Research on the Deicing Robot and Motion Characteristic of the Four Divisions High-Voltage Line

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Abstract. This paper is aimed at the problem of less dehumidification robot for four-split high-voltage line and with some obstacle-removing ability and high efficiency de-icing, developed a four-split high-voltage de-icing robot with barrier capability. Based on the combination of theoretical calculation and virtual prototype simulation, this paper focuses on the key technology of robot, the overall structure design and virtual prototype modeling, and the rigid-flexible coupling of the robot under flexible high voltage line. The Lagrangian method is used to establish the rigid and flexible coupling dynamics model of the robot. The ADAMS dynamic simulation software is used to simulate the obstacle process of the robot to test the rigid and flexible coupling stability of the robot. Through the simulation results, it can be seen that the vibration of the robot in the process of obstacle crossing, by the high-voltage flexible, with the high-voltage lines along the vibration, the vibration in the direction of the space to meet the stability requirements.

1. Introduction

At present, China's long-distance power transmission capacity and operating voltage level continues to increase, to high pressure, high pressure, and even special high pressure direction. High-voltage transmission lines exposed to contact with the outside world and most of the harsh areas in the environment, the biggest challenge is the high ice [1]. With the continuous development of robot technology, the use of robots on the transmission line de-icing has become possible. Compared with the traditional de-icing method, the use of robots for high-voltage lines for de-icing with no casualties, no need to transfer load and power outages [2]. Therefore, the development of a four-split high-voltage line and has a high degree of autonomy navigation and barrier capability of the de-icing robot has important significance.

Many scholars at home and abroad have attached great importance to the technology related to the grid, and have made many researches on the maintenance and deicing of the high voltage transmission line [3]. 2004 to 2010, Shenyang Institute of Automation, Chinese Academy of Sciences (SIACAS) developed three generations of high-voltage line inspection robot [4-7], Respectively AApe-A, AApe-B, AApe-C. 2006 to 2010 Canada Quebec Hydroelectric Research Institute Serge Montambault, Nicolas Pouliot, who developed the high-voltage line inspection robot LineScout mobile platform. 2008 Tokyo Technical University of Japan [8] developed a four-split high-voltage line inspection robot Expliner. 2010 Wuhan University Professor Wu Gongping research team
developed a 220kV high-voltage transmission line of de-icing robot [9]. 2013 Shandong Electric Power Research Institute (SEPRI) [10, 11] has improved the LineROVer de-icing robot to optimize its performance. 2006 University of Illinois at Chicago, USA Sugiyama [12] and so on the absolute node coordinate method. The flexible body is discretized by a uniform mass finite element method. 2008 Iranian Sheriff University of Technology Zohoor H and Khorsandijou S M [13] the nonlinear dynamic model is established by Hamilton principle. The floating coordinate system is chosen as the tangent coordinate system to study the flexible structure. 2011 Harbin Institute of Technology Yang Zhengxian, Kong Xianren and so on[14].Based on the basic theory of continuum mechanics, an efficient and high-precision approximation rigid-flexible coupling dynamic model for the design of the actual control system is established for the flexible body. Peking University, Tianjin University, Northwestern Polytechnical University, Huazhong University of Science and Technology, and many other famous universities in China, in the field of rigid-flexible coupling dynamics of their respective research, and achieved some research results.

2. Design of de-icing robot

Deicing robot debris barrier - walking mechanism is a barrier mechanism and the organic combination of walking, when the obstacle is not encountered, the robot moves along the high voltage line, encounter obstacles through the obstacle barrier through the obstacles. The obstacle mechanism of the robot is a humanoid robot designed according to the principle of bionics, and the walking mechanism is installed at the end of the robot arm.

When the robot is on-line for de-icing, the front drive arm and the rear drive arm are suspended from the two high-voltage lines on the underside of the four-split high-voltage line, the drive wheels at the end of the intermediate auxiliary arm are located below the two high-voltage lines on the underside of the four-split high-voltage line, and the front end of the arm, the rear end of the robot arm drive wheel with each other to match the high-voltage line, the robot walking process, to prevent the robot fall. It’s work as showed in Figure 1, where the part one is percussion deicing, part two front arm, part three auxiliary arm, part four back-end robotic arm, part five Center of gravity adjustment.

