehicle and the rider combined. Applying the safety guidelines for minimum stopping distance using braking force [6]:

Initial velocity, V_i= 25 Kmph = 6.94 m/s,

Final velocity, V_f= 0 Kmph = 0 m/s,

Mass of the vehicle M= 100 kg,

Stopping distance, X= 6 m

We know that braking force,

$$F_{xt} = \frac{(V_i^2 - V_f^2)M}{2*X} \quad (3)$$

By putting this value in above equation, F_{xt} = 401.36 N

4.1.2 Total tractive force:

Total tractive effort (F_t) is the addition of rolling resistance (RR), gradient resistance (GR) and acceleration force (FA) [6].

F_t = RR + GR +FA (4)

a. Rolling resistance (RR):

$RR = W * C_{rr}$ (5)

Where, W= total weight of bicycle and rider =980 N, C_{rr} = Coefficient of rolling resistance [6] between tire and road = 0.017. Thus,

RR= 980 x 0.017 = 16.66 N

b. Gradient resistance [6] (GR):

GR= W * sinα (6)

Where W= total weight of bicycle and rider =980 N,

Inclination angle α = 0(because of no elevation)]

Therefore, GR=0

c. Accelerating resistance (FA):

Force applied [7] $= W * \left(\frac{V_{max}}{g * t_a}\right)$ (7)

Here, W = total weight of bicycle and rider =980 N,

v_{max} = maximum speed of vehicle =6.94 m/s =25 kmph

g= acceleration due to gravity = 9.8 m/s^2

t_a = Desired acceleration time =10 sec

Therefore, Force applied FA = $980 * \left(\frac{6.94}{9.8*10}\right)$ = 69.4 N

So total tractive force (F_t) = RR+ GR+ FA (8)

= 16.66 + 0 + 69.4= 86.06N

4.1.3 Force required at pedal:

Force at pedal, F [7] = $\frac{F_t \times R_w}{(R_C)(R_2)} \times (R_1)$ (9)

Where F = total force on pedal

F_t = total tractive force &R_c= length of crank arm

R_w= radius of rear wheel & R_1 = radius of rear sprocket

R_2=radius of front sprocket

$$F = \frac{86.06 \times 205 \times 127}{180 \times 76.2}$$

= 163.35 N

4.1.4 *Mechanical advantage*

M.A. = $\frac{\text{output force}}{\text{Input force}} = \frac{163.05}{96.06}$ = 1.89

4.1.5 Motor and battery calculations [8]:

We assume 30 seconds for attaining maximum speed of 25 km/hrs.

Mass of the vehicle =100 kg

Acceleration a =dv/dt

Where, dv=25 km/hrs.=6.944 m/sec, dt = 30 seconds

Therefore, a=6.944/30 =0.231 m/sec^2

Force=m .a=100 * 0.231=23.14 N

Power required P = F * v (10)

P = 23.14 * 6.944 =160.68 W

Now considering the air drag force & availability in market, power of hub motor is chosen as 250W.

The specification of selected d.c motor is as follows:

- Model – P40-250
- No load rpm – 3400
- Power – 250W (1/3 of Horse power)

The specifications of selected lead acid battery are:

- Model no. – EP4L-SMF
- Voltage - 12 V (2 batteries required)
- Capacity – 4amph
- Dimension in mm – H94*W75*L115
- Gross weight – 1.34 kg (approx)

4.2 Folding System:

The electric folding bicycle is folded in an easy manner and reduced by 50 percent of its original size. The electric folding bicycle is folded in 4 steps. The handle tube, frame and front wheel is folded. The complete folding of a bicycle consisting of following steps as follows:

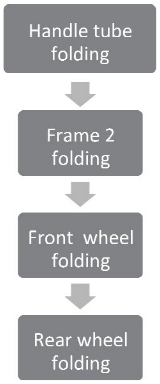

Fig.3 Folding frames sequence

The various folding techniques used in electric folding bicycle are as follows:

4.2.1 Handle tube folding

The first folding of bicycle is handle tube folding, in these the sleeve and two U shape tubes are used which is joined by rivet. For folding, the sleeve is lift upward and then the handle tube is folded and rest on the frame 1.

