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Design, Development and Testing of Hybrid Folding Bicycle

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Abstract: *The alarming state of excessive combustion of non-renewable resources along with the emission of pollutants into the environment has now become a hot topic among the researchers across the globe. The criticality of the current scenario has brought us back to the need of bicycles, even being known as fatigue causing medium of locomotion. An alternative source to compensate the human fatigue is the electric source as power input. Under this designed paper, we have tried to achieve the global goals by design, fabrication and testing of an electric folding bicycle with the main objective to cover short distances about 50 Km in one go.*

*The bicycle powered by 4*12 batteries, acquires the top speed close to 40Kmph. A permanent magnet BLDC motor with 750W capacity is installed along with a special feature of a folding joint with the basic aim to reduce volumetric area to 50%. The material used for fabrication i.e. stainless steel can easily bear weight up to 100Kg. Advanced modelling software like Ansys and Solid works were used to test the design. Thus, we have created a prototype under above stated specifications to reflect practicality, usability and safety of the rider.*

I. INTRODUCTION

Bicycle has been the most adapted mode of transportation to cover short distances through many centuries. Since its acceptance, bicycle has undergone various modifications as to be more comfortable and efficient mode of transportation. Gian Giacomo Caprotti, a pupil of Leonardo da Vinci [1] was known to be the first sketcher maker of bicycle in the year 1534. The first practically used bicycle belonged to a civil servant to the Grand Duke of Baden in Germany, named Baron Karl von Drais. Drais invented his running machine in 1817 with a name as Draisine (English) or Draisienne (French). His design got patented in the year 1818 and became the first commercially successful two-wheeled, steerable, human-propelled machine, commonly called a velocipede, and nicknamed hobby-horse or dandy horse.

This invention had a prodigious effect on transportation and its scale can be sensed by the fact that around 1 billion bicycles were manufactured till the year 2003.

Having centuries of history bicycle went under various modifications, one of which was its electrification. Physically powered drives were replaced by hub motor and rechargeable batteries for power transmission. It was in the late 19th century that the world experienced the first patent of electric bicycle with “6-pole brush-and-commutator direct current (DC) hub motor mounted in the rear wheel.” [2]. The bicycle developed by Ogden Bolton had no gears and the motor had a capacity to withdraw up to 100 amperes(A) from a 10- volt battery.

Further inventions brought “double electric motor” as the source of propulsion. This motor was designed within the hub of the crank set axle.

Later, due to the need of robust and portable transportation source another modification was introduced which was used to reduce the volumetric area acquired by the bicycle when not in use. The folding bicycle became a useful and a smart way to transport basically in metro cities to cover short distances, to be carried easily into the buildings or on the public transport and importantly can be easily stored in boats, cars or planes. Being an eco-friendly means of transportation the bicycle has arose after a great decline due to the introduction of motored vehicles. The side effects of the fuelled vehicles has brought our century to an alarming state, recalling bicycle as the best alternative.

Our attempt was to design, develop and test a hybrid (mechanically and electrically powered) foldable bicycle, with the basic aim to achieve short travels. In metro cities, this effort can help to reduce major pollution level as well as noise level. Daily routine of home to office and office to home can easily be covered. Studies has shown major pollution is caused due to short distance travels in the city, like people use fuelled vehicles even to go to a nearby destination.

Thus our efforts were to make a bicycle helping to reduce pollution, traffic jams and city noise levels and on the other hand to improve human fitness.

II. OBJECTIVES

The designed electric folding bicycle with 750W capacity and top speed of 25Kmph was fabricated under following achieved objectives:-

- A. Introduce a cheap eco-friendly mode of transportation.
- B. To cover short distances from home to office and office to home.
- C. To reduce the use of combustion engines used to cover near areas.
- D. To provide high strength and load bearing capacity.
- E. To reduce the volumetric area so that it can be carried in cockpit in vehicles.
- F. To provide flexibility towards power input i.e. mechanical or electrical thus making it hybrid.
- G. To introduce a noiseless mode of transportation.
- H. A comfortable and easy to handle model with good aesthetics.
- I. Rechargeable batteries so as to meet out frequent travels.

III. SCOPE OF WORK

- A. Selection of the project
- B. Literature study to enhance knowledge about electrical folding bicycle.
- C. Selection of the position and type of joint.
- D. Designing the vehicle and folding joint on modelling software.
- E. Virtual testing on the software using FEA.
- F. Fabrication and testing of vehicle.

IV. DESIGN OVERVIEW

The basic purpose of the design enables us to achieve the comfort level, load distribution, aesthetics, durability, flexibility and visual looks to a product. The electric folding bicycle comprises of an adjustable seat which can be varied according to the desired height of the rider's comfort zone.

