Design of Ordinary Electric Vehicle Movers

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Abstract

To address the growing challenges of disorderly electric bicycle (e-bike) parking and the operational inefficiency caused by electronic rear-wheel locks on shared models, this paper proposes the design of a specialized e-bike mover. Based on an analysis of technical parameters from four typical e-bike models, a worm gear transmission mechanism was selected for its superior self-locking properties and its ability to adjust for various tire diameters. The device was modeled and assembled using SolidWorks, and its structural integrity was validated through static finite element analysis (FEA). The FEA results demonstrate that the maximum von Mises stresses of the transmission shaft (268 MPa) and the main web plate (9.57 MPa) are significantly below their respective yield strengths, with negligible static displacement. These findings confirm that the proposed design possesses sufficient strength and stiffness for reliable operational use. This practical e-bike mover effectively enhances relocation efficiency, reduces urban management costs, and supports the sustainable development of organized urban environments.

Keywords

E-bike Mover; Worm Gear Mechanism; Self-locking; SolidWorks; Finite Element Analysis.

1. Introduction

In recent years, with the continuous enhancement of environmental awareness and the tightening of government restrictions on automobiles, electric bikes (e-bikes) have gradually become the mainstream choice for short-distance transportation in modern cities. According to statistics from the EV Tank (Yiwei) Economic Research Institute, by the end of 2018, the number of e-bikes in China reached 290 million, and this Figureure was projected to exceed 350 million by 2023 [1]. Simultaneously, the shared e-bike industry has emerged. The "Low-carbon Travel for a Better Life — Social Value Report of Shared E-bikes," released in June 2021, pointed out that as of May 2021, nearly 8 million shared e-bikes were operating in over a thousand towns and cities nationwide, with the total number expected to surpass 10 million by the end of 2021 [2]. While the popularity of e-bikes has brought significant convenience to commuters, the uncivilized behavior of some individuals—specifically the haphazard parking of vehicles along roadsides—has severely disrupted daily life. According to data from the Fire and Rescue Department of the Ministry of Emergency Management, as of July 2021, there were 6,462 reported fire accidents involving electric bicycles nationwide [3]. Recently, an e-bike user parked their vehicle on a pile of fireworks during the Lunar New Year, which inadvertently triggered an explosion. Although the resulting fire caused no casualties, the noise of the explosion disturbed nearby residents and pedestrians. This incident, caused by improper use and disorderly parking, serves as a stark reminder to follow traffic rules and parking regulations to avoid safety accidents and public security issues. Furthermore, it is imperative for the government and relevant departments to strengthen the management and supervision of e-bike parking to ensure the safety and tidiness of urban public spaces[4].

However, since the majority of illegally parked e-bikes are shared models with rear wheels secured by electronic locks, maintenance staff can only move them by dragging the front wheels.

This method is time-consuming, labor-intensive, and highly inefficient, posing a significant cost burden on urban management. Consequently, there is an urgent need to design an e-bike mover to facilitate faster and more convenient relocation. A practical e-bike mover will help address the issue of disorderly parking, enhance urban civility, improve travel convenience for citizens, and promote sustainable urban development. To this end, this paper researches a design scheme for an e-bike mover specifically intended to solve problems such as parking inconvenience and non-standardized placement in daily urban environments.

2. Design Preparation for the E-bike Mover

2.1. Data Collection and Organization

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph) [5]. All manuscripts must be in English, also the table and Figureure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use. Tire-related data were obtained through measurements and statistical analysis of four typical types of electric bicycles. The organized data are shown in Table 1:

Table 1. Electric Bicycle Related Parameters

Model	Tire Diameter (mm)	Tire Width (mm)	Overall Length (mm)	Overall Weight (kg)
Large	432	76	2100	80
Medium	371	76	1800	68
Small	330	76	1500	50
Shared	330	76	1400	55

Based on Table 1, the following can be observed:

(1) Among the four types of electric bicycles, the tire width and vehicle length are basically consistent, measuring 76 mm and ranging between 1400–2100 mm, respectively.

(2) The large electric bicycle features the largest tire diameter among the four models, at 432 mm.

