Design of Climbing Robot for Power Transmission Tower Maintenance

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Abstract. Periodic maintenance of transmission lines is a necessary guarantee for stable power transmission and avoiding serious power accidents. In order to reduce the safety risk of the first person climbing the transmission tower and the last person going down the tower when climbing the transmission tower manually, this paper develops an auxiliary climbing robot for the maintenance of transmission tower based on the bionic climbing principle. It includes the modular mechanical structure of the main body lifting, obstacle crossing telescopic, terminal clamping, and body jacking, as well as airborne motion control system and hierarchical control system of upper computer monitoring terminal. The comprehensive test results of indoor and outdoor simulated transmission tower environment show that the robot system can effectively complete the high-altitude climbing of power tower, and ensure the follow-up tasks of hanging, dismantling, and maintenance of safety anti-falling device.

Keywords: Transmission tower, climbing robot, safety anti-falling device, end clamping

1. Introduction

Periodic maintenance of transmission lines is the necessary guarantee for stable power transmission and avoiding serious power accidents. In traditional circumstances, maintenance personnel needs to carry maintenance equipment, climb power poles and towers along the foot nail side, and patrol tower by tower, which not only has a long inspection cycle but also has great danger. Although gradually hanging the safety rope is the most effective safety protection measure, the first staff who climb the tower to install and the last to remove the safety rope hanging device can not get the safety rope falling protection. In the case of strong wind and dust, the falling risk of the climbing tower is very high[1].

Due to the high transmission tower, the path of the robot climbing along the main material of the tower is complex and there are many obstacles. At present, the climbing robot technology which can replace the manual maintenance of the transmission line is not mature. Therefore, it is of great significance to research and develop the installation and disassembly robot system of a temporary anti-falling protection device for a transmission tower. The purpose of the power tower climbing robot is to realize the installation of an auxiliary device for the first boarding personnel of the power tower. It can replace the manual installation of the auxiliary device, avoid the danger of manual installation of first boarding personnel, and ensure the accurate installation of the auxiliary device in various environments, improve efficiency and save cost[2].
In this paper, a robot system based on intelligent control technology for a temporary anti-falling protection device of transmission tower is developed. It includes the modular mechanical structure of the main body lifting, obstacle crossing telescopic, terminal clamping and body jacking, and the hierarchical control system of multi-sensor information acquisition, airborne motion control system, and upper computer monitoring terminal. The system can remotely control the climbing action of the robot body through wireless local area network (WiFi) communication, and effectively complete the task of installing and disassembling the anti-falling protection device with the assistance of video monitoring[3].

2. Mechanical system design

According to the analysis of the working environment and design indicators, combined with several commonly used attachment schemes of climbing robots, a symmetrical mechanical clamping mechanism is adopted to clamp the symmetrical angle steel of the tower to ensure the clamping reliability; secondly, the clamping mechanism is connected with the obstacle crossing telescopic mechanism to realize the obstacle crossing function; finally, the ejection mechanism is installed to support the main material of the tower to prevent the robot from producing in the climbing process tilt. The structure of the top block completely fits the equilateral angle steel of the main material, and steel balls are added in the internal groove of the top block to reduce the friction during climbing[4].

The robot body is mainly composed of the upper and lower bearing platforms. The two bearing platforms can move up and down in a straight line driven by the electric cylinder to realize the crawling operation of the robot body along the Z direction. Each bearing platform is designed with two pairs of independent telescopic mechanism and an end clamping mechanism. The two clamping mechanisms work separately and can move along the guide rail along the Y direction along the sliding block of the obstacle crossing telescopic mechanism so that the mechanical arm can expand outward to achieve the purpose of obstacle crossing. During the climbing process, two pairs of clamping mechanisms alternately clamp and release, and the main body moves vertically so that the robot's body can crawl along with the tower[5]. The overall structure of the robot is shown in the following figure:

![Fig. 1 Overall structure of the robot](image)

The end clamping mechanism is composed of a DC servo clamping motor, a screw rod, a clamping hand, an anti-skid rubber pad, and a guide rail. A locking nut is installed on the screw rod to fix it on the clamping hand at one end. The motor rotates to drive the screw nut forward and backward. The
clamping hand at one end that is not fixed slides along the guide rail with the screw nut to complete the loosening action of the clamping hand, so as to realize the clamping and releasing of the main material of the tower. Clamping structure is shown in the following figure:

