Journal of Electronic Research and Application, 2025, Volume 9, Issue 3
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

An Automatic Charging Method for a 40kV Substation Inspection Robot

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Abstract: In a high-voltage environment of 40kV where no one is working, inspection robots must have an automatic charging system to ensure continuous operation. Currently, inspection robots operating in such high-voltage environments mostly use side-by-side alignment for docking. Given the existence of magnetic track navigation errors in robots, this docking method often fails to achieve successful docking. In response to this situation, this paper designs a new docking module.

Keywords: Inspection robot; 40kV; Hyperbaric environment

Online publication: 6 June, 2025

1. Introduction

The charging plug of the charging module is placed on the robot, and the charging socket of the robot is placed in a charging room. Two electric curtains are installed in the charging station, which are respectively for entering and exiting. The inspection robot does not need to turn around when entering and exiting.

2. Automatic charging module structure

The structure of the automatic charging module for inspection robots is shown in **Figure 1**. Typically, the robot is placed inside a charging chamber to be charged. When it receives an inspection command, the inspection robot sends a command to the microcontroller to retract the charging plug. Upon receiving the command, the microcontroller executes the corresponding operation, controlling the motor to drive the control push rod motor to perform the retraction action. During this process, the position of the push rod motor is fed back to the microcontroller via a limit switch. Once the retraction of the charging plug is complete, the plug separates from the charging base [1]. The robot then performs other initialization actions, such as turning on the camera. After all initialization actions are completed, the robot begins moving forward. When the control cabinet in the charging chamber detects that the robot is approaching the exit through a detection switch at the exit, it controls the roller shutter door at the exit to open. The roller shutter door closes after 20 seconds, which is sufficient for the robot to drive out of the roller shutter door [2].

When the inspection robot completes its patrol task, it returns to the charging room. When the control cabinet inside the charging room detects that the robot is approaching the exit through the detection switch at the entrance, it controls the roller shutter door at the exit to open. After 20 seconds, the roller shutter door closes, providing enough time for the robot to drive out of the roller shutter door. An RFID tag is set up at the entrance. When the inspection robot detects the tag, the industrial PC sends control commands to the microcontroller, causing the telescopic plug to be in a half-stretched state, ready for connection. When the charging plug is at the top of the charging socket, the limit switch at the front end of the charging plug precisely presses against the charging socket. Upon detecting the connection feedback, the microcontroller uploads the feedback information to the industrial PC [3]. After receiving the relevant feedback information, the industrial PC sends a command to the microcontroller to fully extend the charging plug, thus completing the charging connection. At this point, the industrial PC turns off the high-definition camera, infrared imaging device, and navigation thread. The inspection robot then enters a charging standby state [4].

A lithium battery charger is installed in the charging room control cabinet. The charger uses 220V AC power for the lithium battery. After the charging plug is connected to the charging socket, the charger charges the 48V lithium battery through the charging plug and socket. The 48V lithium battery charges the various hardware circuit boards of the robot through the robot power module.