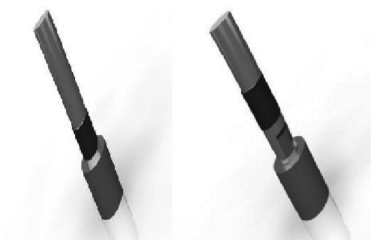

Fig.4 Handle tube folding sleeve

4.2.2 Frame Folding

The second step is to fold the frame 2 of bicycle. The frame 2 and frame 1 is joined together with nut bolt assembly as shown in Fig. 6. The folding is done through this joint and frame 2 is rest on the handle tube.

4.2.3 Front Wheel Folding Joint

The next step is to fold the front wheel. In this joint, an external threaded tube is there in which T nut is used as a locking system. For folding a T shape nut is open and wheel is move outward and fold towards frame 1.After folding the T shape nut is locked.

4.2.4 Rear Wheel Folding

The rear wheel is attached with frame 3 which is further attached with frame 2.The whole assembly is locked by L shaped joint as shown in drawing. To fold the rear wheel L shaped joint is taken out and the rear wheel is move forward and folded.

5. ANALYSIS

Procedure for performing FEM analysis in Ansys 14.0

- Importing the bicycle model into the desired .stl file into Ansys.
- Selecting appropriate material and defining material properties regarding each part of the bicycle and assigning material to the parts respectively.
- Discretization of bicycle model using various methods of meshing and selecting optimal method to achieve fine results of meshing.
- Applying loads and constraints at seat tube of bicycle and wheel axles respectively.
- Determined total deformation and equivalent von Misses stresses and factor of safety of the bicycle.

In the ANSYS testing the load is applied horizontally applied on the seat where the driver seats and the deformation testing is carried out. The testing is mainly done on the three frames i.e frame 1, frame 2, frame 3 and fork of the bicycle. The maximum deformation of 0.3952 mm is occur at the frame 2 as shown in Fig.5.Since it is far less than 1.7784 mm as shown in table.3 which is the failure point and hence the design of bicycle in respect of deformation is safe. In the ANSYS testing, an equivalent elastic stress of folding bicycle is carried out. The testing is mainly carried out at the frame of the bicycle. The horizontal load is applied at the seat of the bicycle. A very minimal stress of 9.3184e-8 MPa is observed in the design as shown in Fig. 6. Hence our design is safe in this respect also.

Table.3 Static structural result analysis for frame one and two

Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von Mises) Stress
		Results	
Minimum	3.3138e-009 mm	7.4275e-013 mm/mm	9.3184e-008 MPa
Maximum	1.7784 mm	1.3444e-003 mm/mm	116.41 MPa

