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An Introduction to the Design of Foldable E-Bike for Clean& Safe Travelling in Smart-Cities

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Abstract: *In the concept of smart cities, quickness is something which everyone craves for. People prefer the fastest means while travelling from one place to another. Generally, while maintaining a trade-off between speed, comfort and cost public transit comes out to be the best solution. But since these vehicles have specific routes and stations, people face difficulty in going to the station from source location and then from the other station to destination. Use of fuel powered vehicles is not recommended due to the depletion of fossil fuels, also these vehicles pose a major threat to the safety to the lives of many. Apart from the noise and air pollution, fuel powered vehicles are quite powerful and thus unsafe if don't used with care. A foldable electric bike may be possible solution to these problems. While serving to the needs for ease and speed, it maintains safety. This bike has an upper limit for the power and speed which ensures safety of the rider. This bike can be folded to an extent (25in * 20in * 15in) that it can be stored in a backpack after use. This foldability makes it compatible for use with public transit, user can use it to travel to station and then fold & store it the backpack while travelling from the public vehicle. The weight of the bike is kept such that it may easily be carried on shoulders without the feeling of uneasiness. This bike is ideal to use for short distance (around 12 kilometers) trips. The major target of this foldable electric bike for commercialization are the people who travel by metros and public transport means for their daily routine work. This bike can be sold in cities where people needs a solution to travel shorter distance at low price.*

I. Introduction

The objective of this paper is to demonstrate the design and virtual testingofafoldable electric bike which runs completely on electrical power.This bike can be commercialized and can be sold in cities. There are several people who travel by metro daily. These people can be the target as they need some transport solution for travelling from their home to the source metro station and then from destination metro station to their workplace and can come back. Moreover due to need of quick transportation, teen students these days are switching to conventional motorcycles which is illegal and also hazardous for their life. This problem can be sought out by using our product which can serve as a good trade-off; it would ensure safety while maintaining ease of use.

II. Literature Review

2.1 Recent Developments

A foldable bicycle was patented by Keun. Soo Yun of Seoul in 2011. The objective of this invention is to provide a foldable bicycle in which folding structures are formed in such a way that volume get reduced to high extent. Also, to improve riding comfort through the interaction of weight of human body and weight. Here in this invention, there is one head frame and a lower frame which is in two parts. One end of first lower frame is first formed with head frame at the front end and terminal end with the fastened part. Second lower frame is connected at rear end and other terminal is a fastening part. There is third connecting part which is connecting head frame and the terminal joining both lower frames. With the help of fastening points, bike will get fold in such a way that volume will get remarkably reduced. [1]

In 2016, Ford Global Technologies patented a foldable electrical bike which seems to be a combination of three parts, viz. front wheel assembly, rear wheel assembly and frame. The front wheel gets folded into the frame and the whole frame slips into the rear wheel assembly on folding. In this way, the cycle is compacted. But this mechanism is very precise and needs high level of calibration. [2]

Then in 2017, a company named Beijing Onemile Technology Co. Ltd. patended a foldable bike which worked on very complex mechanism. It also consisted of a separate foldable frame. This cycle is the most recent patent in the field of foldable bikes, though it is not electric. [3]

2.2 COMMERCIAL Febs IN THE MARKET

Though not much popular in India, the foldable bicycles have made their market in the foreign markets. Some of the foldable electric bikes available in the market are shown below. [4]

1. Raleigh Stow E Way

This bike can be folded into 90x50x70cm^3 and can run up to 24 miles in single charge. It uses Li-ion battery and it is hidden inside the frame, thus it is very good looking. It costs around £1350 (approx.. 1 lakh INR)

Figure 1 *Raleigh Stow E Way*

2. Whoosh Gallego

This cycle comprises of a 270 WH Li-ion battery. It takes just 5 seconds to fold up and it can be rolled after folding. Two smaller wheels are attached for this purpose. It is a value bike and costs about half of the previous one. Cost - £669 (about 53000 INR)

Figure 2 *Whoosh Gallego*

3. A2B Kuo

This bike is quite advanced than the previous ones. It consists of an electronic display which shows the level of battery used. The battery is placed inside the seat tube and it takes about 6 hour to charge for 25 miles. It costs £999 (about 80000 INR)

Figure 3 *A2B Kuo*

4. BH Emotion Neo Volt Sport Lite

This bike looks very simple but it has very good power. It ca also be assisted by pedals and it can reach upto 20mph speed. But this model is very costly, around £2199 (around 175000 INR)

Figure 4 *BH Emotion Neo Volt Sport Lite*

5. FreeGo Folding

This model is focused at large distance travel. It consists of a 16Ah battery. Some of the salient features are head lamp and front disc brake. Though, it is very heavy around 22 kg. It costs £1,099 (around 88000 INR)

Figure 5 *FreeGo Folding*

Thus it is observed that Foldable Electric Bikes are quite popular in foreign market but Indian market lacks this product. Considering the affordability by Indian markets, the bike presented in this paper is not hybrid but purely electric.This would save money and reduce the overall price of the bike.

