A Flexible Connection System for Manipulator

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Abstract. At present, the intelligent inspection robot of substation can carry infrared thermal imager, visible camera and other related detection devices of power plant equipment, relying on magnetic navigation or laser navigation, along the established route of substation to achieve the detection of outdoor equipment. With the continuous deepening of the application of substation inspection robots, some higher requirements are put forward for the application of robots. How to complete the detection of indoor switchgear in substation by robots has become a key research direction in the industry.

Index Terms-- automation; manipulator; robot

1. Introduction

At present, the intelligent inspection robot of substation can carry infrared thermal imager, visible camera and other related detection devices of power plant equipment, relying on magnetic navigation or laser navigation, along the established route of substation to achieve the detection of outdoor equipment. With the continuous deepening of the application of substation inspection robots, some higher requirements are put forward for the application of robots.

Although the robot can complete detection of switch cabinet in substation by carrying a manipulator, due to the motion accuracy of the robot chassis, the manipulator cannot accurately locate on the surface of the switch cabinet. Under the above circumstances, the data detected by the robot is inaccurate and cannot meet the needs of substation routine detection.

In this paper, a new type of manipulator with flexible detection system will be discussed about how the robot detect the electrical cabinet.

In addition, in order to improve the detection accuracy of the manipulator, a new flexible connection system will be introduced and analysed in detail in this paper. Through this system, the detection equipment which is connected at the end of the manipulator can be accurately fitted to the surface of the switchgear cabinet.

Finally, in this paper we will compare the advantages and disadvantages of several different flexible connection systems through the actual application effect in the field, and finally choose the most suitable one for the detection of the light cabinet.

2. Detection of the electrical cabinet

2.1. Partial Discharge Detection Requirements

1. UHF

Partial discharge in switchgear will excite electromagnetic wave signals, which will propagate through air channel from the gap of switchgear cabinet or observation window. By placing the UHF
electromagnetic wave detection sensor in the slot or observation window of the cabinet, the partial discharge detection of the switchgear can be realized by displaying the numerical value of the instrument.

2. Ultrasound Partial Discharge Detection
The partial discharge in the switchgear will excite the ultrasonic signal, which will propagate through the air channel from the gap of the switchgear cabinet. By placing the non-contact ultrasonic partial discharge detection sensor in the slot of the cabinet body, the partial discharge detection of the switchgear cabinet can be realized by displaying the value of the instrument or converting the sound signal from the earphone.

3. TEV
Partial discharge in switchgear cabinet will excite electromagnetic wave signal, which will migrate rapidly from charged body to non-charged body. Due to the skin effect, electrons will only concentrate on the inner surface, but they will propagate along the discontinuity of the switch cabinet to the outer surface, and along the outer shell to the earth, thus creating a transient status to the ground on the outer shell. Transient potential changes can be detected by attaching the transient ground wave sensor to the switch cabinet shell, and then partial discharge detection of the switch cabinet can be realized.

2.2. Structure of switchgear
Compared with other indoor equipment in substation, the shape and structure of switchgear are more uniform, about 2000mm×800mm×1600mm, and the number of switchgear is much more than other equipment. Twenty switch cabinets with different functions are usually arranged in a control room. Therefore, in order to improve the efficiency of the robot, this paper will mainly discuss how to use the mechanical arm to detect partial discharge in switchgear.

2.3. Requirement of the detection of the switchgear
The paths of the three detection methods are shown in Fig1.

The requirements of the detection of the switchgear are summarized as follows:
1. Removing the height of the robot chassis, the maximum arm length or height of the manipulator should reach the height of 2200 mm of the electrical cabinet to meet the detection requirements of the bus area on the top of the switch cabinet;
2. Without increasing the difficulty of control, the manipulator should have enough degree of freedom to meet the requirement of full range detection of the electric cabinet plane;
3. The end of the manipulator needs to carry detection equipment, so the manipulator should have a certain end-bearing capacity, and not less than 2 kg;
4. In order to facilitate wiring and the design concept of simple and generous appearance, the manipulator should have enough internal space to make the control and power harness pass through the interior;
5. The manipulator should have a certain horizontal displacement ability to prevent the platform from deviating, and the manipulator can also be close to the electrical cabinet for detection;
6. The end of the manipulator should have corresponding structure to ensure that the testing equipment can be closely attached to the surface of the electric cabinet.
3. Model of the manipulator and flexible connection system

3.1. Model of the manipulator

The mechanical arm must have two degree of freedom which can satisfy the requirement of the detection of ultrasonic. The principle diagram of the manipulator to do the ultrasonic detection is shown in fig 2.

![Figure 2 Principle diagram of the ultrasonic detection of the manipulator](image)

The structure of the switch cabinet is simplified as shown in the figure. The length of the manipulator is A, the width of the switch cabinet is W, and the height of the switch cabinet is H. If the arm needs to meet the needs of ultrasonic detection, it needs a point A at the end of the arm to reach any position in the flat bolt where HW is located.

The manipulator needs to be mounted on the chassis of a certain kind of robot. In order to transport conveniently and pass better, the manipulator should be retracted to the chassis of the robot as far as possible when it is not in use, and the manipulator should be extended when it is tested.

Under the control of the manipulator, the sensor needs to complete three detection contents of ground wave, ultra-high frequency and ultrasound at one time. In order to keep the integrated partial discharge detection sensor in the correct position and posture, for example, in ultra-high frequency detection, when the sensor needs to be aligned with the observation window, it needs to add a degree of freedom of rotation at the end of the manipulator.

In order to adapt to switch cabinets of different types and heights and GIS equipment that may need to be tested in the future, a vertical degree of freedom should be added to the manipulator.