![Fig. 2 Clamping structure](image)

The obstacle crossing the telescopic mechanism is composed of a stepping motor, screw rod, connecting plate of the end clamping mechanism, and guide rail. The clamping mechanism is installed on the sliding block of the obstacle crossing contraction mechanism, and a locking nut is installed on the screw rod, which is fixed at the bottom of the clamping mechanism[6]. When the motor rotates, it drives the screw nut to move forward and backward, and the whole clamping mechanism slides along the guide rail on the contraction mechanism, thus completing the outward and inward movement of the clamping mechanism and linkage with the body jacking mechanism, so as to avoid various obstacles on the main materials of the tower. Telescopic structure for obstacle crossing is shown in the following figure:

![Fig. 3 Telescopic structure for obstacle crossing](image)

The jacking mechanism is similar to the clamping and telescopic mechanism, including the ejection motor, the screw rod, and the connecting plate of the bearing platform. The top tightening motor drives the screw nut forward and backward to complete the action of clamping hand pushing out and fitting the main material, linkage with the telescopic mechanism, so as to avoid various obstacles on the main material of the tower[7]. The structure of the top block is the right angle, and the equilateral angle steel fully fits the main material. The steel ball is added in the inner groove of the top block to reduce the friction during climbing[8]. The top structure and end block are shown in the following figure:
The traveling lifting mechanism mainly includes the lifting electric cylinder. The vertical direction ejection and retraction of the electric cylinder cooperate with the alternate opening and closing action of the clamping mechanism and the obstacle crossing telescopic mechanism, so as to complete the climbing task of the whole climbing robot.

3. Control system
System control block diagram is shown in the following figure:

The whole working process can be summarized as follows:
1) The camera detects the environment around the robot and transmits information to the main controller. If there is no obstacle, it starts to climb;
2) Through the driving control module, the clamping mechanism of the upper manipulator of the robot is opened to both sides, and the abduction mechanism of the upper manipulator of the robot is controlled to move to the outside of the tower so that the upper mechanical arm of the robot is released relative to the tower;
3) Through the action of the lifting control module, the upper mechanical arm of the robot is lifted, and stops after reaching the set position. The driving control module controls the upper part of the robot to move towards the tower direction, and controls the upper part of the clamping mechanism to clamp the side of the tower;
4) Through the driving control module, the clamping mechanism of the robot's lower manipulator is controlled to open to both sides, and the telescopic mechanism of the robot's lower manipulator is controlled to move to the outside of the tower so that the lower manipulator of the robot is released relative to the tower;
5) Through the action of the lifting control module, the lower mechanical arm of the robot is lifted, and stops after reaching the set position. The driving control module controls the obstacle crossing telescopic mechanism of the robot lower mechanical arm to move towards the tower direction, and controls the lower part of the clamping mechanism to clamp the side of the tower;

6) Repeat steps 1) - 5).

The control flow chart is shown in the following figure:

![Control flow chart](image_url)

**Fig. 6 Control flow chart**

4. **Field experiment**

Through monitoring terminal, PC control robot body movement (gripper opening and closing, obstacle crossing telescopic arm opening and closing, jacking mechanism advancing and retreating, traveling electric cylinder telescopic and other actions), starting and stopping of drive system, motor speed and combination control function are tested. Through the remote control robot, the climbing task under the vertical environment and outdoor tower simulation environment test is completed. In the climbing process, all functional indicators are normal, almost free from electromagnetic interference, and there is no collision interference between the mechanical arms. The robot can remotely adjust the climbing work and keep it parallel to the main material of the tower. There is no sliding and falling phenomenon due to loose grasp, which meets the requirements of safe operation. The picture of the working site is shown in the following figure:

![The picture of the working site](image_url)

**Fig. 7 The picture of the working site**
5. Conclusion
This paper introduces the design of a climbing robot for the transmission line and describes the design of the mechanical structure and control system in detail. The developed robot system can climb along with the main material of the transmission tower under the remote monitoring of the operator. It can replace the manual climbing tower to carry out the hanging, dismantling, and maintenance tasks of the safety anti-falling device. The traditional operation mode reduces the risk of staff falling from the tower.

The system has a good prospect of promotion, and the structural design still needs to be optimized at this stage. The adaptability of a live working environment and intelligent obstacle crossing still need to be further studied.

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