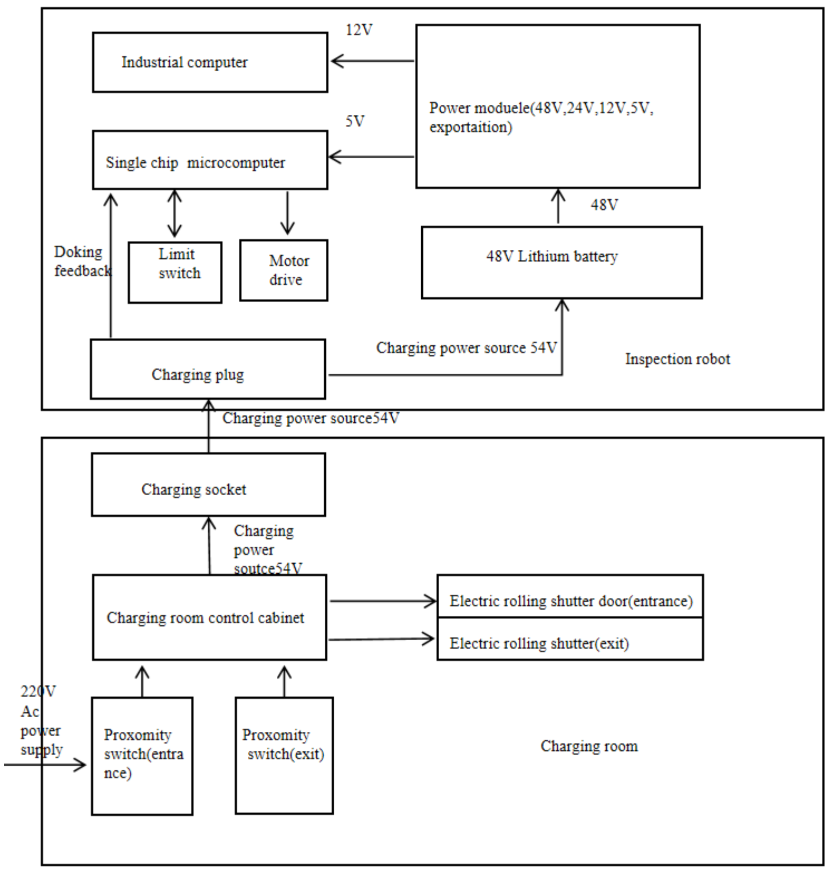

Figure 1. Block diagram of the automatic charging module

3. Charging plug and charging socket design

At present, most of the robots in use in the market adopt the side charging structure. The specific scheme is to put the robot charging plug inside the robot shell, and when it needs to be charged, it extends from the side of the shell to complete the docking with the charging pile.

In this solution, the vertical height of the robot's charging plug relative to the charging station is determined by the mechanical structure, ensuring consistency. However, it is difficult to maintain this consistency in the horizontal direction, as shown in **Figure 2**. The front-to-back direction on the horizontal plane, which is parallel to the magnetic track, can only be accurately positioned through the robot's recognition of RFID tags. However, there is a time lag between when the robot detects the RFID tag and when it stops, making it challenging to ensure precise positioning accuracy. Additionally, in the left-to-right direction on the horizontal plane, which is perpendicular to the magnetic track, the positioning accuracy relies solely on the robot's magnetic track navigation [5]. However, any deviation in magnetic track navigation could lead to positional errors on either side, directly affecting the effective contact area between the charging plug and the charging socket. Furthermore, if the magnetic track navigation of the inspection robot is over-tuned or responds too slowly, the charging plug and the charging socket will have a deviation angle, further increasing the deviation in the magnetic track direction and thus affecting the smooth connection between the charging plug and the charging station [6].

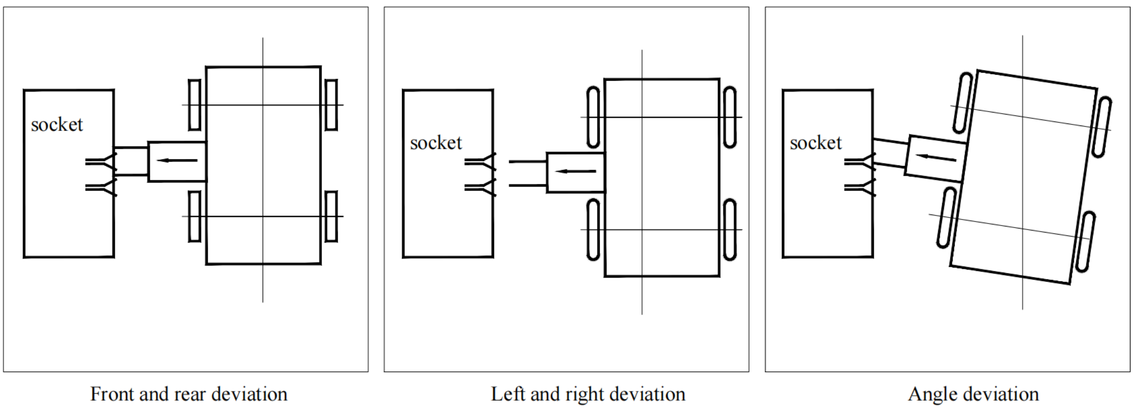

Figure 2. Charging docking deviation

In view of the above problems, this paper designs an automatic charging device for ground insertion. This method completes the charging docking through magnetic track navigation and mechanical guidance [7]. The mechanical guidance method is simple and reliable; in actual experiments, the docking success rate is extremely high. The charging device is shown in **Figure 3** below.

A device for automatic charging of a path-following robot, which moves along a magnetic track 10 on the ground, includes a plug 11 installed at the bottom of the robot and a socket 8 installed on the ground; both the plug and socket are equipped with limit switches 14; the plug has an electrode that can move up and down; the socket has a hole that matches the electrode; the input end of the main control system of the path-following robot is connected to the output ends of the plug and socket, and its output end is connected to the input end of the plug; the main control system of the path-following robot collects the status of each limit switch, determines the positioning of the plug and socket, and then controls the electrode of the plug to move downward and insert into the hole [8].

