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Overall Scheme Design and Related Verification Calculation of Column Lift

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Abstract

The column lifting mechanism is a device that lifts and lowers a car by supporting a certain part of the car chassis or body. Car lifts play a crucial role in maintenance and upkeep, whether it's major or minor repairs, they are indispensable. Mechanical car lifts, as a member of the entire car lift system, have advantages that other lifts do not have, such as a wide working range, the ability to repair high ceiling vehicles, and a small working space. This article provides a comprehensive introduction to the types of lifts, and after determining the design plan, designs and explaining the structure and characteristics requirements of the lifts. Specifically, it involves the analysis and selection of the prime mover, the analysis and design of the belt drive, the analysis and design of the screw drive, the analysis and selection of the guide rail, the stress verification of the support cantilever, and the selection of the locking mechanism.

Keywords: car; post lift; screw transmission; mechanical drive.

1. Introduction and Development Overview of Automotive Elevators

Car lifts play an important role in the automotive maintenance and repair industry. The car lift is a device that reliably and safely lifts a car that needs maintenance or repair from the ground to another suitable height according to the maintenance and repair conditions, in order to facilitate the maintenance and repair work of workers. Therefore, the car lift plays a crucial and irreplaceable role and is one of the most basic maintenance equipment in the automotive maintenance and repair industry.

As early as the early 20th century, in car maintenance, especially in car chassis maintenance, car maintenance technicians generally diagnose and repair faults by drilling under the car. However, this maintenance method has a relatively small space, dark lighting, and is not conducive to maintenance personnel working under the car for a long time, resulting in low maintenance efficiency. The first lift that appeared was powered by electricity and could lift cars into the air, but the lifting height was not high. In the 1920s, the maximum lifting height of car lifts produced by Weaver and Manley could reach 4 feet, and the lifting height could be adjusted arbitrarily at the highest height according to the working conditions. The lift lifted the car by supporting the axle, ensuring that the wheels could rotate freely after the car was lifted. In 1925, Lunati, the founder of Rotary Company in the United States, was inspired by the principle of barber seats and created the world's first hydraulic lift, which made repairing cars easier. Afterwards, a single column frame contact lift appeared, which ensured that the staff could easily repair the four wheels. However, the cost of this design scheme was the sacrifice of vehicle bottom space, making it impossible for the staff to repair certain parts of the vehicle bottom. Subsequently, the appearance of the two column lift enabled technicians to easily repair faults in the chassis area of the car. With the development of science and technology, manufacturers have gradually combined lifting technology and automation control technology, using electronic devices to control the lifting action of the lift. At the same time, they have designed and developed various mature safety protection devices, enabling workers to perform various maintenance operations.

China's car lift started relatively late, and it was not until the early 1980s that it was produced based on foreign technology. Car lifts have gradually replaced the commonly used trench mode due to their ease of maintenance for technicians. And with the prosperity of China's automobile industry, a huge automobile peripheral market has been formed, and the market for automobile lifts has expanded rapidly. By the year 2000, the forms and types of lift products had developed into various types and became essential automotive repair equipment for obtaining Level 2 maintenance qualifications in the automotive repair industry. With the continuous increase in the number of cars in China, private car purchases have become mainstream, and the automotive aftermarket has flourished. Car lifts have become highly frequent and almost indispensable automotive maintenance equipment.

Since China's accession to the WTO, the impact on the Chinese automotive repair industry has been enormous. In order to meet the requirements of after-sales service, foreign automobile manufacturers have begun to enter the Chinese market one after another. The entry of foreign automobile maintenance industry has provided a relatively advanced and efficient international technological environment for the Chinese automobile maintenance market. This is an opportunity to promote the upgrading and transformation of the domestic automobile maintenance industry and accelerate the technological progress of the automobile maintenance industry, which will inevitably play a good driving role.

