Structural Design and Analysis of a Bicycle Stereo Garage

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Abstract. The design of a smart bicycle three-dimensional garage was proposed and designed. The mechanism uses a multi-bar linkage with a combination of universal joints to achieve multi-angle rotation of the mechanical claws and the function of holding and supporting the bicycle. At the same time, the underground garage is used. The design is designed to save land resources, and simulation calculations are performed to determine the feasibility of the relevant design and a movement analysis is carried out to provide a new idea for urban bicycle management.

1. Introduction
The Chinese government actively advocates the use of bicycles as a means of urban transportation. However, the increase of bicycle use has brought a series of problems, such as small parking space and easy damage to the appearance of bicycles. Besides, bicycles are parked randomly, which affects the urban management; Bike lanes overlap with sidewalks and prevent city traffic; Supervision of bicycle parking spots is loose, and bikes are stolen frequently. Thus, fully automatic smart bike three-dimensional garage is born at the right moment, which has high automation level, strong ability to store, easy access and good anti-theft performance [1].

The mechanism proposed in this design adopts the combination of multi-lever mechanism and universal coupling to realize the multi-angle rotation of the mechanical claw and the clamping and righting function of the bicycle. The design of underground parking garage saves the land resources and reduces the operation cost. Centralized receiving-dispatching management is beneficial to improve management efficiency and is in line with the current development trend.

2. Overall program of new energy shore power supply system
This design adopts modular function design, which mainly consists of four parts: clamping module, storing module, partition sorting module and control module.

2.1. Application method
2.1-storage module 2-bike 3-clamping module 4-partition storage module

FIG. 1 Overall structure

The overall structure of the robot is shown in Figure 1. The mechanical arm clamps the bicycles around the collection box and brings them into the planetary gear train collection system, and then they will be taken into the underground parking places by the guide lift platform. The clamping module is designed as a mechanical arm, which is driven by a motor to move the universal joint up and down, left and right. One group of bevel gear train drives the lead screw to move forward and backward in fine adjustment, while the other group drives a multi-lever mechanism to tighten the block from left to right and centralize it from up and down. The receiving module is driven by the motor, which increases the torque through a set of planetary gear system to drive the opening of the louver type receiving entrance, and the collection is completed. As for the partition module, the pinion in reducer box is meshed with the epicyclic gear to rotate the mechanical arm by 360°. Double column hydraulic lifting mechanism drives the guide lifting platform to sink down to the underground parking space, to achieve space turnover movement and complete partition storage.

2.2. Introduction to working process

The smart three-dimensional garage is divided into underground and aboveground modes, which are applicable to areas with high density of people, high frequency of bike use and extremely tight land resources, such as business circles and subway stations. To reduce the area of urban road and increase the amount of bicycle storage, a three-dimensional bicycle garage is referred. It adopts a multi-layer three-dimensional design. Twenty-one parking spots are designed for each floor, and the number of floors can be set according to the specific construction conditions. The garage takes up a small aboveground area of the city, and most of it is buried under the ground to ensure the safe storage of bicycles, which can realize automatic access to the garage and real-time monitoring of the garage [2]. Therefore, a 1:10 underground three-dimensional garage model is designed and built.
The mechanical structure of smart three-dimensional garage is composed of garage entrance, annular parking rack and central access vehicle platform. The overall structure is shown in Figure 2.1. The entrance is located at the top of the device, and the crank slide mechanism is driven by the door opening and closing gear to open and close the door. The annular parking rack is supported by four supporting racks, and the central access vehicle platform is placed in the hollow position of the annular parking rack. The clamping mechanism drives the mechanical arm to pick up the bike through the steering gear, and the push mechanism drives the screw rod forward and backward by the stepping motor, so that the bike can enter and exit the parking space smoothly. The lifting mechanism motor is decelerated by the reducer box to drive the gear and rack mechanism to move. With the linear guide rail and slide block, the access vehicle platform can be lifted and lowered smoothly. At the same time, the self-locking of worm gear and worm mechanism can be utilized to realize the self-locking of power cut. The rotary mechanism rotates through the central axis driven by the bevel gear group to align the access vehicle platform with different parking spaces.

The process of bike parking in the smart three-dimensional garage is shown in Figure 2.2. When the user arrives at the entrance, he or she scans the QR code or presses the buttons to send out parking request. The garage and the back-end server establish TCP/IP connection. First the back-end server checks for the available parking spots and sends signals to each motor. Then the garage door opens, and a mechanical arm clamps the bike into the available spot, thus finishing the parking. The process of taking a bike is the reverse of the process of parking.

2.3. Mechanical arm clamping module

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2.3. Mechanical arm clamping module
As shown in Figure 3, the module is mainly composed of the universal joint, bevel gear drive, four-rodd mechanism and guide rail. Firstly, the power output from two motors is driven by the belt, which makes one group of bevel gears rotate and drive the ball screw through the bevel gear structure. As a result, it drives the motion of connecting rod mechanism, and the mechanical arm makes clamping action. The mechanical arm is closed from four directions, and the left and right sides can play a clamping effect, with up and down as the supporting effect. Secondly, another group of bevel gear drive mechanism drives the universal joint to rotate, which can realize the forward and backward motion fine-tuning of the mechanical arm. Finally, the mechanical arm clamps the bike and places it through the rail to the rail lift.