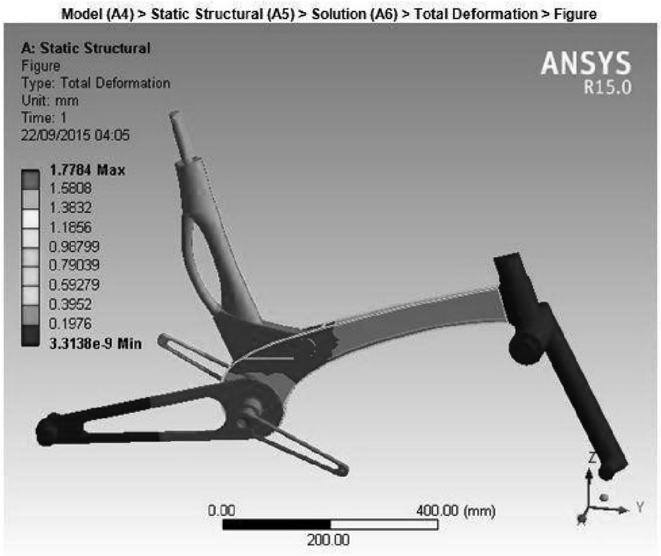

Fig.5 Maximum deformation in frame2

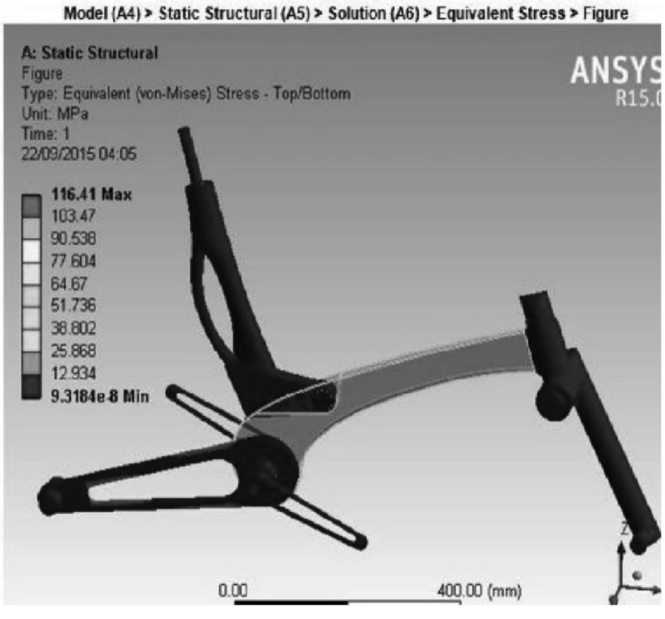

Fig.6 Maximum equivalent stress in frame2

6. 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 frame and folding joints as per design of bicycle. Gas welding is used during the fabrication process of frames which are made of aluminium sheet 6061. It provides high strengthwhich can sustain dynamic and impact loading efficiently as compared to electric arc welding. The front Part ofbicycle covers handlebar, head tube, fork etc. Chromoly4130 pipe is used tomake folding joint of front wheel. Aluminium sheet is used to make head tube which is fixed with frame by mechanical fasteners. Frame 1 & 2 are joined together with bush arrangement.

Fig.7 Fabrication of folding frame1

Fig.8 Fabrication of folding frame2 and frame3

This folding bicycle has 3 frames. The frame-1 of bicycle is made by aluminium sheet 6061. The desired profile of frame1 and frame2 is obtained by making profile of all faces of frame over sheet. The final shape of frames covers cutting and welding process to get desired shape. Metal inert gas welding [MIG] welding is used in manufacturing of frame, the filler rod used in MIG welding is of aluminium having bead diameter 2.4 mm ,arc length of about 1/6 inch and voltage supplied is about 23 volt. The frame 3 of bicycleconnects rear wheel with frame 1. It is an aluminium plate 4 mm thickness. Frame 3 is cut by milling machine and hand cutter. The handle tube and fork is manufactured by chromoly4130 and assembled with frames with the help of nut bolt assembly. Final assembly would be prepared as per assembly drawing and assembled view of electric folding bicycle in normal mode can be seen in fig.9 and after folding in fig.10

Fig.9 Assembled view of EFB in normal mode

Fig.10 Assembled view of EFB after folding

7. CONCLUSION

The proposed electric folding bicycle undoubtedly presents an eco-friendly and potential solution to the ever increasing petrol crises both in India and abroad. Fabrication and testing of an efficient electrical folding bicycle, is a potential answer to this need. The vehicle is able to fold in half for easy transportation. To operate the bicycle by electric D.C. motor running by lithium ion battery which would be charged by the electric current as well apply the human power and transport its rider from one location to other in a safe and comfortable manner. It can be suitably used for hustle free transportation with maximum speed of 30km/hrs and minimum weight of 9kg which is just around half from the conventional bicycles available in Indian market. Electric folding bicycle required only a minute to convert into folding mode from normal mode especially in a moderate traffic scenario.

8. FUTURE SCOPE

Electric folding 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 by professionals. Vehicle involves the following possible modifications:

- No need of electric power supply by adding solar powered drive.
- The folding technique can be enhanced to fold in a single fold.
- The cost aspects can be taken into consideration and economies of scale may be employed to reduce the unit cost of the bicycle.
- The concept can replace the traditional bicycles for passenger transportation.
- It can also be modified by giving it a jazzy and lucrative look to make it more eye-catchy.

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