Modern car maintenance methods will inevitably replace traditional car maintenance methods, maintenance systems, and business models. In the past, car maintenance usually involved discussing repairs, while modern car maintenance integrates car sales, parts sales, information, and after-sales service. The high-tech transformation of maintenance targets, modernization of maintenance equipment, networked maintenance consulting, specialized maintenance diagnosis, diversified maintenance management, and socialization of service targets will be the new trends in modern auto repair. Foreign automobile repair enterprises enter the domestic market through automobile service trade, which poses severe challenges to China's automobile repair industry. Among the development factors of automobile repair enterprises, management, technology, assembly, and information will play a leading role. It is imperative to promote high-quality, branded, and digitized services in the automotive maintenance industry.

2. Overall scheme design

After reviewing relevant materials and conducting research on automotive maintenance companies, the overall transmission plan includes the following aspects, which are listed as alternative solutions.

Based on the actual dimensions and quality of the sedan, as well as on-site inspections by maintenance shops, the parameters required for designing the column lift of the car are rated lifting mass, maximum lifting height, lowest height of the cantilever tray from the ground, full rise/fall time, and lift dimensions.

Due to the lack of unified national regulations on the parameters of different types of cars on the market, the various parameters of each car are not the same, and corresponding adjustments need to be made when facing different types of cars.

Categories	Possible solutions
Motor	1. Single motor scheme.
configuration scheme	2. Dual motor scheme.
	1. Gear transmission.
Transmission mode	2. Ball screw transmission.
	3. Sliding spiral drive.
	4. hydraulic transmission.
synchronization mechanism	1. Spiral pair - bevel gear - long shaft - bevel gear - mechanical transmission structure of spiral pair.
	2. Select two motors with similar external rotation and two screw pairs with similar machining accuracy for adjustment and selection during assembly.
	3. Chain drive structure.
	4. synchronous belt transmission.
Locking safety device	1. Self locking safety device including electromagnet, spring or brake plate.
	2. Set up several stop plates to achieve necking effect.
	3. Adopting rail clamps suitable for use on fixed Z-axis (vertical axis).

Table 1: Alternative functional solutions for each category.

Based on the above information, two options can be determined. Option 1: The prime mover adopts a motor, which transmits motion and torque to the right screw through a common V-belt transmission. The spiral transmission converts the rotational motion of the right screw into linear motion of the nut, and the rotation of the left screw is transmitted to the right screw through a chain transmission with a transmission ratio of 1, achieving synchronous motion of the left and right screws, that is, the rotation of the right screw is converted into linear motion of the nut. Option 2: The prime mover is two motors installed on the left and right columns respectively. The synchronous motion of the left and right screws is achieved through the power on/off of the two motors. The screw converts its rotation into linear motion, which in turn causes the nut to move up and down synchronously. The car lifting prime mover is two motors installed on the left and right columns respectively. The synchronous motion of the left and right screws is achieved through the power on/off the two motors. The screw converts its rotation into linear motion, which in turn causes the nut to move up and down synchronously, realizing the car lifting.

3. Analysis and selection of nuts

The basic principle of spiral transmission is to transmit motion and power through the rotation of screws and nuts. Spiral transmission mainly converts rotational motion into linear motion, which can obtain large thrust with small torque or be used to adjust the mutual position of parts. When the spiral drive is not self-locking, linear motion can also be converted into rotational motion.

According to the different friction properties of threaded pairs, they can be divided into sliding spiral transmission, rolling spiral transmission, and static pressure spiral transmission. Different types of spiral drives have different applicable scenarios and need to be adjusted according to the actual situation. If used in the wrong situation, it may cause problems such as inability to achieve the expected effect. The characteristics and application examples of each type of spiral transmission are as follows:

Categories	characteristic
Sliding spiral drive	1. High frictional resistance and low transmission efficiency
	2. Simple structure and easy processing.
	3. Easy to self-lock.
	4. Smooth operation, but crawling may occur at low speeds or during fine-tuning.
	5.The thread has lateral clearance, and there is clearance in the reverse direction.
	6. Quick wear and tear.
Rolling spiral transmission	1. Low frictional resistance and high transmission efficiency
	2. Complex structure and difficult manufacturing.
	3. It has reversible transmission capability.
	4. Smooth operation, no vibration during start-up, and no crawling at low speeds.
	5. Poor impact resistance.
	6. Long working life and less prone to malfunctions.
Static pressure spiral transmission	1. Extremely low frictional resistance and high transmission efficiency.
	2.The nut structure is complex.
	3. It has reversible transmission capability.
	4. Work smoothly without crawling phenomenon.
	5. No empty travel in reverse.
	6. Low wear and long service life.

