MEDWIN PUBLISHERS
Committed to Create Value for Researchers

Open Access Journal of Data Science & Artificial Intelligence
ISSN: 2996-671X

The Design and Implementation of Automatic Battery Swap Stations for Electric Vehicles: A Technical Study Focused on Battery Lifting and Transfer Mechanisms

Junrong Xu and Bin Zhao*

School of Science, Hubei University of Technology, China

***Corresponding author:** Bin Zhao, School of Science, Hubei University of Technology, Wuhan, Hubei, China, Tel: +86 130 2851 7572; Email: zhaobin@hbut.edu.cn

Research Article
Volume 3 Issue 1
Received Date: December 30, 2024
Published Date: January 10, 2025
DOI: 10.23880/oajda-16000158

Abstract

With the increasing development of technology, people's living standards have soared, and their awareness of environmental protection has gradually improved. This has led to a significant shift in transportation preferences, with the proportion of electric vehicles in private car ownership constantly increasing. Electric vehicles, powered by new energy sources, offer immense market potential due to their eco-friendly nature. However, despite their promising outlook, the path to their widespread adoption in China has not been smooth. Numerous challenges and shortcomings, such as limited battery life and charging infrastructure, still need to be addressed and optimized. Among the myriad of issues hindering the development of electric vehicles, battery charging stands out as a critical concern. When an electric vehicle's battery runs out, the owner is often left with the inconvenience of spending considerable time charging it. To alleviate this issue, the establishment of automatic battery swapping stations for electric vehicles equipped with replaceable batteries has emerged as a viable solution. These stations would enable electric vehicles to swiftly and conveniently replace their batteries, akin to how fuel vehicles refuel at gas stations, thereby minimizing downtime and enhancing user convenience. In this paper, we delve into the functionality of electric vehicle battery replacement and propose a feasible level changer structure scheme. Based on this structural scheme, we meticulously analyze and calculate relevant data to ensure the feasibility and efficiency of the design. Subsequently, we design the battery lifting mechanism and the battery pack transmission mechanism of the electric vehicle level changer.

Keywords: Electric Vehicle; Battery Swapping Station; Structure Design; Lifting Mechanism; Transmission Mechanism

Introduction

Plug in electric vehicles have problems such as high battery replacement costs, limited charging equipment, and long charging times, which make it difficult for the development of electric vehicles to be widely popularized, even though they are already very rapid. According to the "Work Plan for Stable Growth in the Automotive Industry (2023-2024)" released by the Ministry of Industry and Information Technology in 2023, as of July 2023, the market share of new energy vehicles in China is only 32.7%, and most of them are concentrated in cities such as Shanghai and Shenzhen. Fuel vehicles still occupy the main position in the market, and the popularization of new energy vehicles will still be difficult to achieve in the long term, with a long and arduous road ahead.

The battery swapping mode of the electric vehicle automatic battery swapping platform is to replace the old battery in the vehicle with a new battery that has been fully replenished through a battery swapping station. The old battery is left at the battery swapping station for charging, allowing the battery to be recycled and thus achieving an efficient swapping mode. But a major problem faced by current battery swapping platforms is that different car companies have different standard rules for controlling costs, which makes it difficult for battery packs used in various electric vehicles to have a unified standard, and battery swapping platforms naturally struggle to provide corresponding batteries for all models of cars. The limitations of standard rules are not only reflected in the model of the battery, but also in the significant differences in the layout position of different electric vehicle batteries. Once the battery swapping standards are unified, the original standards of enterprises will also change, and their interests are easily affected. This also makes it difficult to promote the standardization of battery standards and find effective methods.

In addition, the initial investment in the construction of charging facilities is large, and the current construction cost of charging stations is about tens of thousands to tens of thousands. If we want to build a charging facility system of a certain scale, the total investment is large, and the economic benefits are difficult to achieve in the short term. For a long time, the pain points of unclear ownership of battery property, high operating costs, inconsistent standards, and safety hazards in battery swapping have affected the enthusiasm of social capital participation.

