Design of A GIS Pipeline Robot for 220KV Substation

Wensheng Li¹, Zhipeng Jiang²,* and Liqiang Zhong¹

¹Electric Power Research Institute of Guangdong Power Grid Co.
²Changsha University of Science and Technology

*Corresponding author email: cslg@csust.edu.cn

Abstract. As an important development direction of substation equipment, a large number of GIS equipment are installed in the power system. Once the GIS equipment has internal faults, it is very inconvenient to find and deal with. This article designs a miniature maintenance robot for GIS equipment, which can be put into the busbar be through the GIS equipment maintenance hand hole cover; the robot has the ability to walk in the GIS equipment busbar tube; the robot carries a small camera device, which can check internal problems and return images; The robot is equipped with a manipulator, with vacuuming and grasping functions, which can complete simple cleaning and bolt tightening operations.

Keywords: GIS maintenance robot; Mechanical arm; Bolt fastening.

1. Introduction

According to the statistics of equipment failure types of State Grid Corporation from 2006 to 2015, gas insulated switchgear (Gas Insulated Switchgear, GIS) failures account for an increasing proportion, and the causes of failures are diverse, and the failure types are as large as possible There are 10 types, as shown in Figure 1.

![Figure 1. Statistics of GIS equipment failure types in the past 10 years.](image)

Among them, the number of discharge failures caused by foreign objects is more, reaching 29%, and the foreign objects inside the GIS are mostly free particle foreign objects[2-3].

In order to accurately obtain the internal status of GIS equipment in the maintenance work, there are currently two methods commonly used by various units: endoscopic method and robot method [4]. The periscope method is to fix the camera on a long pole that can be extended, and then extend into the GIS equipment to observe it. This method is relatively simple to operate. However, the periscope method
only achieves the inspection function and cannot carry out internal operations. In comparison, the robot is small in size, simple in operation, highly intelligent, and capable of carrying out maintenance operations, and has become the main research direction of all parties. Therefore, this paper proposes a method that can walk freely inside the pipeline of the GIS equipment bus and can climb up along the pipe wall. At the same time, it has a multi-functional inspection robot for internal inspection, cleaning and vacuuming, picking up foreign objects, and simple handling of bolts. Its innovation is that it can enter into the bus duct of GIS equipment through the handhole cover when the GIS equipment is in power failure for inspection, and it has the function of fault handling. It realizes the purpose of automatic inspection of GIS equipment bus duct, and does not disassemble or less disassemble GIS equipment bus duct during equipment maintenance. It is of great significance to improve work efficiency, save human resources and realize automatic maintenance.

2. Working Principle and Structural Design

2.1. How the Robot Works
The GIS pipeline maintenance robot is mainly used to detect the internal situation of the GIS pipeline, clean the metal debris and foreign particles in the pipeline, and fasten the joint bolts of the busbar section. When in use, the robot trolley is put into the pipeline through the pipeline access port, and the robot can be remotely controlled by operating the buttons on the hand-held control terminal.

2.2. The Overall Structure Design of the Robot
Robot structure design The robot is divided into two parts, a robot car (carriage) equipped with control circuit boards, mechanical arms, vacuum cleaners and other equipment, and a remote control box (control box) including a video server, data transmission, image transmission and exchange, the car and Signals and instructions are sent between the control boxes through the wireless communication module. The overall structure is shown in Figure 2:

![Figure 2](image)

**Figure 2.** The overall structure of the pipeline robot.

The trolley includes a body frame part, a controller circuit board, a vacuuming module, a wireless communication signal transmission module, a driving circuit and a walking wheel, a camera and image transmission, a battery, and a mechanical arm with replaceable end terminals. Its main function is to control the robot car to travel inside the GIS equipment bus section pipeline with a diameter of about 650mm, to detect the inside of the GIS equipment in real time through the video information returned by the camera and the image, and use the vacuuming module to process the metal fragments at the bottom of the GIS equipment. Chips, remove the bulky foreign objects and tighten the bolts by replacing the parts of the robot arm terminal.