The plug consists of a push rod motor 5, the plug body 3, and the frame 4; the plug body is placed inside the frame with gaps left between it and the frame; two electrodes are set at the bottom of the plug body, with a conical inclined surface 6 at the front end of its bottom; a fourth limit switch 18 is installed on the inclined surface; the fixed end of the push rod motor is attached to the top of the frame, while its moving end connects to the top of the plug body; the plug body moves up and down under the drive of the push rod motor; the side of the frame sequentially has first to third limit switches 15,16,17 from top to bottom; the socket includes a base 9 fixed on the magnetic track on the ground, a guide rail 19, and a U-shaped guide plate 7; the guide rail is perpendicular to the magnetic track and is fixedly installed [9].

The base is described as follows: the U-shaped guide plate is connected to the rail through a spring 20 at its bottom; the opening direction of the U-shaped guide plate is opposite to the direction of the robot's movement; two holes that match the electrodes are set at the center of the U-shaped guide plate; a fifth limit switch 12 is placed between the two holes, and both holes contain electrode inserts connected to the power supply [10].

The push rod motor is a DC 24V motor, which controls the extension and contraction of the push rod through forward and reverse control.

The U-shaped guide plate is installed on the guide rail and can slide 20mm to the left and right.

The patrol robot is equipped with an RFID card reader, and the RFID card is fixedly installed on the ground of the charging area.

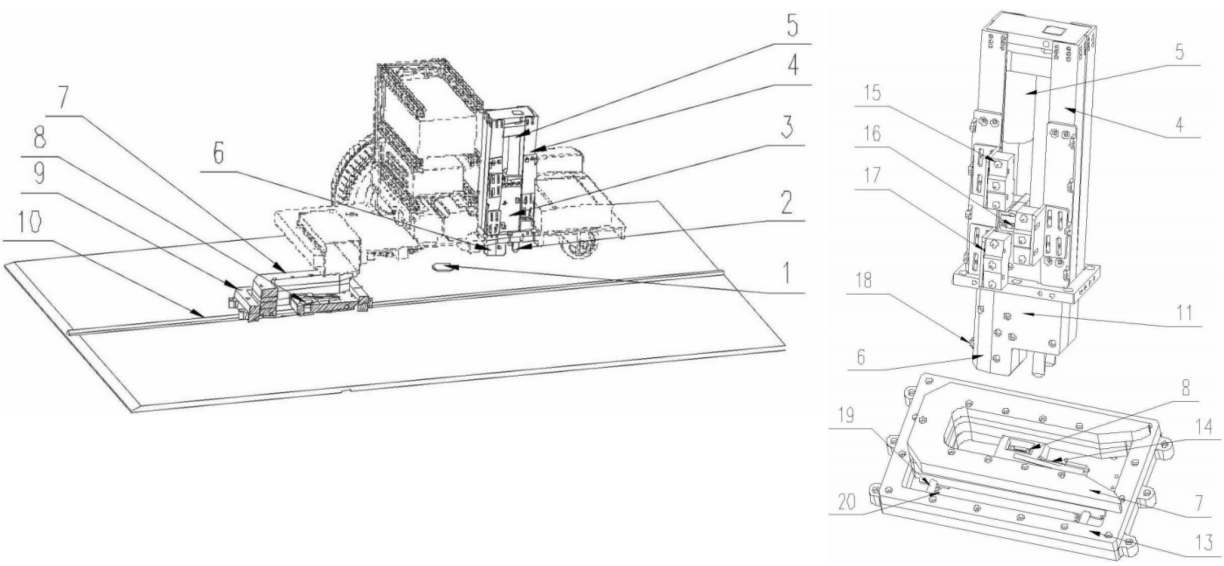

Figure 3. Left: Structure diagram of inspection robot; Right: Charging plug and charging socket structure diagram. Figure markings: 1, RF card; 2, copper plate; 3, plug body; 4, frame; 5, push rod motor; 6, inclined surface; 7, U-shaped guide plate; 8, socket; 9, base; 10, magnetic track; 11, plug; 12, fifth limit switch; 13, base; 14, limit switch; 15, first limit switch; 16, second limit switch; 17, third limit switch; 18, fourth limit switch; 19, guide rail; 20, spring.

4. Automatic charging process

When the patrol robot enters the charging area, the RFID card reader will read the signal emitted by the RFID card, and the main control system will determine that the patrol robot has entered the charging area, stop its forward movement, and control the push rod motor to drive the plug body to extend to the second limit switch, as shown in **Figure 3** above.

