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Formulating a Foldable Electric Bicycle

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Abstract - *The objective of this endeavour is to develop and build a folding electric bicycle for modern commuters that is lightweight, inexpensive, and convenient to use. The bicycle incorporates an Electric Hub motor into its transmission system, enhancing its functionality and efficiency. The vehicle is designed to accommodate only one rider at a time and utilises a regular chain drive system that is manually operated by the rider. The main structural component of the bicycle is a single rigid square pipe, upon which various kinematic linkages are made. It features two kinematic systems, one at the front supporting the front wheel and the other at the rear, supporting the saddle. The primary material used for construction is aluminium alloy (6061), ensuring the stability and durability. In addition to the Electric Hub motor, the main components of the bicycle include cylindrical tubes, a pair of wheels, a power transmission chain, a freewheel, and a regular rim-type braking system. The foldable design of the bicycle is optimised for portability and ease of storage, making it convenient for commuters.*

Key Words: Bicycle, Kinematic structure, Hub motor, Chain drive, Folding Mechanism.

1. Introduction

1.1 Background of Bicycle

The bicycle, a two-wheeled human-powered vehicle, has a rich and diverse background rooted in the quest for transportation efficiency and personal mobility. Its origins can be traced back to the early 19th century, when inventors and innovators sought to create a mode of transportation that was faster and less strenuous than walking. Over time, various designs and iterations emerged, each building upon the previous to improve performance and comfort. The introduction of chain drive systems in the late 19th century revolutionised the bicycle industry, enabling riders to efficiently transfer their energy to the wheels. As technological advancements continued, bicycles became more accessible, affordable, and widespread, becoming a popular means of transportation and a symbol of freedom and independence. Today, bicycles have evolved to cater to different needs, with specialised designs for commuting, racing, mountain biking, and more. They continue to play a vital role in modern society, offering environmentally friendly transportation options, promoting physical fitness, and serving as a versatile and practical means of getting around.

1.2 Background of Foldable Electric Bicycle

In recent years, there has been a growing demand for innovative and versatile transportation options that cater to the needs of modern commuters. One such solution that has gained significant attention is the foldable bicycle. The concept of foldable bicycles originated from the need for a compact, portable, and convenient mode of transportation that could easily be stored and carried when not in use. These bicycles have quickly become popular among urban dwellers, commuters, and individuals seeking an eco-friendly and cost-effective means of travel. The development of foldable bicycles has been driven by advancements in materials, engineering, and design, aiming to strike the perfect balance between functionality, durability, and compactness. With their lightweight construction, foldable bicycles offer a practical solution for users who face challenges with limited storage space or the need for multi-modal transportation. Additionally, technological advancements such as the incorporation of electric hub motors have further enhanced the efficiency and usability of foldable bicycles, making them an attractive option for those seeking an effortless and eco-conscious commuting experience.

2. Problem Identification

The increasing demand for sustainable and efficient modes of transportation in urban areas has led to a surge in interest in foldable electric bicycles. However, there are several challenges that need to be addressed in the design and implementation of these bicycles. The problem lies in the lack of optimized and affordable solutions that strike the right balance between portability, durability, and performance. Current foldable electric bicycles on the market often face limitations in terms of weight, cost, range, and overall design, hindering their widespread adoption and practicality for modern commuters. Therefore, there is a pressing need to conduct research and develop innovative approaches to overcome these challenges, focusing on the design, construction, and optimization of foldable electric bicycles that offer enhanced portability, extended range, improved affordability, and a seamless integration of electric propulsion systems. By addressing these issues, we can unlock the full potential of foldable electric bicycles as a sustainable and convenient solution for urban transportation.

3. Proposed solution

To address the challenges hindering the practicality and adoption of foldable electric bicycles, this research paper proposes a comprehensive solution. The solution involves a multidisciplinary approach, integrating expertise from materials science, mechanical engineering, electric propulsion systems, and human factors design. It aims to explore advanced materials and structural designs for the bicycle's frame, maximizing the strength-to-weight ratio for durability and portability. Integration of efficient Electric Hub motors within the transmission system will be investigated to ensure seamless power delivery and enhanced efficiency. Battery technologies and management systems will be explored to extend range and improve performance. Human factors and ergonomic considerations will inform the design process, resulting in a comfortable and user-friendly foldable electric bicycle. Prototyping and testing, along with user feedback, will validate the solution, leading to highly functional and affordable bicycles. The research will contribute to sustainable and convenient urban transportation, addressing challenges of congestion and pollution while providing individuals with an eco-friendly mode of travel.