III. The Design

3.1.1 Study of Mechanism – So many mechanisms were studied in the concept phase. Many research papers were read and also mechanisms used by the existing bicycle manufacturers were looked. Then after discussing with Paper mentor, this mechanism was finalized.

3.1.2 General Layout and Joining Methods – The general layout has already been finalized alongside with mechanism. Threaded fasteners will be used for joining the individual components.

3.1.3 Design Individual Components – The individual components were designed in SOLIDWORKS software. The drawings are shown in the next section.

3.1.4 Assembly and Testing – Assembly is done in SOLIDWORKS using assembly module and testing is done using ANSYS. The reports from ANSYS are also shown below.

3.1 MATERIAL SELECTION

Based on studies by several scientists and engineers, a comparison table between all the materials available for 3D printing has been formed [6] [7] [8] [9].

Table 1 *Basic Features of 3D Printing Materials*

Type	Pros	Cons	Cost Per Kg
ABS	Tough;Common; Non-toxic; impact- resistant material	High melting point; Unpleasant fumes	$20 to $50
PLA	Easy to print with; Biodegradable	Prints degrade over time; Rough texture	$20 to $50
PVA	Water soluble; Fairly easy to print; Good for supports	Expensive; Risk of toxic fumes	>$100
Nylon	Tough; Inexpensive	High temperature requirement	$18
HDPE	Easy to dissolve; Lightweight	High temperature requirement	$30
T-Glass/PETT	Food-safe; Glass-like look	Slow to print; Heated printing bed needed	$30
Wood Filament	Attractive wood-like look	Finicky to use; Requires sanding	$60 to $100
Metal Filament	Attractive metal-like finish	Finicky to use; Expensive	$75 to $120
Carbon Fiber Mix	Mimics carbon fiber's lightweight strength	Tough on extruders; Expensive	$50 to $120
Flexible Filament	Produces flexible prints	Requires tinkering with the printer	$50 to $120
Conductive Filament	Conducts electricity; Similar to PLA	Expensive; Still experimental	$70 (for a 100g reel)

The comparison of physical properties is given in the table shown below:

Table 2 *Properties of Various Materials*

Property	ABS	PLA	PETG	Carbon Fiber Filament	ASA	Polycarbonate	Metal Filament
Ultimate Strength (MPa)	40	65	53	45-48	55	72	20 - 30
Young's Modulus (GPa)	2.3	3.5	2.2	150	2.6	2.6	90
Stiffness	5/ 10	7.5/ 10	5/ 10	10/ 10	5/ 10	6/ 10	10/ 10
Durability	8/ 10	4/ 10	8/ 10	3/ 10	10/ 10	10/ 10	4/ 10

Maximum Service Temperature	98°C	52°C	73°C	52°C	95°C	121°C	52°C
Coefficient of Thermal Expansion (µm/m-°c)	90	68	60	57.5	98	69	33.75
Density (g/cm^3)	1.04	1.24	1.23	1.3	1.07	1.2	2 - 4
Price ($ per kg)	10 - 40	10 - 40	20 - 60	30 - 80	38 -40	40 - 75	50 - 120
Printability	8/ 10	9/ 10	9/ 10	8/ 10	7/ 10	6/ 10	7/ 10

Thus, on the basis of above properties rating(out of 10) to these materials has been given according the preference of the design.

Table 3 *Rating of Materials*

	ABS	**PLA**	**PETG**	**Carbon Fiber**	**ASA**	**Polycarbonate**	**Metal Filament**
Ultimate Strength	7	9	8	7	8	2	5
Young's Modulus	6	8	5	10	7	7	9
Stiffness	5	7.5	5	10	5	6	10
Durability	8	4	8	3	10	10	4
Max. Temperature	9	5	6	4	8	10	4
Coefficient of Thermal Expansion	7	8	9	9	5	8	10
Density	10	9	9	9	10	9	7
Price	10	10	8	2	4	3	1
Printability	8	9	9	10	7	6	7
Total (out of 90)	**70**	**69.5**	**67**	**64**	**64**	**61**	**57**

Thus, ABS has been chosen to be the primary material from which the main frame and fork of the bike will be manufactured.