Methods

Functional Analysis

According to the battery replacement process of electric vehicles, the general process is that an under charged electric vehicle enters a battery swapping station and stops at a designated location, where the battery replacement is carried out by an automatic battery swapping platform located on the vehicle chassis. Firstly, the undercharged battery pack on the electric vehicle should be removed from the battery slot by the battery swapping platform. There should be a battery lifting platform to temporarily store the removed batteries. After removing the undercharged battery pack, the transportation agency should send it to the designated storage location inside the swapping station. After the undercharged battery pack is sent to the charging station, the transportation agency takes out the suitable fully charged battery pack from the fully charged battery storage box of the battery exchange station and hands it over to the battery exchange platform. It is then sent to the electric vehicle chassis according to the predetermined path and lifted to a certain height to be sent into the battery slot. After confirming the successful docking of the battery plug, perform the battery fixing operation and reset all devices.

The Model

Based on the analysis of the above swapping process, the battery lifting mechanism and battery transportation mechanism are the core mechanisms in this mechanism, occupying a large proportion in the overall mechanism. The focus of this article is on the design and implementation process of automatic battery swapping stations for electric vehicles, with a particular emphasis on the research of key technologies such as battery lifting and transmission mechanisms, and in-depth analysis of their working principles, design optimization, performance evaluation, and other aspects to verify their feasibility and efficiency in practical applications.

During the process of reviewing relevant literature, it was found that there is currently no national unified standard for size, chassis height, and other data of different electric vehicles on the market. Therefore, the same battery swapping station cannot be applied to different models of electric vehicles. Therefore, this design chooses the BYD Han 2024 EV Honour model as the electric vehicle model. Please refer to the official website of BYD Electric Vehicle to view the relevant data of this model of electric vehicle as follows. Additionally, based on this data, relevant load equations are established to determine whether the theoretical results obtained are reliable [1-4].

Categories	Explanations for each category	Parameters
L(mm)	The length of vehicle body	4995
S(mm)	The width of vehicle body	1910
H(mm)	The height of vehicle body	1495
e1(mm)	The distance between the two front wheels of a car	1640
e2(mm)	The distance between the two rear wheels of a car	1640
d(mm)	Distance between front and rear wheel axles	2920
M(kg)	The weight of the entire car	1920
h(mm)	The height of the car chassis	150
l(mm)	The length of the battery pack	2408
s(mm)	The width of the battery pack	1210
h(mm)	The height of the battery pack	238
m(kg)	The weight of the battery pack	549

Table 1: BYD Han 2024 EV Honour Edition related size parameters.

Scheme Selection of Lifting Mechanism

In the selection of battery lifting mechanisms, we found that there are many options available, such as scissor lift mechanisms, roller screw lift mechanisms, motor-driven gear rack lift mechanisms, etc. In terms of functional structure, these mechanisms can all achieve the lifting action. However, based on the investigation of existing lifting mechanisms on the market, we found that most electric vehicle battery swapping stations currently use scissor lift mechanisms for battery lifting. Therefore, in order to meet the market demand, this design chooses to use a scissor lift mechanism to achieve the lifting process of the battery.

The Scissor Lift Mechanism has many Advantages:

- The scissor lift mechanism consists of a base, pillars, scissor arms, and hydraulic system, with a simple and clear structure, making maintenance and repair relatively easy.
- Adopting hydraulic drive mode, the scissor lift mechanism runs smoothly and is easy to operate, which can meet various high-altitude operation needs.
- The scissor lift mechanism is equipped with multiple safety protection devices, such as overload alarm, automatic power-off function, etc., to ensure the safety of operators. In addition, anti-slip platforms, safety railings, and emergency landing devices are designed to further ensure the safety of workers.
- The scissor lift mechanism is suitable for various working environments, whether indoors or outdoors, and can easily handle them. Its adjustable height also allows it to adapt to different job requirements.

There are three main structural forms of scissor type hydraulic mechanisms, namely upright fixed scissor type, horizontal fixed scissor type, and double hinged scissor type. The hydraulic cylinder of the main action mechanism of the upright fixed scissor type hydraulic mechanism is not fixed to the frame, and the piston rod is connected to the upper flat ball socket with a ball head. The hydraulic cylinder of the horizontal fixed scissor type is fixed in position and always kept level with the ground. The hydraulic cylinder drives the piston rod, which in turn drives the mechanism to lift and lower the platform. The double hinged scissor type uses a hydraulic cylinder to drive the piston rod, which then drives the middle structure of the bracket to achieve platform lifting.