The main control system, upon detecting the signal that the plug body has touched the second limit switch, controls the inspection robot to continue moving slowly along the magnetic track at a low speed. The U-shaped opening faces the direction of the robot's movement, aligning with the inclined part of the plug body, allowing it to slide in smoothly. Since the inspection robot does not travel exactly centered along the magnetic track, there will be some lateral deviation. Therefore, the socket is designed with a horizontal guide rail that can slide left and right within a certain range, ensuring that the position of the socket matches the plug on the robot in the lateral direction; the bottom spring of the U-shaped guide plate returns it to the center, as shown in **Figure 4(a)**.

The fourth limit switch is used to determine the front and back direction of the socket position. When the plug body is in place, the fourth limit switch on the plug body presses on the U-shaped guide plate and feeds back the signal to the main control system, which controls the robot to stop moving forward, as shown in **Figure 4(b)**.

At this point, the main control system continues to drive the push rod motor to extend the socket body downward and insert it into the socket hole. Since the plug and socket have already determined their left-right and front-back positions, this ensures that the copper electrode on the plug is precisely inserted into the socket, completing the power connection and charging process; simultaneously, the fifth limit switch is pressed down, sending a feedback signal to the charging system to indicate proper charging, as shown in **Figure 4(c)**.

After charging is complete, the patrol robot restarts. The main control system activates the push rod motor to drive the socket body upward to the first limit switch. At this point, the plug body is pulled out and retracted to its highest position, with the first limit switch sending a signal back to the main control system. Under the control of the main system, the robot begins to move. The U-shaped guide plate of the socket returns to the center under the action of the spring, awaiting the robot's next entry into the charging chamber for recharging, as shown in **Figure 4(d)**.

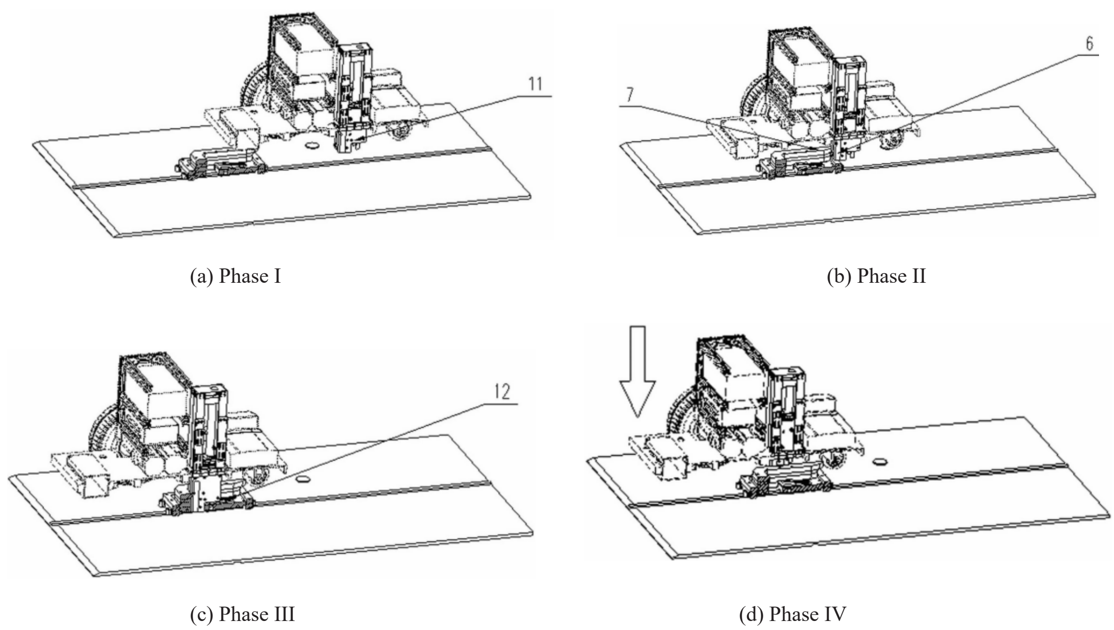

Figure 4. Four phases of the U-shaped guide plate

5. Conclusion

This paper mainly develops an automatic charging module for inspection robots. First, it provides the overall composition of the automatic charging module. Second, it analyzes potential deviations in traditional charging structures and presents an improved charging mechanism design. It also introduces the charging docking process of the automatic charging module.

Disclosure statement

The author declares no conflict of interest.

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