(3) The shared e-bike is the lightest of the four, with a total mass of only 55 kg, while the large e-bike is the heaviest, weighing up to 79 kg.

(4) The vehicle length of the medium e-bike sits at the median position among all models; furthermore, its other indicators are relatively average.

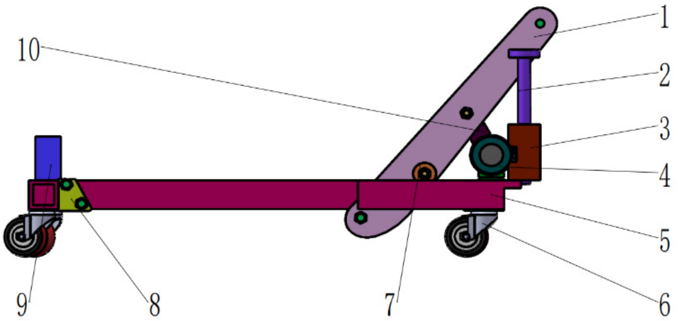
(5) The small e-bike is 300 mm longer than the shared e-bike but is heavier, weighing approximately 6 kg more than the shared model.

2.2. Selection of Tire Clamping Methods

The advantage of this method is the ability to rely on external force to drive the linkage, allowing it to rapidly reach the dead point position for quick tire clamping and self-locking. However, the disadvantage is the instability of the linkage's dead-point self-locking. It is highly susceptible to vibrations, which can cause the mechanism to deviate from the dead point. Once the self-locking effect vanishes, the tire can no longer be held securely. Furthermore, this mechanism cannot be adapted to tires of different diameters, presenting significant limitations that make it unsuitable for moving electric bicycles.

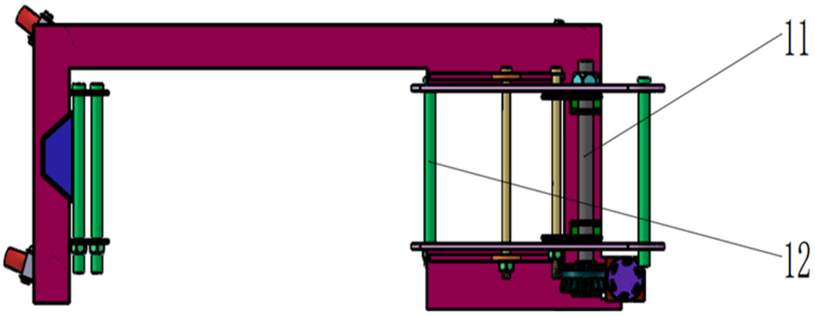
Self-locking can be achieved when the lead angle of the worm is smaller than the friction angle of the worm gear contact. The worm gear transmission pair possesses an irreversible characteristic: motion can only be transmitted from the worm to the worm gear, preventing reverse rotation. Consequently, this transmission pair is widely utilized in actuators and positioning mechanisms. By leveraging its reverse self-locking property, interference from the load side to the power input end can be effectively prevented [6]

By utilizing the universal casters at the base, the e-bike mover is positioned beneath the tire. The worm is then manually rotated, which drives the worm gear. The rotation of the worm gear's transmission shaft subsequently moves the support plate. Pushed by the support plate and guided by the support wheels, the main web plate (large web) executes a simultaneous forward and upward motion. This works in coordination with the front baffle to lift the tire. Due to the inherent self-locking property of the worm gear mechanism, the tire is firmly clamped in place. This allows the electric bicycle to be moved effortlessly using the mover's bottom universal casters. The overall structure of the e-bike mover is illustrated in Figurers 1 and 2.



1-Main Web Plate, 2-Worm, 3-Worm Gear Positioning Base, 4-Worm Gear, 5-Base, 6-Universal Caster, 7-Chassis, 8-Driven Clamping Plate, 9-Baffle, 10-Intermediate Plate.