The electric folding bicycle constitute of the following specifications: -

- 1) Top speed = 25kmph
- 2) Material used = stainless steel (3CR12)
- 3) Range/Autonomy = 75km to 80km @ 70Kg & 55km to 60km @ 130kg
- 4) Motor = Permanent Magnet BLDC motor
- 5) Wattage = 750W
- 6) Batteries = 12v*4
- 7) Charge time = 6 to 8 hours
- 8) Power/Charge = 2 units
- 9) Dimensions in folding and unfolding

state	Dimensions (cms)		
	length	breadth	height
Unfolded	163	24	42
Folded	104	24	42

- 10) Dimensions of tyres

Tyre	Dimensions (cms)	
	Diameter	Width
Front	43	8
Rear	60	5

- 11) Number of gears = 1
- 12) Volumetric reduction = 42.27%
- 13) Brakes type = Manual
- 14) Angle of climb (inclination) = 20 degrees
- 15) Input type = Hybrid (Mechanical & Electrical)
- 16) Time to reach top speed = 5s
- 17) Pitch of chain = 1.58 cm
- 18) Number of teeth on (larger) front sprocket = 44
- 19) Number of teeth on (smaller) rear sprocket = 18
- 20) Number of chain links = 87
- 21) Sprocket reduction ratio = 0.409
- 22) Length of chain = 1.38

A. Design Calculation

Various parameters have been studied and evaluated for effective and better output of our design .These calculations depicts the aspects achieved and used for its development.

B. Frame design

Various fabricating material were studied so as to meet out our strength, machinability, cost effective goals. The most feasible material was found out to be grade 3CR12 stainless steel. Grade 3CR12 stainless steel is a low-cost grade chromium, containing stainless steel fabricated by modifying the properties of grade 409 steel. It resists mild corrosion and wet abrasion. It was originally developed by Columbus Stainless, which designated the registered trademark “3CR12” [3]. Other designations of this grade include UNS S40977/S41003 and 1.4003.

S. no.	Property	Carbon Steel
1)	Grade	3CR12
2)	Density(kg/m^3)	7740
3)	Elastic modulus (GPa)	200
4)	Mean coeff. of thermal expansion($\mu m/m/^\circ C$)	10.8
		11.3
		12.5
5)	Thermal conductivity (W/m.k) at 100°C At 500°C	30.5
		31.5
6)	Specific heat 0-100°C ($\frac{J}{kg} \cdot k$)	480
7)	Electrical resistivity ($n \cup . m$)	570

C. Braking Analysis

v (initial velocity (top speed))=25Kmph=

6.94m/s

u (final velocity) =

0Kmph = 0m/s

m (total mass) = 100kg

x (distance to stop) = 7m

We know that braking force,

$$f = (v^2 - u^2) \frac{m}{2 \cdot x}$$

By putting the values in above equation,

$$f = 344.02N$$

D. Length of chain

Length of chain is expressed as $L = L_N * P$ L = Length of chain
 P = Pitch of chain = .0158m

L_N = number of links in the
 Number of links in the chain is determined by the

following relationship:

$$L_N = \left(\frac{T_1 + T_2}{2} \right) + \left(\frac{2 * C}{P} \right) + \left(\frac{T_1 - T_2}{2 * \pi} \right)^2 * \left(\frac{P}{C} \right)$$

Where

T_1 = Number of teeth on front sprocket = 44
 sprockets (m) = .44

T_2 = Number of teeth on rear sprocket = 18

C = Distance between

Putting values in above equation

$$L_N = 87.20$$

So, length of the chain is = $87.20 * 0.0158$

$$= 1.38m$$

Total tractive force

Total tractive force is the summation of rolling resistance (RR), gradient

force (GR) and acceleration force (FA).

$$F_t = RR + GR + FA$$

a. Rolling resistance (RR):

$$RR = W * C_{rr}$$

Where,

W = total weight of bicycle and rider = 980N

C_{rr} = Coefficient of rolling resistance between tire and road = 0.017

Therefore,

$$RR = 980 * 0.017 = 16.66N$$

b. Gradient resistance (GR):

$$GR = W * \sin \alpha$$

where,

W = total weight of bicycle and the rider = 980N

Inclination angle $\alpha = 0$

(because of no elevation)

Therefore GR = 0

c. Accelerating resistance (FA):

$$\text{Force applied} = W * (V_{max} / g * t_a)$$

Here,

W = total weight of bicycle and rider = 980N

$V_{max} =$

maximum speed of vehicle = 25Kmph = 6.94m/s

g = acceleration due to gravity = 9.8 m/s²

t_a = desired acceleration time = 5 sec

Therefore putting values we get FA = 138.8 N

So, total tractive force = RR + GR + FA

$$= 16.66 + 0 + 138.8 = 155.46N$$

Motor and battery calculations

We assume 7 seconds for attaining maximum speed of 25Kmph

Mass of vehicle = 100 kg

Acceleration = dv/dt

Where, dv

= 25Kmph = 6.94 m/sec ,

$dt = 7\text{sec}$

Therefore, $a = 6.94/7 = 0.991$

m/sec²

$$\text{Force (F)} = m * a = 100 * 0.991 = 99.1 \text{ N}$$

$$\text{Power required } P = F * v$$

$$P = 99.1 * 6.94 = 687.75 \text{ W}$$

Now considering the air drag force & motor standards available in

market , 750W electric wheel was chosen.