Acrylonitrile butadiene styrene (ABS) is the same plastic used in Legos. It's tough, nontoxic and retains color well. It's also easy to shape, but tough to break, as it melts and becomes pliable at about 220°C [10].

It's also water- and chemical-resistant. ABS does produce a slightly unpleasant smell when heated, and the vapor can contain some nasty chemicals. Because ABS is broken down by UV radiation, it isn't suitable for long-term outdoor use, as it loses its color and becomes brittle [10].Considering all these factors, ABS is the best for the purpose.

Figure 6: *3D Rendered Images of Bicycle (Unfolded on left, Folded on right)*

Electrical Design And Calculations

For the electrical parts like Motor, Battery, Controller etc., wide ranges of variety are available in the market. All the options available were studied and a comparison table was prepared and rated the options from 1 to 4. The option with highest rating was opted at the last.

Table 4 *Ranking for Battery Comparison*

Specifications	Lead Acid	Nickel Cadmium (NiCd)	Lithium Ion (Li-ion)	Nickel Metal Hydride(NiMH)
Cycle Life	1 (200-300)	3 (1000)	4 (1000-2000)	2 (300-500)
Charging Time	1 (8-16h)	3 (1-2h)	3 (1-2h)	2 (2-4h)
Self-Discharge/month	3 (5%)	2 (20%)	4 (<5%)	1 (30%)
Internal Resistance	3 (low)	4 (very low)	2 (moderate)	1 (high)
Power To Weight Ratio	1	3	2	4
Toxicity	1 (high)	2 (moderate)	4 (very low)	3 (low)
Maintenance	1 (high maintenance required)	2 (full discharge after 90 days)	3 (maintenance free)	2 (full discharge after 90 days)
Weight	1	2	4	3
Cell Voltage (nominal)	2 (2 V)	1 (1.2 V)	3 (3.7 V)	1 (1.2 V)
Overcharging Tolerance	1 (high)	2 (moderate)	4 (very low)	3 (low)
Cost	4	3	1	2
Total Ratings	19	27	34	24

Here, Numbers **1, 2, 3** and **4** signifies the ratings for the corresponding battery out of **4** according their functionality.Hence, the highest rating is for Li-ion Battery for use in theFoldable Electric Bike.

A lithium-ion battery or Li-ion battery (abbreviated as LIB) is a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. Lithium-ion batteries are common in home electronics. They are one of the most popular types of rechargeable batteries for portable electronics, with a high energy density, tiny memory effect and low self-discharge. LIBs are also growing in popularity for military, battery electric vehicle and aerospace applications. [11]

Similar process was repeated for the motors,

Table 5 *Ranking for DC Hub Motor Comparison*

Specifications	Permanent Magnet (PMDC)	Brushed (BDC)	Brushless (BLDC)
Starting Torque	1	2	3
Size	1	2	3
Efficiency	3	1	2
Heat Dissipation	2	1	3
Output Power	1	2	3
Maintenance	1	2	3
Noise	1	2	3
Speed Range	1	2	3
Cost	3	2	1
Total Rating	14	16	24

Here, Numbers 1, 2 and 3 signifies the ratings for the corresponding Motor out of 3 according their functionality. Hence, the highest rating is for Brushless (BLDC) Motor for use inFoldable Electric Bike.

The biggest advantage of BLDC motor is efficiency, even small BLDC motors can deliver considerable power.The second big advantageis controllability. BLDC motors can be controlled, using feedback mechanisms, to delivery precisely the desired torque and rotation speed. BLDC motors also offer high durability and low electric noise generation. [12]

The calculation for the parameters of Battery and Motor are done now –

1). For Motor

Total Forces or Loads on the Bike:-

The Calculations are done by taking 100 kg mass (m) including both bike and rider.