Figure 1. Overall Assembly View



11, 12-Transmission Shafts

Figure 2. Overall Assembly View

3. Finite Element Analysis of Major Components of the Mover

3.1. Transmission Shaft

The transmission shaft is a critical structure connecting the worm gear. It utilizes a key and keyway for connection, transferring power to the main web plate. This allows the support wheels to move and lift the transmission shaft to clamp the tire, making it an essential axial component of the e-bike mover. The left end of the shaft features a 28mm diameter shoulder for axial positioning of the worm gear, while the right end is threaded to facilitate fixation to the main web plate using a nut. The shaft is constructed from 40Cr steel. Its 3D model is shown in Figure. 3.

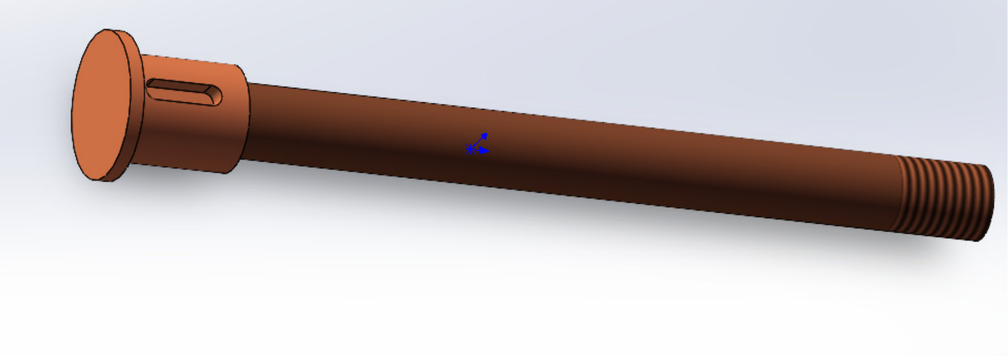


Figure 3. 3D Model of the Transmission Shaft

3.2. Main Web Plate

The main web plate serves to support the lifted tire. It contains 7.25mm diameter holes to support and fix the transmission shaft, and 10mm diameter holes to support the axle of the support wheels. With a thickness of 5mm, the plate provides sufficient strength to bear the weight of the electric bicycle. The finalized model of the main web plate is shown in Figure. 4.

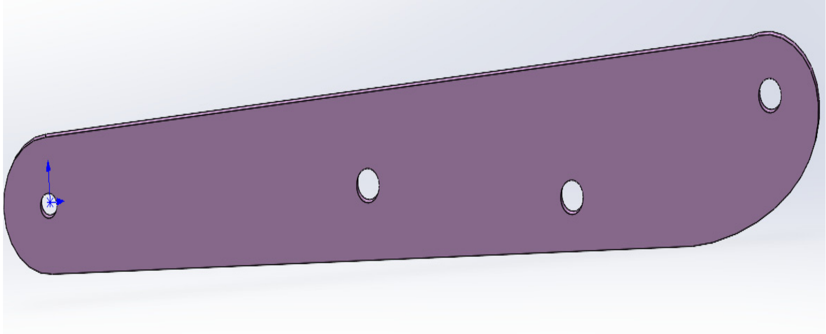


Figure 4. 3D Model of the Main Web Plate

3.3. Finite Element Analysis of the Transmission Shaft

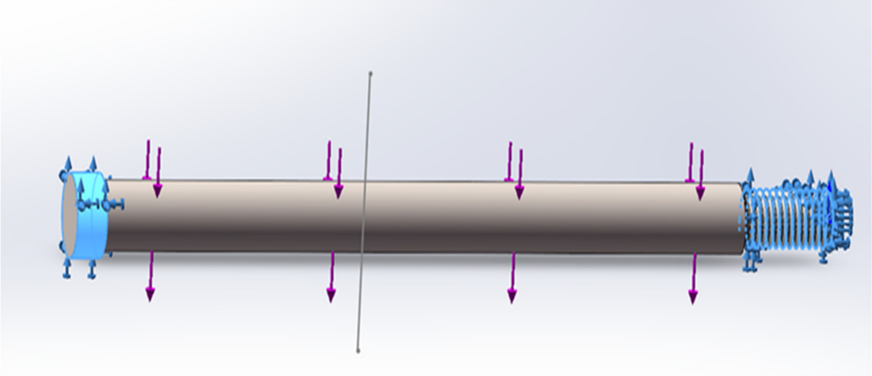


Figure 5. Fixed Fixture Diagram

In finite element analysis, fixed constraints refer to the process of restricting specific nodes or boundaries to fixed positions during structural simulation. This limits movement in certain directions to simulate the actual connection or boundary conditions between the loaded structure and its supports. By applying fixed constraints, boundary conditions are defined to prevent displacement or rotation, ensuring the accuracy of the analytical results. Since this shaft is mounted between the main web plates on both sides, both ends are fixed as shown in Figure. 5.