Table 2: Characteristics and Applications of Various Spiral Transmission Systems.

Categories	Explanations for each category
Integral nut	The structure is simple, but the axial clearance caused by wear cannot be compensated for and is only suitable for low precision spiral transmissions.
Combination nut	The structure is complex, but it can be adjusted regularly to eliminate axial clearance and avoid backlash caused by reverse rotation.
Split nut	The structure is complex, but it can compensate for the wear of the mating thread.

Table 3: Characteristics of three types of nut structures.

Although combination nuts and split nuts have the advantages of compensating for clearance, avoiding reverse travel, or compensating for wear, their structures are too complex, and split nuts are mainly used in conductive screws. Therefore, in most cases, column lifts choose integral nuts.

Applicable spiral pair calculation methods

The failure of sliding screw pairs is mainly due to thread wear, so the diameter of the screw and the height of the nut are usually determined based on wear resistance calculations.

$$d_2 = \xi\sqrt{\frac{F}{\varphi[p]}} \qquad (1)$$

Rectangular thread ξ=0.8; F represents single column axial load, with a safety factor of 1.5 [p]. represents the allowable pressure, with different values depending on different usage situations. The value of π is selected according to the form of the nut, and the overall value is taken as 2.5~3.5.

Due to the need to meet the design requirements of wear resistance, self-locking, screw strength, thread strength, screw stability, and lateral vibration of the screw, the selected value of the screw diameter should be greater than the actual calculated value, and rounding should be carried out according to the national standard value.

The nut height H, the number of turns Z, the working height H, and the working pressure P can be calculated from the following formulas to determine the relevant parameters.

$$H = \varphi \times d_2 \qquad (2)$$

$$Z = \frac{H}{P} \leq 10 \sim 12 \qquad (3)$$

$$p = \frac{F}{\pi d_2 h z} \leq [p] \qquad (4)$$

For column lifts, the verification of self-locking performance is an essential step, and the self-locking screw should be checked for its self-locking performance.

$$\rho' = \arctan \frac{\mu_s}{\cos\frac{\alpha}{2}} \qquad (5)$$

$$\psi = \arctan \frac{L}{\pi d_2} \qquad (6)$$

The value calculated by formula (5) is the equivalent friction angle. If the value calculated by formula (6) is less than formula (5), it meets the self-locking requirement.

In structural mechanics, a dangerous section refers to a section where the internal forces (such as bending moment, shear force, and axial force) reach their maximum value under the action of internal forces. These sections are usually located at critical parts of the structure, such as support points, connection points, or changing sections of beams. Due to the concentration of internal forces in these locations, they are more prone to damage or deformation, hence they are referred to as dangerous sections.We can verify the dangerous section according to formula (7).

$$\sigma = \sqrt{\left(\frac{4F}{\pi d_1^2}\right)^2 + 3\left(\frac{T}{0.2d_1^3}\right)^2} \qquad (7)$$

In terms of material selection, screw and nut materials should not only have sufficient strength and good processing performance but also have intersecting friction coefficients and high wear resistance when screwed together. Therefore, the screw of this car lift should undergo heat treatment to ensure its wear resistance.

For medium precision general transmission, 45 steel is selected as the screw material, and the heat treatment process is as follows: preliminary heat treatment: normalizing (170~200HBS); Final heat treatment: quenching and tempering (220~250HBS).

The traditional nut material is ZCuAl10Fe3Mn2, which is used in conjunction with steel screws to achieve low friction coefficient and high strength, making it suitable for heavy-duty and low-speed transmission.