Acceleration forces on the bike (AF) = m*a

Where, m = Mass of Rider and bike = 100 kg

a = acceleration = dV/dT

V (initial) = 0 m/s

V (Final) = 20 m/s

T = Accelerating time or time to attain maximum speed = 45 s

a = dV/dT = (20-0)/ (45-0) = 0.1234 m/s2

AF = m*a = 100*0.1234 = 12.345 N

Radius of the tyre (R) = 6 inches = 6*0.0254 = 0.1524 m

Torque required to move wheel (T) = AF*Radius of the tyre

= 12.345* 0.1524 = 1.88 N-m

w = angular velocity of tyres = V/R

Power Required (P) = T*w = 1.88*(20/0.1524) = 246.72 W

Hence, due to availability of BLDC hub motors in market, 250 W power output motor is being used.

2). For Batteries

From the internet search and study, it was established that for every 20 Watt-hours (Wh) of battery power the electric bike runs upto 1.6 kms or 1 mile.

Standard Minimum voltage required for batteries for an electric bike = 24 V

And the range of the bike per charge = 12-15 kms

Ampere Hours = 10 Ah (can vary from 8 Ah to 20 Ah but we are using optimum capacity battery for bike)

Watt-hours = Voltage*Ampere hour = 24*10 = 240 Wh

Hence, a battery pack of 24 V and 10 Ah capacity is being used.

3.2 SIMULATION

The assembled frame and front fork designed in SOLIDWORKS was imported in ANSYS for analysis.

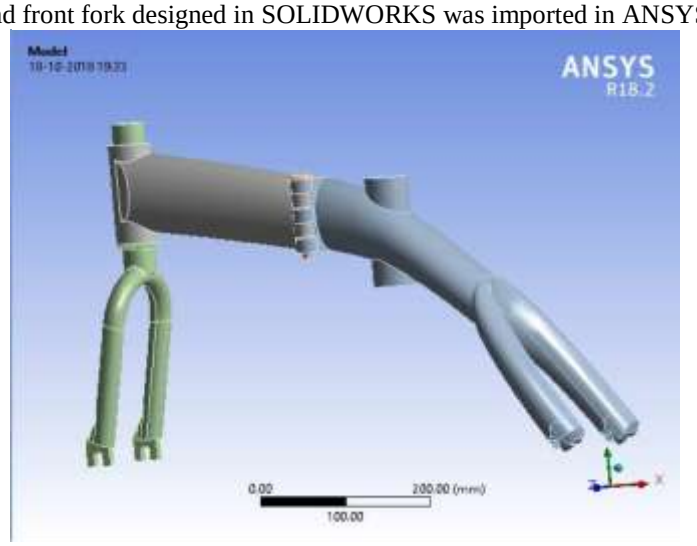

Figure 7 *ANSYS Model*

The steps followed for FEA of the frame are -

1. Importing the bicycle model from desired SOLIDWORKS file into ANSYS.
2. Selecting appropriate material and defining material properties regarding each part of the bicycle and assigning material to the parts respectively.
3. Discretization of bicycle model using various methods of meshing and selecting optimal method to achieve fine results of meshing.
4. Applying loads and constraints at seat tube of bicycle and wheel axles respectively.
5. We have determined total deformation and factor of safety of the bicycle.

It was seen that the equivalent elastic strain is very minimal (about 0.53%), so the design is safe in this aspect. For maximum principal stress, the Factor of safety comes out to be more than 10, thus the design is safe in this aspect also. Finally, assuming the ultimate shear stress to be almost half of the ultimate tensile stress, the factor of safety in shear comes out to be 7.5, thus the design is safe in shear also.
Thus, the design is safe in all aspects according the FEA reports.

IV. Conclusion

This paper has discussed all the aspects of the Foldable Electric Bike in details. It can be concluded that the design of the bicycle as per the initial specifications is successfully carried out.

While enhancing the proficiency of team members in technical aspects, this project provided a lot of learning beyond technical skills. It taught to be concentrated towards a goal and to complete it in the given frame of time with the available resources. The team had to deal with a wide variety of people. A major learning is to have a never give up attitude which helped in bringing this project to the end.

Any project is a long run team activity which requires a healthy coordination among the team members. A lot of research has been done by the team members in the process, starting from the brainstorming sessions with the faculty to decide the idea of the project, followed by the literature review of various design reports and research papers of different electrical folding bicycles. These documents helped in deciding the parameters of the bicycle with their pros and cons. Also, the market analysis was done with full dedication and research work to check the availability of various parts. Apart from this, the design and fabrication processes helped in brushing the technical knowledge and to obtain a practical application of this knowledge.

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