External loads were applied to the transmission shaft. The pressure exerted by the tire onto the shaft is treated as a uniformly distributed load. Given a total force $F_{total} = 400\mathrm{N}$, the force per shaft is $F = 0.5F_{total} = 200\mathrm{N}$. Therefore, an external load of 200N was applied as shown in Figure. 6.

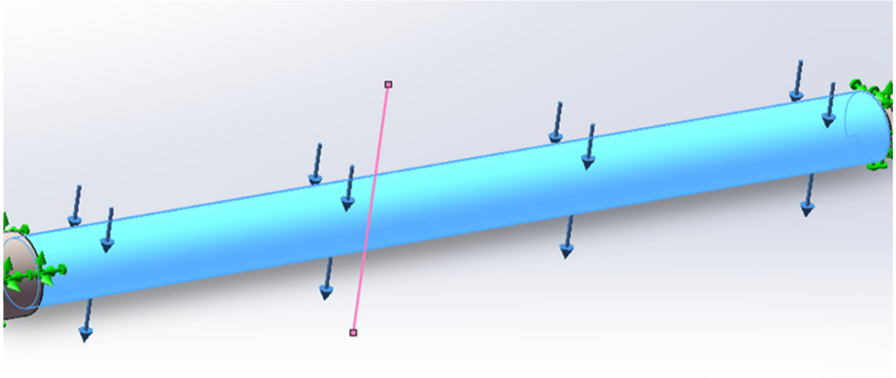


Figure 6. Load Application Diagram

During the analysis, the shaft was discretized into a finite element model through meshing. The mesh was partitioned according to the actual geometry and loading conditions, ensuring that the shape and size of each element adapted to the requirements of stress and deformation to improve calculation accuracy. Finer mesh elements were used in regions of deformation or stress concentration to guarantee model precision before solving.

The stress plot illustrates the distribution of internal intensity and the loading state of the component. By analyzing the von Mises stress plot (Figure. 7), the stress levels at different locations of the transmission shaft can be identified to evaluate structural strength and stability. As shown in Figure. 7, the yield strength of the material is 620 MPa, while the maximum stress on the shaft is 268 MPa. Since the maximum stress is below the yield strength, the shaft's strength is sufficient.

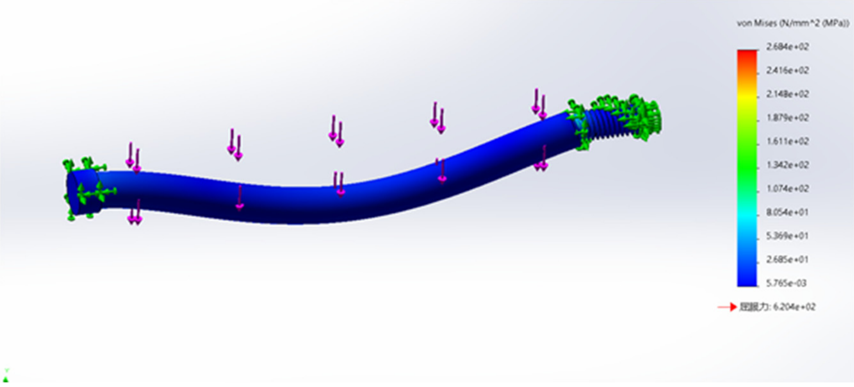


Figure 7. von Mises Stress Plot of the Shaft

The static displacement plot (Figure. 8) displays the deformation of the shaft under load, serving as a basis for checking strength and stiffness to ensure safety. The analysis shows a maximum displacement of only 0.0016 mm, indicating sufficient stiffness. Furthermore, the static strain plot (Figure. 9) allows for the observation of local strain distribution and potential concentration areas. The results show a maximum strain of 0.000508, further confirming that the shaft's stiffness meets the operational requirements. In summary, both the strength and stiffness of the transmission shaft are satisfactory.