Compared to the upright fixed scissor type and the horizontal fixed scissor type, the double hinged platform has a lifting height greater than that formed by hydraulic cylinders, with a reasonable structure, and is widely used for lifting various heavy objects on the market. Therefore, the battery lifting mechanism in this paper adopts a double hinged scissor lifting mechanism.

Data Calculation of Lifting Mechanism

Correlation analysis of the geometric configuration of the double hinged scissor hydraulic lifting mechanism.

Based on geometric relationships and consulting the content of the Journal of Gansu University on hydraulic cylinder driven scissor lift mechanisms, relevant calculations can be carried out to determine the relationship between the movement speed of the hydraulic cylinder piston rod and the lifting speed of the table, as well as the relationship between the thrust of the piston rod and the load on the Table 1.

$$v=\frac{\sqrt{a^2+l^2+2al\cos 2\alpha \sin(\theta-\alpha+\gamma)}}{2l\cos\alpha}v_y \quad (1)$$

$$P=\frac{2l\cos\alpha}{a\sin(\theta+\alpha)+l\sin(\theta-\alpha)}W \quad (2)$$

In the calculation formula

$$\alpha=\sin^{-1}\frac{h}{21} \quad (3)$$

$$\theta=\tan^{-1}\left[\frac{1+a}{1-a}\tan\alpha\right] \quad (4)$$

$$\gamma=\sin^{-1}\left(\frac{a}{d}\sin 2\alpha\right) \quad (5)$$

When the alpha angle is minimized, the scissor lift mechanism experiences maximum pressure, this position should be given special consideration in subsequent hydraulic cylinder calculations.

For the preliminary selection of relevant data for each connecting rod, based on the previous research, the length of the battery pack was found to be 2.408m. After roughly estimating the platform size, the initial selection of the connecting rod length was 2.8m, which is l=1.4m, and the initial selection was a=0.7m. The initial selection range for alpha is 20 °~40 °.

On this basis, calculations can be made based on geometric relationships

$$h_{min}=2\times1.4\times\sin20°=0.95m \quad (6)$$

$$h_{max}=2\times1.4\times\sin40°=1.8m \quad (7)$$

$$\Delta h=1.8-0.95=0.85m \quad (8)$$

Therefore, in the model we established, the maximum height of the lifting platform is 1.8m, the minimum height is 0.95m, and the maximum lifting height is 0.85m. When the institution uses an underground installation method, it has sufficient space to meet the requirements.

After completing the calculation of the lifting height, calculate the stroke of the hydraulic cylinder. The stroke of hydraulic cylinder can be calculated according to the above formula, which is 47.2 ° and 68.3 ° when α is 20 ° and 40 °, respectively.

Therefore, the stroke of the hydraulic cylinder should not be less than 0.4804m, and the minimum length of the hydraulic cylinder should not be less than 0.9696m.

When the weight of the battery pack is 549kg and the starting angle is 20 °, according to the formula, the maximum load on the piston rod can be obtained as:

$$P=\frac{2l\cos\alpha}{a\sin(\theta+\alpha)+l\sin(\theta-\alpha)}W=11014.3\text{N} \quad (9)$$

Scheme Selection of Battery Transportation Mechanism

After consulting relevant materials extensively, it has become evident that there are two primary mechanisms capable of achieving the planar displacement of the battery lifting mechanism. These mechanisms are the Mecanum wheel and the roller screw slide table, each offering unique advantages and suitability for different applications.

The Mecanum wheel, known for its omnidirectional mobility, is a remarkable choice for systems requiring flexibility and maneuverability.

Its unique design allows for smooth and continuous movement in any direction, making it ideal for battery lifting mechanisms that need to navigate complex layouts or tight spaces. This versatility can greatly enhance the efficiency and operational range of the overall system.

On the other hand, the roller screw slide table is renowned for its precision and stability. It employs a roller screw mechanism to provide smooth and accurate linear motion, making it an excellent option for applications where precision is paramount.

In the context of battery lifting mechanisms, this precision can ensure reliable and consistent performance, reducing the risk of errors or malfunctions during operation.

Both devices, the Mecanum wheel and the roller screw slide table, thus represent viable solutions for achieving planar displacement, but their choice will ultimately depend on the specific requirements and constraints of the system in question.

By understanding the unique advantages of each mechanism, engineers can make informed decisions that optimize the performance and reliability of battery lifting mechanisms in various applications.