4. Supporting structure analysis

The cantilever part of the lifting platform belongs to the support mechanism of this car lift. When the target car enters the range of the car lift, the entire support mechanism changes the width of the entire working range of the cantilever by changing the angle and length of the cantilever. The support mechanism designed for this car lift is a symmetrical cantilever, which is beneficial for maintaining the stability of the car during maintenance, making the force distribution of each mechanism in the column more uniform, and also meeting the distance requirements of various types of cars.

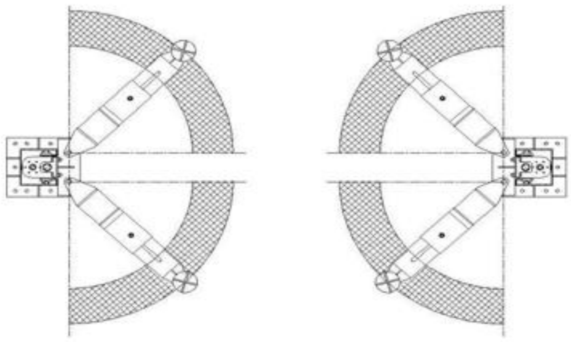

Fig.1: Schematic diagram of symmetrical cantilever.

Stress verification method for supporting mechanism

This section will verify the supporting structure by simplifying the model. The entire cantilever can be simplified as a cantilever beam, with a load applied at the end of the cantilever beam. The cross-section of the cantilever beam is a hollow rectangle. Below, we will verify the bending normal stress and bending shear stress of the cantilever separately.

The verification formulas for bending normal stress and bending shear stress are as follows:

$$\tau = \frac{F_S S_z^*}{I_z b} \quad (8)$$

$$\sigma_{max} = \frac{M_{max}}{W} \quad (9)$$

$$W = \frac{I_z}{y_{max}} \quad (10)$$

Meaning of each data item in the formula:
Fs - Shear force on the cross-section. b - Section width.
Iz - the moment of inertia of the entire cross-section about the neutral axis.
S * z - The static distance of the area outside the horizontal line y from the neutral axis on the cross-section to the neutral axis.
Mmax - maximum bending moment of cantilever.
W - Bending section coefficient, related to the geometric shape of the section. ymax - The horizontal line on the cross-section that is y away from the neutral axis.
Fs and other data should be adjusted based on the actual weight of the lifted vehicle.

Stress verification method for supporting mechanism

Select the rolling linear guide according to the working conditions of the car lift. Rolling linear guides have four directions of equal load type, light load type, separation type, radial type, and cross roller V-shaped linear guide pairs.If a four-way equal load rolling linear guide pair is used, it has the following advantages.

1. The rolling element is in contact with the circular groove, which has a higher load-bearing capacity and better rigidity compared to point contact.

2. The friction coefficient is small, generally less than 0.005, only 1/20~1/50 of the sliding rail pair, saving power and able to withstand loads in four directions: up, down, left, and right.

3. Longer lifespan, easy installation, maintenance, and lubrication. Flexible and impact free movement, it can effectively control the position and size during low-speed micro feed.

5. Conclusions and recommendations

By analyzing and calculating the transmission mode and internal structure of the car lift, a relatively simple and reliable transmission mode was selected based on the existing transmission mode and structure of the lift. At the same time, the strength and stiffness verification of the main load-bearing components were introduced; Introduced the selection and verification calculation of the spiral transmission device and belt transmission device and introduced the selection and verification calculation of important threaded connections to ensure the safety and practicality of the designed machinery.

However, there are still many shortcomings and limitations of column lifts, and there is still research significance. For example, the double column car lift is suitable for light and medium vehicles and cannot be used for the maintenance of heavy vehicles. The double column car lift needs to be fixedly installed on other structures on the ground and cannot be moved or transported, which limits its flexibility and versatility. The operation of a double column car lift requires high skills and experience, otherwise safety accidents may occur, requiring regular maintenance and inspection, replacement of oil seals and hydraulic pipe components, resulting in high operational requirements and maintenance costs. Future research directions can focus on optimizing these defects.

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