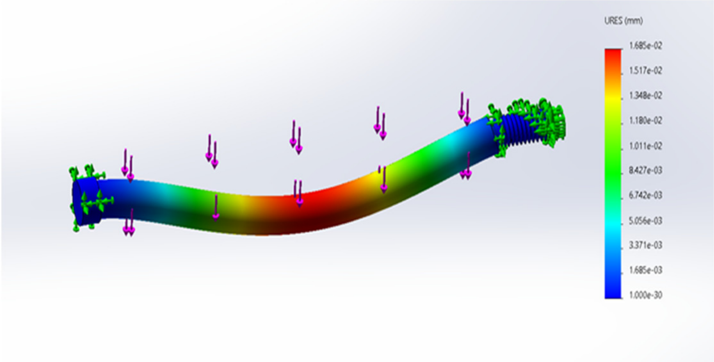


Figure 8. Static Displacement Plot of the Shaft

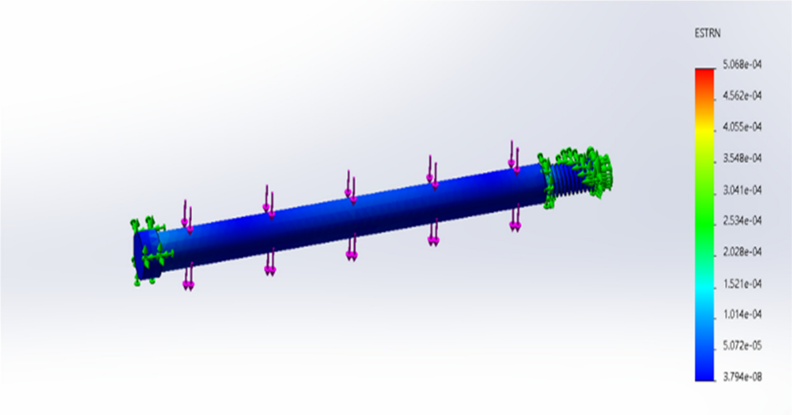


Figure 9. Static Strain Plot of the Shaft

3.4. Finite Element Analysis of the Main Web Plate

The main web plate supports and lifts the tire within the mover assembly. To ensure it can safely support the load, a static finite element analysis was performed using SolidWorks Simulation to determine if the maximum stress exceeds the allowable limit.The material selected for the main web plate is 40Cr alloy steel, with a yield limit of 624 MPa defined in the material library. For the boundary conditions, the two middle shaft holes were set as hinge constants. A vertical downward pressure of 225N was applied to the surface of the first shaft hole. Meshing was performed using an intermediate density setting to balance calculation efficiency and accuracy, as the plate structure is relatively simple.Based on the von Mises stress results (Figure. 10), the maximum stress under pressure is 9.57 MPa, which is far below the yield stress. This confirms that the strength of the main web plate is qualified for safe use during the moving process of large e-bikes.

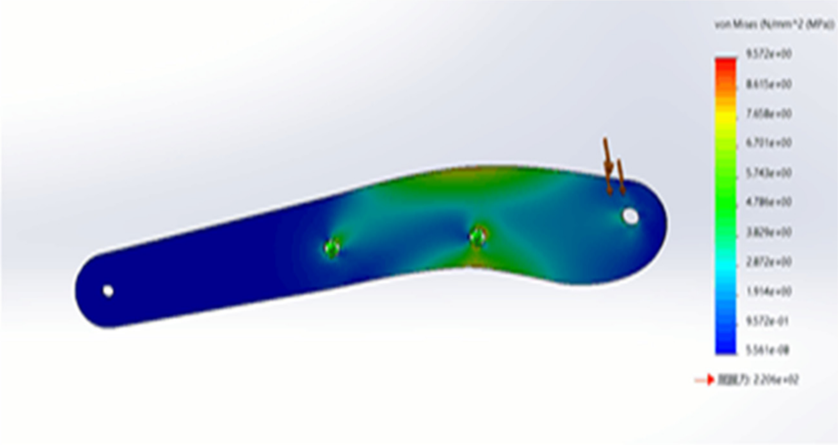


Figure 10. von Mises Stress Plot of the Main Web Plate

The static displacement plot (Figure. 11) reveals a maximum displacement of 0.00179 mm. This negligible value does not affect the normal operation of the plate, proving the structural design is reasonable and the stiffness is sufficient. Finally, the static strain plot (Figure. 12) shows the strain distribution, highlighting a maximum strain of 0.0000321 at the support wheel axle hole. These results confirm that the main web plate possesses adequate strength and stiffness for the e-bike mover's intended operations.