4. Methodology

A thorough and iterative design technique was used to create the folding electric bicycle. It begins with extensive research and data collection, including a literature review and data on user preferences and market trends. Based on this research, the conceptual design and ideation phases take place, generating innovative ideas for the bicycle's design. Solidworks CAD software is then used to develop detailed digital models, which are analyzed through structural analysis and simulations to ensure the bicycle's integrity and safety. Physical prototypes are built and undergo rigorous testing to evaluate performance and the user experience. Feedback from testing informs iterative refinement and optimization of the design. Cost analysis and manufacturing considerations are taken into account to ensure affordability and feasibility. By following this methodology, the aim is to create a well-designed, efficient, and user-friendly foldable electric bicycle that meets the needs of modern commuters.

5. Selection of Materials and Hardware

By identifying lightweight yet durable materials such as carbon fiber composites and high-strength alloys, along with evaluating hardware components like drivetrains, braking systems, folding mechanisms, and electrical components, the goal is to develop foldable electric bicycles that are lightweight, robust, cost-effective, and user-friendly. Performance and compatibility analysis will be conducted to assess factors such as strength, stiffness, fatigue resistance, and overall mechanical behavior. The research outcomes will contribute to the development of foldable electric bicycles that offer an efficient, convenient, and eco-friendly mode of transportation for modern commuters. Further due to lower cost, lower weight and higher strength we choose Aluminium alloy (6061) as our material as shown in Table 1.

Table -1: Material Selection

Material	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Fatigue Limit (MPa)
Steel	700-1200	300-700	10-20	150-200
Aluminum Alloy (6061)	600-700	200-300	15-20	100-150
Titanium	900-1100	400-600	10-15	200-250
Carbon Fiber	2500-3500	1000-1500	1-3	100-150

Electric hub motor provide seamless and efficient propulsion for foldable electric bicycles, enhancing their performance and ease of use by integrating the motor directly into the wheel hub and their specification is in Table 2.

Table -2: Motor Specification

Specification	Value
Motor Type	Brushless DC Hub Motor
Motor Power	250W
Motor Voltage	36V
Motor Speed	Up to 32 km/h
Motor Weight	2.5 kg
Motor Efficiency	Up to 80%
Motor Noise Level	50 dB
Motor Lifespan	Up to 10,000 km

In addition to the structural analysis and design considerations, the choice of battery technology is a critical aspect of a foldable electric bicycle. Incorporating a Lithium-Ion battery provides numerous advantages, such as improved energy storage capacity and minimal power losses. The properties of the battery pack, as outlined in Table 3, play a vital role in determining the overall performance and range of the electric bicycle. Table 3 presents key specifications including voltage, capacity, weight, and charging time, which are essential for assessing the battery's suitability for the foldable electric bicycle design. By utilizing a Lithium-Ion battery with the specified properties, the foldable electric bicycle can achieve enhanced energy storage capabilities, efficient power utilization, and extended riding range, ensuring a reliable and practical mode of transportation for modern commuters.

Table -3: Battery Specification

Specification	Value
Battery Type	Lithium Ion
Battery Voltage	36V
Battery Capacity	13 Ah
Battery Range	Up to 30 km
Battery Charging Time	4-6 hours
Battery Weight	2.5 kg
Battery Lifespan	Up to 1,000 cycles

6. Design and Modeling of Foldable Electric Bicycle

The design of a foldable electric bicycle encompasses various aspects that are crucial for its functionality, practicality, and aesthetics. Starting with frame geometry, careful consideration is given to shape, angles, and dimensions to ensure optimal weight distribution, riding posture, and handling characteristics. Fig 1 gives the skeletal sketch of our design. The folding mechanisms play a pivotal role, allowing for easy and secure folding and unfolding, striking a balance between compactness and stability. Efficient integration of components such as the Electric Hub motor, battery system, drivetrain, brakes, and controls is essential, considering space optimization and structural integrity.