Categories	Explanations for each category
Ball screw slide table	1. Higher work accuracy 2. Carrying a greater load capacity 3. Can achieve mechanical self-locking to avoid movement due to changes in load
Mecanum wheel	1. High flexibility, able to achieve motion in any direction on a plane 2. Can move in multiple directions simultaneously, with higher efficiency 3. Stronger stability, able to work on uneven surfaces

Table 2: Comparison between Roller Screw Sliding Table and Mecanum Wheel.

The design purpose of this institution is to transport the battery lifting mechanism to a designated location, which is usually the chassis and battery storage area of electric vehicles.

The latter is a fixed position in the battery swapping station, but for the former, although the parking position may vary slightly among different car owners after entering the swapping station, it is relatively small.

Therefore, it does not require overly flexible planar degrees of freedom, and choosing a roller screw slide table can meet the requirements. At the same time, due to the weight of the battery pack being 549kg, which is already large, a roller screw slide table with high load-bearing capacity is more in line with the requirements of this design.

Data Calculation of Battery Transportation Mechanism

A cross-shaped slide table, a critical component in many mechanical systems, typically consists of two primary parts: the top and the bottom. In the initial design phase, we focus on the upper slide table, ensuring its functionality and durability. The design and selection of the roller screw slide table are pivotal, and this process should primarily hinge on precise axial force calculations.

Considering the specific requirements of the battery swapping station, we meticulously select the parameters. For instance, we preliminarily determine the total weight of the lifting mechanism to be 251kg, accounting for the mechanical components and any additional load.

Furthermore, we set the load capacity at 800kg to accommodate the weight of the batteries being swapped. These calculations and selections are essential to ensure the stability and reliability of the entire system.

Categories	Explanations for each category	Parameters
S(mm)	Roller screw slide table movement distance	5441
V(mm/s)	Roller screw slide table moving speed	500
M(kg)	Maximum load-bearing capacity of countertop	800
P(mm)	The positioning accuracy of roller screw slide table	±0.01
d(mm)	Nominal diameter	25
p(mm)	Lead of screw	20
F(N)	Provided traction force	600N

Table 3: Parameters of the upper screw slide table.

Based on the data in the table, we conducted relevant calculations and used the results as the basis for selecting the model. In the design and calculation process of the roller screw sliding table, appropriate friction coefficient and operating conditions should be selected as conditions. After referring to relevant literature, we take the friction coefficient as 0.1 and the operating condition fp as 1.1.

$$\text{axial loading: Fa } 800\times 9.8\times 0.1\times 25\div 20+600=1580\text{N} \tag{10}$$

$$\text{run time:}t=5441/500=10.9\text{s} \tag{11}$$

$$\text{motor speed:}n=60\frac{V}{P}=1500r/\min \tag{12}$$

As calculated in the previous text, the motor speed is 1500r/min. We know that the servo motor accelerates from a standstill to its rated speed very quickly, usually taking only a few milliseconds to tens of milliseconds. It is commonly used in devices with fast start stop. The electric vehicle battery swapping station should be able to quickly enter the working state to reduce the waiting time for car owners and ensure that the waiting time meets the requirements. Therefore, in this design, servo motors were chosen for motor selection.

The required driving power for the motor:

$$P=FaV=1580\times 0.5\text{m/s}=790\text{w}=0.79\text{kw} \tag{13}$$

The selected motor model is ZMYV-380-165S-15-80-1R5.

After selecting the motor for the roller screw slide table, it is necessary to choose the screw. The main function of the screw in the roller screw slide table is to convert rotational motion into linear motion. The motor drives the coupling to rotate the ball screw, which, in conjunction with the ball bearing at the bottom of the linear module, enables the screw to complete the rotation process without moving, thereby converting rotational motion into linear reciprocating motion. In terms of performance, due to the low friction of the ball screw, high-speed movement can be achieved. Applying it to the automatic battery swapping platform of electric vehicles can effectively reduce the waiting time for vehicle owners.

The calculation of pre twisting force and pre tightening pressure is an important basis for selecting the lead screw.

$$\text{pre twisting force: } P_{bm}=\frac{F_a f_p}{2.8}\frac{1580\times 1.1}{2.8}=620.7\text{kgf} \tag{14}$$

$$\text{pre tightening pressure: } T_d=\frac{K_p\times 620.7\times 9.8}{2\times\pi}=1064.9 \tag{15}$$

Based on the calculated data, as the lead of the lead screw had already been selected as 20, the screw model 25-25K2 was chosen. Its dynamic and static loads were 1260 and 3370, respectively, which were greater than 1064.9 kgf and met the requirements.

