Clamping Mechanism Design of Robot for Tower Hanging-Removing Anti-Falling Device

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Abstract. Aiming at the problem of high risk of manual hanging and removing safety ropes when tower overhauling workers are working at high altitude, we have designed a V-shaped angle steel symmetrical clamping mechanism which is mainly composed of clamping claw. The clamping and releasing of the angle steel of the clamping claw was realized by the cooperation of the screw elevator and the sliding guide rail. The abducting mechanism vertically arranged with the clamping arm can change the position of the clamping claw by adjusting the display distance, and the ejecting mechanism can ensure that the robot body is always parallel to the angle steel. The static model was established, and the static analysis and simulation of the clamping mechanism were carried out. Finally, the prototype was tested, and the experimental results verified the feasibility of the clamping mechanism design.

Introduction

In China, the number of power towers is large and widely distributed, and it has been exposed to harsh environments in the wild environment and even dusty, strong winds and high humidity[1]. In the traditional way, people climb the tower and the risk of detaching the anti-falling rope is extremely high. With the development of robot technology, various power special robots have successfully replaced the manual completion of tasks including transmission line inspection and live working[2]. However, the research on robots for climbing high-altitude anti-drop devices for climbing power towers is still blank. Therefore, it is especially important to design a robot that can carry out power power tower climbing to complete the safety rope connection and carry electric power inspection equipment.

In recent years, domestic and foreign scholars have conducted a lot of research on climbing robots such as power towers, three-dimensional trusses and trees. Shady3D robots can climb space trusses made up of rectangular sections[3]; Wu Weiguo and Xu Fenglin propose a two-armed robot that can freely climb space trusses; Balaguer C, Gimenez A et al. designed A six-degree-of-freedom two-arm articulated robot ROMA that can climb trusses made of rectangular or i-section steel[4].

The existing climbing robots mostly adopt tandem joint mechanism, which has good flexibility. However, the above robots are only suitable for climbing bars with regular structure, and do not have the ability to climb angle iron with irregular shape and different specifications[5].

This paper develops a power tower climbing robot that can effectively clamp the angle iron and complete the safety anti-falling rope straddle through the obstacles for the most widely used power towers in the transmission system. And it was subjected to mechanical analysis and experimental verification.

Robot Mechanism Design

Climbing Environment Analysis

As shown in Figure1, the obstacles encountered during the climbing of the main material along the
nailed side of the robot are mainly the outer angle angle fixing portion, the bolt fixing area, the joint plate at the joint, the foot nail and the angle iron superimposed area.

The robot developed in this paper can climb to the top of the tower along the side of the foot nail to complete the lifting of the safety rope. In the climbing process, the power tower climbing robot can overcome the obstacles such as nails, outer angle iron and bolts, nodal plates and inclined timber, reach the designated position, complete the hanging and dismantling operation and return to the ground safely, providing safety guarantee for the follow-up maintenance personnel.

**Climbing Robot Design**

Since the main obstacles on the tower are the nails, the angled steel and the bolts, the gusset plates, the slanting materials and the auxiliary materials, climbing and obstacle crossing are the basic movement functions of the tower climbing robot. To overcome the effects of these obstacles on the climbing process of the robot, it is necessary for the clamping jaws to open enough space in the direction perpendicular to the advancement direction to avoid interference between the claws and the angle joint.

Reference Angle between two opposite sides on the shackles interval is 450 mm, the adjacent two ipsilateral shackles interval is 900 mm, the minimum distance between two adjacent nodes is 925 mm, maximum distance of 1608 mm, but the minimum distance of node plate in the tower bottom, a certain height from the ground to start climbing robot, so the size cannot be considered, coupled with the node plate near the intersection of inclined material and advocate material space is limited, a vital need to avoid the robot movement. Based on the above factors, the original state size of the climbing robot is $800 \times 800 \times 1200 \, mm^3$, the maximum climbing distance of one step is $600 \, mm$, and the maximum movement speed is $0.06 \, m/s$. The structure scheme of the climbing robot is shown in Figure 2.

1 First clamping mechanism, 2 Linear motion mechanism, 3 Second clamping mechanism, 4 Mechanical arms, 5 Tower

**Figure 1.** Obstacles on the tower.

**Figure 2.** Three-dimensional diagram of the robot.
The robot must always be parallel to the main material of the angle iron during the climbing process. Only in this way can the robot be firmly clamped and climbed smoothly. However, since the angle iron is not perpendicular to the ground, and the robot can only clamp the angle iron alternately during the climbing process, the robot subjected to gravity may swing toward the inside of the tower. In order to solve the above problems, the upper and lower collinear ejection mechanisms are designed, and the ejection mechanism will always be placed on the angle iron and follow the robot to move.

**Design of Clamping Mechanism**

The gripper mechanism of power tower climbing robot is shown in Figure 4, which is mainly composed of gripper claws, abduction mechanism, ejection mechanism and fixed plate with symmetrical structures on both sides.

![Figure 4. Clamping mechanism model.](image)

1 reducer, 2 clamping screw nut pair, 3 clamping claw, 4 DC motor, 5 clamping arm, 6 outreaching arm, 7 rotating motor, 8 sliding guide pair, 9 ejector reducer, 10 ejector motor, 11 outreaching motor, 12 outreaching screw nut pair

The clamping mechanism is mainly composed of power system, transmission mechanism, abduction mechanism, ejector mechanism and clamping claw.