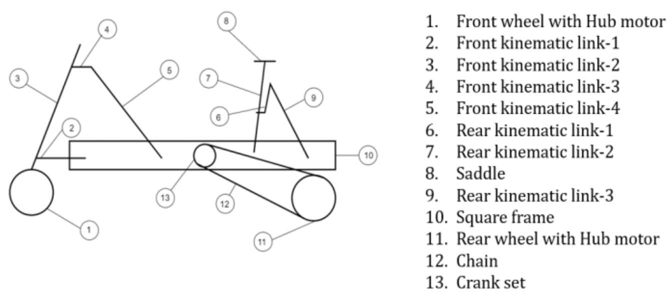


Fig -1: Line diagram

Ergonomics are carefully addressed to provide rider comfort and usability, incorporating adjustable handlebars, saddle position, and ergonomic placement of controls and display panels. Aesthetics are also considered to create a visually appealing design that attracts users. Safety, durability, and manufacturability are integrated throughout the design process, with prototyping, testing, and user feedback contributing to continuous refinement. By considering these design principles, a well-engineered and user-friendly foldable electric bicycle can be achieved as shown in Fig 2-5.

Fig -2: Side View when Unfolded

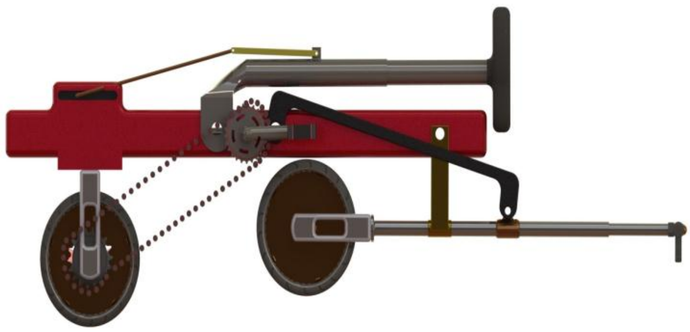


Fig -3: Side View when Folded

Fig -4: Isometric View when Unfolded

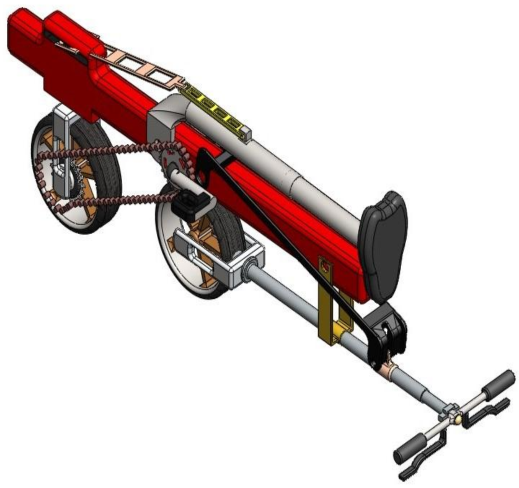


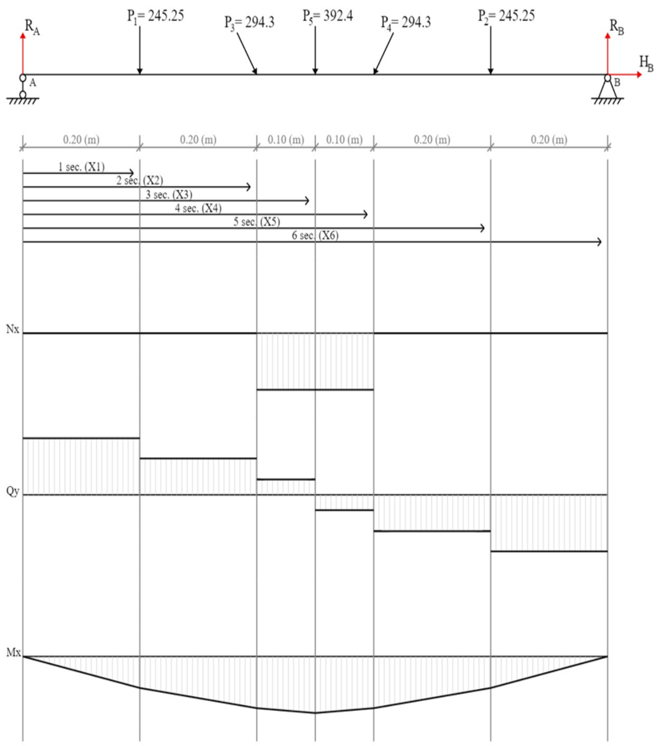
Fig -5: Isometric View when Folded

7. Calculations

7.1 Bending moment and Shear force calculation

The Bending moment and Shear force diagrams play crucial roles in the design and analysis of foldable electric bicycles. These diagrams provide valuable insights into the structural behavior of the bicycle, aiding in its optimization and ensuring its safety and performance. The Bending moment diagram helps engineers understand the distribution of bending stresses along the frame and components, identifying critical points that require reinforcement. This makes the Design engineer to get idea on making the desired changes by interpreting the diagram.