Verification of Screw Efficiency and Screw Stiffness

Efficiency and stiffness verification are essential parts of the overall design, which are related to the safety and feasibility of the mechanism. Therefore, we have conducted verification on the calculated data in this regard to ensure that the mechanism can work normally.

$$\delta_1=\pm\frac{F_a a}{ES}\pm\frac{Ma^2}{2\pi l E} \tag{16}$$

$$\lambda=\arctan\frac{p_n}{\pi d_o} \tag{17}$$

$$\eta = \frac{\tan\lambda}{\tan(\lambda+\phi)} \tag{18}$$

Based on the above three formulas, we calculated the screw efficiency to be 98.15% and the deformation to be 0.1046mm. When using a 7-level precision, the maximum deviation is less than the allowable deviation, which meets the safety requirements.

Additionally, after completing the data calculation of the top screw slide table, we performed the same calculation and verification on the bottom slide table. The result we obtained is that the screw model is 25-25K2 and the motor model is ZMYV-380-165S-15-80-1R5 [5-9].

Conclusion and Discussion

After analyzing the overall functional requirements of the swapping station, we identified the battery lifting mechanism and battery pack transportation mechanism as the core mechanisms and conducted relevant analysis based on them. After studying the characteristics of the institution, the final institutional structure scheme was determined. Next, we conducted data analysis and calculations on it, selected the lengths of each rod of the lifting mechanism, and calculated its stroke and load.

Additionally, in the analysis and calculation of the roller screw sliding table, we used the load as the basis, consulted relevant formulas, and performed calculations. Finally, we obtained the available screw and motor models and determined their specifications. At the same time, in order to ensure their feasibility and safety, we have verified the efficiency and maximum bending degree of the screw rods.

After designing and calculating the lifting mechanism and transportation mechanism, it can meet the functional requirements of electric vehicle battery swapping. However, there are still many areas that can be optimized and improved in the overall mechanism. The electric vehicle automatic battery swapping platform still has its research significance and value.

The scissor type lifting mechanism does not lift the platform in a direction perpendicular to the plane during lifting, but rather in a certain arc, which requires the bottom plane displacement mechanism of the platform to be fine-tuned to maintain its position after lifting. Further optimization in the future may consider optimizing the scissor type lifting mechanism to an upright lifting mechanism to avoid this problem.

References

1. Sanchari D, Sulabh S, Toni Z (2022) Optimal Location of EV Charging Stations by Modified Direct Search Algorithm. School of Engineering, University of Warwick.

2. Priyanka R, Chayan B, Koteswara R (2022) Swarm Intelligence-Based Energy Management of Electric Vehicle Charging Station Integrated with Renewable Energy Sources.

3. Ashish K, Partha S, Baseem K (2022) EV Fast Charging Station Planning with Renewable Energy Sources: A Case Study of Durgapur System. National Institute of Technology.

4. Vishu G, Srikanth R, Rajesh K (2019) Collaborative Multi-Aggregator Electric Vehicle Charge Scheduling with PV-Assisted Charging Stations under Variable Solar Profiles. The Institution of Engineering and Technology.

5. Akanksha, Kusum V, Rajesh K (2019) Impact of EV Fast Charging Station on Distribution System Embedded with Wind Generation. The Journal of Engineering.

6. William I, Jin M, Ariel L (2017) Operational Strategy Analysis of Electric Vehicle Battery Swapping Stations. IET Electrical Systems in Transportation.

7. Hongtao Y, Gang W, Lan X, Zhang Z, He Z (2018) Optimal Scheduling for Micro-Grid Considering EV Charging-Swapping-Storage Integrated Station. IIT Generations.

8. Aazim R, Xiangwu Y, Urfa R, Farukh A, Muharmmad N, et al. (2019) Enhanced Control Strategies of VSG for EV Charging Station under a Low Inertia Microgrid. IET Power Electronics.

9. Zhigang L, Hao Z, Haifeng X, Jiangfeng Z, Xueping L, et al. (2016) Robust DED Based on Bad Scenario Set Considering Wind, EV, and Battery Switching Station. University of Technology Sydney.