The clamping claw comprises two DC motors, two reducers, two screw nut pairs, two sliding guide rails pairs, two fixing claws and two moving claws. In order to increase the friction between the clamping claw and the angle steel, a rubber plate is respectively added on the inside of the fixing claw and the moving claw. The outreaching mechanism includes two stepping motors, two speed reducers, two screw nut pairs, two sliding rail pairs and baffles. The internal and external movement of the abduction mechanism allows the clamping mechanism to adapt to different types of angle iron, and at the same time, the clamping mechanism can be used to avoid obstacles. The ejector mechanism includes a stepping motor, a reducer, a screw nut pair, a fixing plate and a V-shaped top block. The ejector mechanism always tightens the angle iron to keep the parallel movement of the robot relative to the angle iron.

In order to ensure the rigidity of the clamping mechanism, aluminum alloy profiles are used for both the abducting arm and the clamping arm, and rubber-attached steel plates are used for the clamping claws. In addition, all connections of the robot are rigid connections, so the robot has good rigidity.

To further verify the performance of the clamping jaws, we used ANSYS Workbench finite element analysis software to carry out static analysis of its structure, the specific process: The model of Solidworks is to be introduced into the ANSYS Workbench—setting material properties—meshing—defining the contact relationship between parts—applying constraints and loads—generating analysis results. The deformation cloud diagram and stress cloud diagram are respectively shown in Figure 5 and Figure 6.
It can be seen from Figure 5 that the deformation of the clamping jaw is at the middle of both sides of the moving claw, and the maximum deformation is only 0.00057 mm, and the overall structure has almost no obvious deformation. this also verifies that the clamping mechanism we designed has good rigidity.

Figure 6 shows that the maximum stress position of the clamping jaw mechanism is located at the mating of the lead screw and the nut pair, which is also consistent with the actual situation. Because the clamping force provided by the moving claw is derived from the screw nut pair, during the process of clamping the angle iron, the moving claw will be subjected to the reaction force from the angle iron and transmitted to the screw through the nut. The contact area between the lead screw and the nut is small, so the stress at this position is large.

Through the above analysis and calculation, it is proved that the clamping mechanism can provide sufficient clamping force and can achieve the centering clamping of the whole machine, and then the clamping performance of the clamping force will be verified through experiments.

**Experiment and Analysis**

On the basis of the previous analysis, combined with the actual characteristics of the angle iron, the prototype of the power tower climbing robot was developed. In order to increase the friction, the rubber blocks were fixed at the front end of the clamping claw and the ejection mechanism of the robot. The total weight of the robot is 76 kg, the weight of a single clamping mechanism is 28 kg, the clamping mechanism and the whole machine experiment are shown in Figure 7.

Figure 7(a) is tests of single-claw clamping and machine climbing angle iron in a laboratory environment, the angle of the clamped steel is 150 mm (width) × 12 mm (thickness); Figure 7(b) is a climbing test conducted by the robot under actual iron tower conditions. The angle of the angle is 120 mm (width) × 10 mm (thickness).
Table 1. Prototype experiment results.

| Experimental project           | Number of experiment | Number of successful | Success rate |
|-------------------------------|----------------------|----------------------|--------------|
| single claw clamping          | 40                   | 40                   | 100%         |
| hind jaw clamping             | 40                   | 37                   | 92.5%        |
| front paw movement            |                      |                      |              |
| front jaw clamping            | 40                   | 36                   | 90%          |
| hind jaw movement             |                      |                      |              |

The driving ability of the robot driving motor was verified by clamping the hand clamping performance related experiments, and the bearing capacity and clamping ability of the robot clamping mechanism were verified. In the experiment, the clamping force of the single clamping mechanism of the robot can easily carry the weight of an adult. When the upper clamping mechanism clamps the angle iron, the lower clamping mechanism is loosened, and the lifting mechanism can move the entire lower machine stably. When the lower clamping mechanism clamps the angle iron, the upper clamping mechanism is released, and the lifting mechanism can also push the entire upper mechanism to move upward. In this cycle, a total of 40 experiments were completed, including 20 groups of robots climbing up and 20 groups of robots climbing down, and the experimental results were able to meet the expected requirements.

It can be seen from Table 1 and Figure 7 that the clamping force of the clamping mechanism of the power tower climbing robot is sufficiently large. The single-jaw clamping can withstand the weight of the whole machine and the reaction force generated during the movement of the robot, which can ensure the robot crawls stably on the tower. In addition, the clamping mechanism adapts to different types of angle iron by adjusting the exhibition distance of the exhibition mechanism and the opening distance of the clamping jaws of the clamping mechanism.

In the experiment, the whole machine debugging result is not as high as the single-claw clamping success rate. Because the main controller Trio has a problem during the whole machine debugging, it is always disconnected from the upper computer, and the instructions issued by the upper computer cannot be executed in time. Later After repurchasing the controller, the experimental success rate has also been significantly improved.

**Summary**

This paper proposes a robot for the power tower to hang the temporary high-altitude anti-drop device. The robot consists of two upper and lower clamping mechanisms and a linear motion mechanism. In order to verify the clamping performance of the clamping mechanism, corresponding experiments were carried out in the laboratory environment and the actual iron tower. The experimental results show that the clamping mechanism not only has good clamping performance, but also can clamp different angles of angle iron.

The clamping mechanism and the climbing robot will be further optimized to reduce the weight of the robot in terms of materials and structure. Sensors are added to the gripper to monitor the horizontal and vertical angles of the gripper relative to the side of the Angle steel to improve the performance of the gripper. The parallel movement of the robot body with respect to the Angle steel is maintained during the climbing process of the robot to improve the climbing stability and clamping accuracy of the robot.

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