In the analysis of the foldable electric bicycle, real forces of 245.25 N, 294.3 N, 392.4 N, and 245.25 N are applied at specific distances from the front wheel. These forces are distributed at distances of 0.2m, 0.4m, 0.5m, 0.6m, and 0.8m, respectively, based on the 1m wheelbase length of the bicycle. Fig. 6 provides a diagram illustrating the appropriate Bending moment and Shear force distribution. This diagram helps analyse the structural behaviour of the bicycle by considering the bending moment, which indicates the tendency to bend, and the shear force, which represents the internal resistance to shearing forces. Analysing the bending moment and shear force is crucial for ensuring the foldable electric bicycle's structural integrity, as it guides material selection and design modifications to ensure optimal strength, rigidity, and overall performance of the bicycle under the applied forces.



7.2 Chain calculation

Input data

N1 = 100 rpm Z1= 48 teeth Z2= 18 teeth N2=?
Weight of rider= 75kg
Weight of bicycle= 15kg
Radius of wheel= 0.5588m
Torque (T) = (Weight of the rider + Weight of bicycle) × 9.81 × Radius of the wheel
⇒T = (75+15) × 9.81 × 0.5588 =493.36Nm
Torque = 493.36Nm
Power= (2πNT)/60
⇒Power=5.166 KW
Centre Distance (a) = 550 mm Gear ratio= $(N_1/N_2) = (Z_2/Z_1)$
⇒N_2=37.5 RPM

STEP 1: Determination of pitch:

Optimum Centre Distance (a) = (30 to 50) P_a = 550 mm
P_{min} =18.33 mm P_{max} = 131mm
Standard Pitch = 12.7 mm

STEP 2: Determination of length of chain:

Length = l_p * p
Approximate center distance, $a_p = a_0/p$ = 43.3mm
Length of continuous chain:
$L_p = 2*a_p+((Z_1+Z_2)/2)+((Z_2-Z_1)/(2\pi a_p))^2$
Length=1770mm

STEP 3: Determination of Sprocket Diameter:

Tip diameter d_{a1} = ((P)/ (180/Z_1))+ (0.6 * P) = 201.38 mm
Tip diameter d_{a2} = ((P)/ (180/$Z2$))+ (0.6 * P) = 76.65 mm
Input Sprocket diameter d_{a1} = ((P)/ (180/Z_1)) = 194.18 mm
Output Sprocket diameter d_{a1} = ((P)/ (180/$Z2$)) = 73.14 mm

STEP 4: Verification of centre distance:

$a' = (da_1+da_2)/2 = 140$ mm
$a_{max1} = 1.2*a' = 168$ mm
$a_{max2} = 80*p = 1016$ mm
$a_{max1} < a_{max2}$
Design is safe
Final center distance corrected to number of pitches, a=344.69 mm

STEP 5: Determination of breaking load:

Q= ((p .102.n.ks)/v)
For pitch = 12.7
N=7
$K_s = K_1.K_2.K_3.K_4.K_5.K_6$
Values suitably assumed K_s= 2.34
Q=26523 Kgf

Summary:

ISO 20 B-3/ Rolan TR 3119 Pitch, P = 31.75mm
Roller Diameter D_r=19.05mm Width between inner Plates min = 19.360 mm Pin body diameter Max D_p = 25.60mm Bearing Area = 7.74 cm2
Weight per Meter = 11.9 kgf Overall joint max A1, A2, A3 = 121.4 mm

7.1 Wheel Design calculation

Designing a wheel for a bicycle requires several factors to be taken into consideration such as the load acting on it, the diameter of the wheel, the material of the wheel, the number of wheels, and the speed of the bicycle.