E. Folding system

The electric folding bicycle can easily be folded and unfolded by using its folding mechanism comprising of hinge joint with a T-bolt and nut lock system. Aim of the folding joint was to achieve reduction in 50% volumetric area but its practical fabrication resulted in 42.27% of volume reduction. The joint was fabricated to withstand about 200kg to be able sustain under dynamic load condition. The folding joint has been installed at an angle of 20° so as to minimize the area. The folding system can easily withstand the normal working situations of a normal standard bicycle. The two states of the bicycle i.e. folded and unfolded are depicted in the figure below. The procedure for folding is described as below:-

- 1) Untighten the nut
- 2) Pull the T lever out of the clamp by rotating it anticlockwise.
- 3) Now push the T rod down so to unlock the clamps, as the lever when moved down frees the motion.
- 4) Now rotate the front and rear parts of the bicycle in opposite direction either by keeping one portion stable or rotating both.
- 5) Now put the folding lock lever welded under the bicycle seat into the lock welded under the handle.
- 6) Place the bicycle stand and the bicycle is now folded.

To attain the unfolded state perform the reverse of the procedure described above.



Fig 1:- Unfolded state of the bicycle



Fig 2: - Folded state of bicycle

V. ANALYSIS

Procedure for performing FEM analysis in Ansys 14.0

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

After the analysis cast iron was chose for the fabrication of folding joint and 3CR12 carbon steel frame was used.

VI. FABRICATION

The fabrication process is one of the most important part of the project building. Fabrication deals with bringing the virtual design of the project into the actual real world. Here basically the most important part to be fabricated was the folding joint, as it has to be strong enough to sustain the dynamic loads and flexible enough to get folded easily. The fabrication process was first initiated by cutting two rectangular pieces of the 10mm thick cast iron bar. After that the pieces were cut into the desired shape. In addition to this a common hinge system was to be implemented to both the rectangular metallic pieces., for this we used electric arc welding as this welding method was adequate for the parameters we required by the joint. A 10 mm pitch circular diametrical bolt was inserted into the hinge assembly and was tighten up to some extend from the free end of the bolt with the help of 10 mm nut. Now for the push up lock mechanism an 8 mm T-bolt was used. The limbs of the t bolt other than the threads were inserted into the clamps provided on the rectangular pieces. An 8 mm bolt was used to tighten the lock system when unfolded.

The folding system has been shown below produced using solid works: -

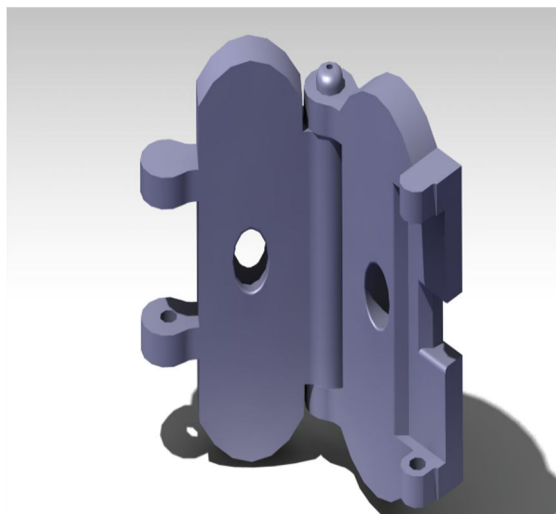


Fig 3:- Folding Joint in software



Fig 4:- Folding Joint in folded state

Now for installing the folding system into the bicycle the front frame was laterally cut at an angle of 20 degrees from the vertical. Two rectangular plates of 5 mm thickness and 20 mm in length were welded on both sections of the frame that was cut. And then the folding system was welded over the plates. The plates were introduced so as to compensate the distance between the two bars of the frame. The plates provides singularity to the frame.



Fig 5:- Folding joint in unfolded state



Fig 6:- Assembling the parts

VII. CONCLUSION

The fabricated project i.e. Hybrid Folding Bicycle undoubtedly provides eco-friendly and potential solution to the ever increasing petrol crisis in India and abroad [4]. This bicycle possess the ability to fight against the challenges of like pollution, combustion of fuels and would also reduce the traffic. The bicycle is powered by the electric source of 48 v battery as well as can work on human power. The bicycle provides the top speed of 25kmph along with 50 km of distance in one full charge, while the batteries take only 2 units to get charges i.e. about 14 rupees per 50 km which is very cheap as compared to the fuel powered vehicles.

VIII. 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:-

- A. No need of electric power supply by adding solar powered drive.
- B. The folding technique can be enhanced to fold in as single fold.
- C. The cost aspects can be taken into consideration and economics of scale may be employed to reduce the unit cost of the bicycle.
- D. The concept can replace the traditional bicycles for passenger transportation.
- E. It can also be modified by giving it a jazzy and lucrative look to make it more eye-catching.
- F. The design's weight can be reduced by using composites.

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