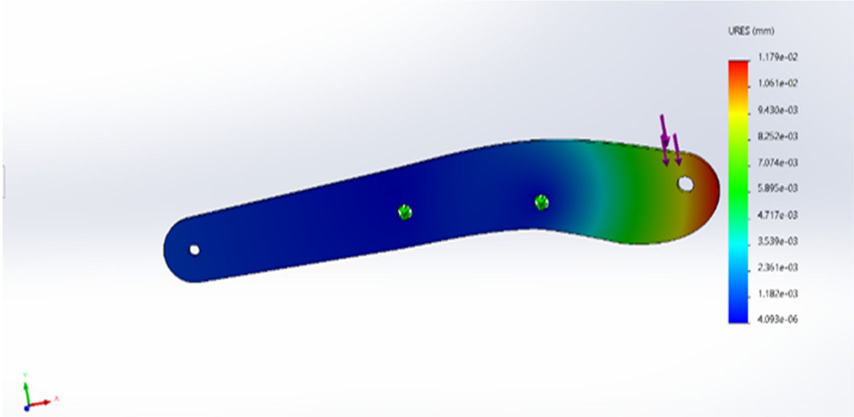


Figure 11. Static Displacement Plot

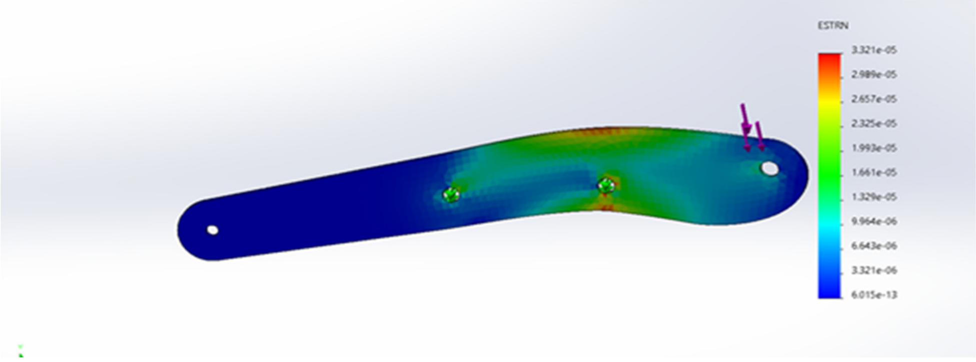


Figure 12. Static Strain Plot

4. Conclusion

This paper addresses the widespread issue of disorderly electric bicycle parking by designing a practical e-bike mover. This device improves upon traditional manual lifting methods, significantly increasing the efficiency of vehicle organization. Unlike many existing movers designed primarily for flat tires, the proposed design includes a tire clamping mechanism, offering superior practicality and functionality. The research achieved the following milestones: Firstly, based on collected data of common electric bicycles, the basic dimensions of the mover were established. A worm gear transmission mechanism was implemented to allow manual adjustments for clamping tires of various sizes. Secondly, structural parameters and component profiles were determined through rigorous calculation of major part dimensions. Thirdly, 3D modeling and assembly of the mover were completed using SolidWorks. Finally, finite element analysis was conducted using SolidWorks Simulation to evaluate von Mises stress and deformation, confirming that both the transmission shaft and the main web plate possess sufficient strength and stiffness. In conclusion, this e-bike mover meets the fundamental requirements for vehicle relocation, effectively solving the challenges associated with disorderly parking and difficult manual handling. This design holds significant potential for application in residential areas, schools, and urban streets, contributing to the development of organized and civilized urban environments.

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