Step 1: Calculate the load per wheel:

Since the bicycle is driven by 2 wheels, we need to calculate the load acting on each wheel. Therefore, the load per wheel is:
Load per wheel = Total load / Number of wheels
Load per wheel = 110 kg / 2 = 55 kg

Step 2: Calculate the required load-bearing capacity of the wheel:

The load-bearing capacity of the wheel is the maximum weight that the wheel can support without getting damaged. To calculate the load-bearing capacity of the wheel, we can use the following formula:
Load-bearing capacity = Load per wheel / Safety factor
Here, we assume a safety factor of 1.5, which is the industry standard.
Load-bearing capacity = 55 kg / 1.5 = 36.67 kg

Step 3: Determine the material of the wheel:

Given that the material of the wheel is steel, we need to choose a suitable steel grade that can withstand the load-bearing capacity calculated in Step 2.

Step 4: Calculate the wheel dimensions:

The diameter of the wheel is given as 0.1524 meters. To calculate the width of the wheel, we need to use the following formula:
Load-bearing capacity = Wheel width x (0.5 x Wheel diameter) x Material strength
Here, Material strength is the maximum stress that the material can withstand without getting deformed or damaged. Assuming a material strength of 600 MPa, we can calculate the wheel width as follows:
Wheel width = Load-bearing capacity / (0.5 x Wheel diameter x Material strength)
Wheel width = 36.67 kg / (0.5 x 0.1524 m x 600 MPa)
Wheel width = 0.015 meters or 15 mm

8. Cost Estimation

In order to produce a folding electric bicycle that achieves both cost-effectiveness and high-quality standards, the cost estimation process encompasses several technical considerations. This includes evaluating the cost of materials such as the frame, wheels, drivetrain components, and battery system.. After careful analysis, the estimated cost for the folding electric bicycle is ₹ 16,400.00, as depicted in Table 4. This cost estimation allows for a balance between affordability and delivering a product of excellent quality, ensuring that the folding electric bicycle remains accessible to a wide range of users.

Table -4: Cost Estimation

Sno:	Parts	Number of components	Cost
1	Cylinder tubes	4	₹ 300.00
2	Square channel	1	₹ 600.00
3	Flat plates	2	₹ 100.00
4	Crank	1	₹ 250.00
5	Chain	1	₹ 100.00
6	Pedal	2	₹ 100.00
7	Free Wheel	1	₹ 150.00
8	Wheel	2	₹ 2,300.00
9	Bolts and Nuts	10	₹ 100.00
10	Clamps	2	₹ 50.00
11	Electric Hub Motor	2	₹ 7,550.00

12	Battery module	1	⍰ 4,800.00
	Total	29	⍰ 16,400.00

9. Future work

The folding electric bicycle will require more development and invention in a number of areas. To improve energy storage, range, and charge times, battery technology developments are included in this. Further reducing weight and increasing portability can be accomplished by investigating lightweight materials such as sophisticated alloys and carbon fibre composites. The functionality and user experience may be improved by integrating smart features and connection possibilities. Continuous advancements in folding technology may result in more streamlined and user-friendly designs. Sustainability concerns, improvements to user-centric design based on feedback, and advancements in electric propulsion systems are also crucial. By pursuing these options, the foldable electric bicycle might develop into a more effective, convenient, and environmentally friendly means of transportation, satisfying the demands of contemporary commuters and encouraging greener urban mobility.

10. Conclusion

In conclusion, our discussion on the foldable electric bicycle highlights its significance as a modern and practical mode of transportation for commuters. The design of a foldable electric bicycle involves considerations such as frame geometry, folding mechanisms, component integration, ergonomics, and aesthetics, all aimed at achieving a balance between functionality, portability, and user satisfaction. Additionally, the analysis of bending moment and shear force diagrams contributes to ensuring the structural integrity and safety of the bicycle. The application of an Electric Hub motor enhances its performance and efficiency, while the use of a Lithium-Ion battery provides better energy storage with minimal losses. Cost estimation factors into materials, components, manufacturing methods, and assembly, enabling the production of an affordable yet high-quality product. The foldable electric bicycle offers a sustainable, convenient, and eco-friendly solution for urban commuters, addressing challenges related to congestion, pollution, and limited storage space. With further research and development, the foldable electric bicycle has the potential to revolutionise urban transportation and provide an efficient and enjoyable commuting experience for individuals worldwide.

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