Among them, the car body part is rectangular. The front section is equipped with a mechanical arm and a camera; the inside is equipped with a main control circuit board and traveling equipment, including the main control chip STM32 single-chip chip, motor drive and traveling wheel; the rear is equipped with a camera detection module and a dust suction module.
The main control chip STM32 inside the car controls the driving of the motor to achieve the purpose of controlling the travel and steering of the robot and the movement of the robot arm. The manipulator module is composed of a three-degree-of-freedom manipulator and a two-degree-of-freedom steering gear. The terminal part of the three-degree-of-freedom manipulator can be switched to electric grippers and bolt sleeves. Treat falling objects and bolts that need to be tightened [5-6].

The schematic diagram of GIS equipment maintenance robot is shown in Figure 3:

![Figure 3. Schematic diagram of pipeline robot.](image)

3. Robot Motion Control

3.1. Robot Drive Motor Selection

The choice of driving motor directly affects the working performance of the GIS maintenance robot. The main factors affecting the power of the robot drive motor include: the quality of the robot body, the size of the traveling wheel, the required speed, and various other resistances. To simplify the calculation, assume the following:

1. The robot travels inside the pipeline of the bus section of the GIS equipment with a tilt angle of $\alpha$;
2. The operating state of each drive wheel is the same.

Suppose the running speed of the maintenance robot in the normal travel of the GIS equipment is $v$, the acceleration of the robot is $a$, according to the analysis of kinematics, the driving force required for the robot to work normally is:

$$M = \sum_{i=1}^{n} M_i = \sum_{i=1}^{n} M_{il} + \left( m + \sum_{i=1}^{n} \frac{I_i}{R_i^2} \right) \frac{dv}{dt} + mg \sin \alpha + F_x + f_1$$

In the formula:
- $m$- the quality of the inspection robot itself;
- $M_i$- the driving torque of the motor;
- $M_{il}$- the friction resistance torque of the GIS equipment pipeline to the driving wheel;
- $R_i$- the radius of the driving wheel;
- $F_x$- the power required to walk inside the GIS equipment pipeline;
- $f_1$ - other resistance;
- $I_i \frac{dv}{dt}$ - the acceleration resistance of the robot.

According to the analysis of the driving force of the robot, the power $P$ of the driving motor is determined as:

$$P = \frac{KMv}{\eta}$$

In the formula, $K$ is the redundancy coefficient, $\eta$ is the transmission efficiency of the mechanism.
In this project, a 4 kg robot is set to advance at a speed of $v = 10 \text{m} \cdot \text{min}^{-1}$ in a GIS pipeline with a slope of 0, the radius of the robot drive wheel $r = 30 \text{mm}$, the friction coefficient $\mu = 0.5$, $K = 2$, $\eta = 0.65$, $F_z = 2\text{N}$, $f_i = 6\text{N}$. According to formula (1) and formula (2), the motor power is calculated as follows:

$$M = \frac{\mu mg + mgsi\alpha + F_z + f_i}{r}$$

$$= 0.5 \times 4 \times 9.8 + 4 \times 9.8 \times \sin 0^\circ + 2 + 6 = 27.6\text{N}. \quad (3)$$

The total power of the driving motor required by the pipeline robot is:

$$P = \frac{2 \times 27.6 \times 10}{0.65 \times 30} = 28.3 \quad (4)$$

According to the actual pipeline smoothness, the calculated dynamic value is slightly larger. Therefore, the design adopts four-wheel drive, and the drive motor power is 7W.

3.2. Robot Motion Control
Because the robot is walking in a smooth pipe, when the tire on one side is affected by the metal debris in the tube, it will cause some deflection in the direction of travel of the robot. When the robot is skewed, because the robot is parallel to the bus inside the pipe when it is running horizontally, you can observe whether the bus collected by the camera in the front is perpendicular to the cart through the robot. Adjust the PWM pulse width of the left and right wheels, and use the differential speed to force the car to turn to return to the horizontal position.