2.4. Mechanical arm clamping module

Figure 5 shows the structure diagram of the steering connection module, which is mainly composed of a planetary gear train and the entrance imitating shutter. The motor drives the rotation of the planetary gear system through the belt. After reducing the speed and amplifying the torque, it acts on the big gear, which meshes with the small gear of the shutter to drive the shutter to open and close. The shutter is designed to be open on multiple sides and can park multiple bikes at the same time, which improves the system's work efficiency and meets people's need for bike parking, coping with the peak traffic.

2.5. Partition storage module
As shown in Figure 6 and 7, the partition storage module consists of three parts: turning over mechanical arm, lifting platform, and annular underground parking space.

The rotating motion of mechanical arm consists of three parts: reduction gear box, large inner gear and annular guide rail. The motor drives the worm and gear and drives the gear of the reducer box to rotate [3]. The small gear meshes with the gear in the large turnover, so as to drive the reducer to rotate on the annular guide rail and realize the rotational motion of the mechanical arm. The movement of the lifting platform was made by the lifting platform and double column hydraulic lifting transmission. Double column hydraulic transmission working principle is as follows: Hydraulic oil made certain pressure by vane pump, and the oil goes through the oil filter, flameproof electromagnetic directional valve, throttle valve, hydraulic control one-way valve, balance valve into the lower cylinder; The hydraulic cylinder piston move upward to lift the object; The upper cylinder oil return back to the fuel tank by the explosion-proof electromagnetic directional valve; The rated pressure is adjusted by the overflow valve and the reading value is observed by the pressure gauge [4]. The piston of the cylinder moves down (the object drops). The hydraulic oil enters the upper end of the hydraulic cylinder through the explosion-proof electromagnetic directional valve, and the oil of the lower end of the cylinder goes back to the oil tank through the balance valve, the hydraulic control one-way valve, the throttle valve and the explosion-proof electromagnetic directional valve. In order to make the object drop steadily and ensure the brake’s safety and reliability, a balance valve is set to balance the circuit and maintain the pressure, so that the descending speed is not changed by the object. Throttle valve will adjust the flow rate and control the lifting speed. In order to make sure the brake is safe, a hydraulic control one-way valve, namely the hydraulic lock, is added to ensure that the hydraulic pipeline can be self-locked when accidentally exploded. Overload acoustic alarm is installed to distinguish overload or equipment failure. Double column hydraulic lifting has the characteristics of light weight and good maneuverability, which is smooth and steady, and is suitable for one-man operation.

2.6. Controlling module
The three-dimensional receiving-dispatching system is driven by the motor and the hydraulic cylinder. The motor drives the mechanical arm for fine-tuning steer to realize the centralization function and drives the ball screw to realize the clamping function. The spatial rotation and the opening and closing of the shutter entrance can be realized by increasing the torque by the reducer box and planetary gear reducer. Two-column hydraulic lift is used as power source to realize bicycle parking in a very short time.

3. Design and Analysis of the Main Spare Parts

3.1. Design and analysis of central gear

(1) Material selection of central gear
The power of the planetary reducer is taken into account when making the model, so the central gear adopts the involute gear of hard tooth surface and 45 steel normalizing [5].

(2) Size design of central gear

| Parameter name                  | Level          |
|---------------------------------|----------------|
| Model                           | 20             |
| Number of teeth                 | 52             |
| Tooth angle                     | 20°            |
| Precision contour               | JBI79-838-7-7HK|
| Ring gear radial runout         | 0.063          |
| Common normal length deviation  | 0.028          |
| Kylk limit deviation           | 0.013          |
| Tooth tolerance                 | 0.011          |
| Public normal inspection length | 16.21          |
| Common normal line test tolerance | -0.168 ~ -0.112 |
| Cross tooth count               | 4              |

After the check calculation of the gear, the parameters of the center wheel of the planetary wheel are designed as shown in Table 1:

3.2. Stress analysis

(1) Analysis of the mechanical arm
It can be seen from Figure 9 that the maximum stress of the driving shaft is 14.71 MPa, and the material of the bar is alloy steel. According to the Table, the yield strength of alloy steel is 400 MPa, which is within the allowable stress range. Therefore, the drive shaft meets the design requirements.

As can be seen from Figure 10, the maximum stress of the clamping plate is 3.048 MPa, and the material of the clamping plate is aluminum. According to the Table, the yield strength of aluminum is 80 MPa, which is within the allowable stress range, so it meets the design requirements.

(2) Analysis of the transmission part

As can be seen from Figure 11, the maximum stress of transport components is 119.5 MPa, and the bar is made of low-alloy high-strength steel. According to the Table, the ultimate tensile strength of alloy steel is 448 MPa, which is within the allowable stress range. Therefore, the transport components meet the design requirements.

4. Conclusions
This paper proposes a design of a new smart bicycle three-dimensional garage, which has the characteristics of simple structure and space saving and is suitable for occasions with large bicycle flow and small occupation area, such as business center, streets with large human flow, schools, clubs, etc. [6]. At the same time, the system can regulate bicycle parking in accordance with national policy requirements. The standardized design will provide new ideas for regulating the bike garage industry. What’s more, with the complete process of bike storage, it is convenient, fast and applicable for most bikes. It is believed that the bike parking system will provide new ideas for the green development of the vehicle storage industry in the future.
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