1. Horizontal movement: to ensure that the mechanical arm can be close to the surface of the switch cabinet;
2. Vertical lifting descending: adapting to different detection equipment, and further optimizing the length of the manipulator;
3. Three degrees of freedom of rotation: control the detection position of the partial discharge sensor, and adjust the attitude of the partial discharge sensor to meet the detection requirements.

According to the above calculation results, the final model of the manipulator is built up by SW, as shown in Figure 3.
In order to improve the detection efficiency and reduce the load to the greatest extent, this paper does not use a 6-DOF manipulator to drive, although the 6-DOF manipulator can theoretically achieve all kinds of detection actions perfectly.

3.2. Flexible connection system based on air spring

Air spring is filled with compressed air in a sealed container, and its elastic effect is realized by the compressibility of gas. The load capacity of air spring is large, and it can be selected according to the load at the end of the manipulator, which is shown in fig 4.

According to the requirement of 2kg load at the end of the manipulator, four air springs with 0.6kg load are selected to connect the manipulator and the discharge sensor in this paper. The final structure schematic diagram of the flexible connection system of the manipulator based on air spring is shown in figure 5.

3.3. Substation-test of air spring flexible connection

After the prototype is completed, the flexible connection system based on air spring is tested in substation.
The manipulator with flexible connecting system which is based on air spring can successfully complete UHF and Ultrasound partial discharge detection. However, due to the restriction of air spring travel, when the angle between the vertical detection datum of the manipulator and the switch cabinet plane is too large, there will be a situation which one side of the sensor will shrink completely[1]. As the same time, the other side will still not fit on the switch cabinet surface, so it is impossible to detect the partial discharge of ground wave in switch cabinet[2].

Obviously, this kind of flexible connection which is based on air spring can’t fully adapt to the partial discharge detection of substation indoor switchgear.

3.4. Flexible connection system based on cardan link
In order to further improve the accuracy of partial discharge (Ground Wave) detection, a new type of flexible connection system is designed in this paper. The design inspiration of this system comes from the joystick which is used in the PC game, as shown in fig 7.

This lever can tilt at any angle in three-dimensional space and automatically restore to the initial position under the action of spring. The application of different loads can be realized by adjusting the spring elastic factor. The detailed structure of this flexible connection is shown in figure 8.

Figure 6 Test effect diagram of air spring flexible connection system

Figure 7 Schematic diagram of PC-Game joystick
According to the requirement of 2kg load at the end of the manipulator, in this paper, spring with diameter of 1.5mm and 6 coils is selected as reset spring. The final structure schematic diagram of the flexible connection system of the manipulator based on cardan link is shown in figure 9.

Relative to the type of air spring, cardan link flexible connection system can fully adapt to the partial discharge detection of substation indoor switchgear, the test effect diagram of cardan link flexible connection system is shown in fig 10.

3.5. Substation-test of cardan link flexible connection
After the prototype is completed, the flexible connection system based on cardan link is tested in substation.

The manipulator with flexible connecting system which is based on cardan link can successfully complete all the partial discharge detection, and the total weight of the connecting system is lower than the air spring type, which is beneficial to reducing the actual load of the manipulator and improving the endurance of the robot.

Relative to the type of air spring, cardan link flexible connection system can fully adapt to the partial discharge detection of substation indoor switchgear, the test effect diagram of cardan link flexible connection system is shown in fig 10.

3.6. Kinematic analysis of three Mecanum wheel driven platform
As it is really inconvenient to do the modeling in the Adams, so in this paper, Solidworks model will transform into kinematic modeling by *.X_T format. *.X_T is a more stable format, in particular, is not easy to lose parts.

After building up the modeling, the model material properties should be defined. Different material properties, corresponding to different elastic modulus and Poisson's ratio, have a direct impact on the results of kinematics simulation. In this paper, the material of the platform is defined by Aluminum.

In order to analyze the kinematic characteristics of the system, four pressure sensors are added to the four corners of the sensor, which is shown in fig 11, 12, when the pressure sensor has a numerical value, it proves that the angle of the sensor has touched the surface of the light cabinet.

![Figure 11,12 Kinematics model of this system](image)

As shown in fig 13, when the system moves slowly towards the switch cabinet, under the action of rigidity, point 4 and point 5 contact with the switch cabinet of the switch cabinet and pop up quickly. As shown in fig 14, after point 4 and point 5 and switch cabinet, the system continues to move forward, then point 2 and point 3 contact with switch cabinet and quickly pop up, the last four points are all close to the switch cabinet, at this time, the pressure increases continuously until the end of the system movement[5].

![Figure 13 Kinematic analysis of the point 4 and point 5](image)

![Figure 14 Kinematic analysis of the point 2 and point 3](image)

4. Conclusion
- Compared with other indoor equipment in substation, the shape and structure of switchgear are more uniform, and the number of switchgear is much more than other equipment. Twenty switch cabinets with different functions are usually arranged in a control room. Therefore, in order to improve the
efficiency of the robot, this paper will mainly discuss how to use the mechanical arm to detect partial discharge in switchgear.

- In this paper, there is study about how to detect partial discharge of indoor switchgear in substation.
- In this paper, two new type of flexible connection system is invented. The whole research process includes the determination of the degree of freedom of the manipulator, the choice of the key part of the flexible connection system, the 3D modeling of the flexible connection system, and so on.
- Through field test, the cardan link flexible connection system can successfully complete all the partial discharge detection (UHF, ultrasonic, Ground wave), the application effect is much better than the air spring flexible connection system.
- Based on the kinematics simulation analysis software, this paper simulates the process of the elastic system closing the switch cabinet, and verifies that the system can fully fit the switch cabinet.

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