4. Image Processing
The in-tube state monitoring function of the trolley is mainly realized by image processing. First, the camera carried by the carriage head collects the image information on the bottom of the pipeline and the bus, and then transmits it to the host computer, and then the host computer grays the image. Processes such as valveization, image denoising, feature extraction, etc., make debris inside the pipeline easier to identify.

(1) Grayscale image
The image collected by the camera is generally a model of three color channels of RGB, that is, the three components of blue, green, and red are mixed in different proportions. Each component can obtain all color information, but this information occupies a large storage space and cannot be targeted at the image for mathematical calculations, it is necessary to process the RGB model into a single color channel model that is grayed. The formula is:

$$\text{Grayscale} = 0.229R + 0.587G + 0.114B \quad (5)$$

(2) Binarization
The pixel value $g(x, y)$ of each point of the grayscale image is between (0, 225), and a threshold $\Delta$ is set, then the binary image $f(x, y)$ is:

$$f(x, y) = \begin{cases} 225, & g(x, y) < \Delta \\ 0, & g(x, y) > \Delta \end{cases} \quad (6)$$

Due to the influence of pipeline environment and light, using a fixed threshold for image binarization cannot obtain satisfactory results. For this reason, we use the Otsu algorithm with adaptive threshold determination, which is simple to calculate and is not affected by image brightness and contrast.

(3) Image denoising
Due to the uneven light intensity in the tube and camera shake caused by the movement of the robot, the image quality is affected during the image acquisition process, so the source image must be denoised before image analysis. Field test results show that impulse noise is the most important noise that affects image quality. For this reason, we use the median filter algorithm, which is a typical low-pass filter that can effectively filter out spike interference in the image. The filtering algorithm is:
\[ Y(k) = \text{median}\{K(k - N), X(k - N + 1), \ldots, X(k), \ldots, X(k + N)\}. \] (7)

In the formula, ‘median’ represents the median operation.

(4) Feature extraction

When there is no various debris in the pipe, the pipe wall is a highlight area, and the depth of the pipe is a dark area, forming a circular area in the middle to distinguish it from the pipe wall. And when there are various scattered debris in the pipe, under the illumination of the lamp, the highlight area is formed like the pipe wall, and the more debris, the greater the highlight area. According to this feature, we propose the following method for extracting the characteristics of sundries:

In the binarized image \( f(x, y) \), if the value of a pixel is 0 or 1, the area \( S \) is:

\[ S = \sum_{m=0}^{m-1} \sum_{n=0}^{n-1} f(x, y). \] (8)

Center \( C \) is:

\[ C_x = \left( \frac{\sum_{m=0}^{m-1} \sum_{n=0}^{n-1} x}{S} \right), \quad C_y = \left( \frac{\sum_{m=0}^{m-1} \sum_{n=0}^{n-1} y}{S} \right). \] (9)

Where \( f(x, y) \neq 0 \), \( x \) and \( y \) are the coordinate values where the pixel value is not zero, and whether the current pipeline is determined by comparing the size of the current area \( S \) and the center \( C \) of the image with the size of \( S \) and \( C \) when the pipeline is empty. The presence of debris and debris.

Figure 4 shows the image recognition results of the empty pipeline and the pipeline with debris.

![Figure 4. The effect of foreign object recognition in the pipeline.](image)

The robot provides the identification result of the debris in the control box tube. The metal debris can be sucked through the dust suction module. When there is a large volume of debris, it can be processed by the mechanical arm.

5. Conclusion

Aiming at the current situation that new-type substations use GIS equipment more and more, but the maintenance work is extremely labor-intensive and material-intensive, this paper designs a GIS equipment pipeline robot to inspect and repair the GIS equipment bus section pipeline. The robot uses wireless communication to control actions through the control box, which can identify and handle debris in the tube, and design a mechanical arm to tighten the bolts. The field test proves that the robot can work stably and reliably in the GIS pipeline and has great use value.

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