![Figure 1. The overall scheme of virtual prototype of deicing robot](image1)

![Figure 2. Robot arm motion diagram](image2)

The key technology of the de-icing robot is the obstacle function of the robot, and the robot movement diagram is shown in Figure 2. In summary, the robot arm I consists of a robot support platform (base), shoulder joint, arm, elbow, arm, wrist and drive wheel. There are five degrees of freedom in the arm I, followed by the rotation and pitch of the shoulder joint, the pitch between the arms and the joints, the pitch between the arms and the arms, the pitch and rotation between the wrist and the arm. In order to meet the robot in the obstacle position on the requirements of the position, the arm of the joints of the pitch angle and rotation angle should meet a certain range of motion. The motion parameters are shown in Table 1.

| Joint | Pitch/rotation angle | Movement range |
|-------|----------------------|----------------|
| 1     | $\theta_1$          | $-90^\circ$–$90^\circ$ |
| 2     | $\theta_2$          | $30^\circ$–$180^\circ$ |
| 3     | $\theta_3$          | $0^\circ$–$180^\circ$ |
| 4     | $\theta_4$          | $90^\circ$–$270^\circ$ |
| 5     | $\theta_5$          | $-90^\circ$–$90^\circ$ |
3. Simulation method

3.1. The rigid and flexible coupling dynamics model of the robot is established

Consider the elasticity of the flexible high-voltage line caused by the elastic force of virtual work, acting on the flexible high-voltage line of all the power of virtual power:

\[ \delta W = \delta U + \delta W_e = -q^T K \delta q + F^e \delta q = F^e \delta q \]  \hspace{1cm} (1)

Where: \( F = -qK + F_e \), \( F_e \) is generalized force vector associated with generalized force coordinates \( q \).

According to the Lagrangian function and the generalized force vector, the Lagrangian kinetic equation of the flexible high voltage line can be obtained [15]:

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}} \right)^T - \left( \frac{\partial L}{\partial q} \right)^T = F \]  \hspace{1cm} (2)

The constraint equation for the complete constraint is:

\[ C(q,t) = 0 \]  \hspace{1cm} (3)

In a socioeconomic constraint, the constraint relation is velocity dependent and not integral, Select the appropriate Lagrange multiplier vector \( \lambda = [\lambda_1, \lambda_2, ..., \lambda_n]^T \), make

\[ \lambda^T C(q,q,t) = 0 \]  \hspace{1cm} (4)

Among them: \( n_c \) - The Number of Mechanical System Constraint Equations. Equation (4), (3) and (2) are combined to obtain the rigid and flexible coupling dynamic equations of the robot with contact constraints.

\[ \begin{align*}
    \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}} \right)^T - & \left( \frac{\partial L}{\partial q} \right)^T + C^T(q,q,t) \lambda = F \\
    C(q,t) &= 0
\end{align*} \]  \hspace{1cm} (5)

3.2. Stability analysis of rigid - flexible coupling based on ADAMS

Robot in flexible four-split high-voltage line walking de-icing process, the de-icing device in the percussion process, percussion shock on the high-pressure line shaking less impact. In the process of obstacle crossing, the front end of the manipulator needs to extend forward and the motion amplitude is large, which will affect the deformation and shaking of the flexible four-split high-voltage line, thus affecting the spatial position of the robot's center of gravity.

The influence of the obstacle process and the flexible high voltage line on the spatial position of the robot's center of gravity is analyzed by the rigid-flexible coupling simulation of the robot by ADAMS. The flexible four-split high-voltage line with the actual span is simplified, and the flexible four-split high-voltage line model with a 10m pitch is established. The influence of the dancing of the flexible high-voltage line on the stability of the robot is simulated, Robot and flexible four-split high-voltage rigid-flexible coupling model showed in Figure 3.

![Figure 3. Rigid and Flexible Coupling Model of Robot and Flexible High Voltage Line](image)

When the robot hangs on the flexible four-split high-voltage line, the de-icing robot's rear-end arm drive wheel, the middle arm drive wheel and the flexible high-voltage line contact, the robot's spatial
position will change with the flexible high-voltage line dancing. Robot and flexible four-split high-voltage line rigid-flexible coupling obstacle process is shown in Figure 4 (a) ~ (d).

(a)  
(b)  
(c)  
(d)  

Figure 4. Robot Rigid and Flexible Coupling

4. Simulation Results and analysis
Taking the overall center of gravity of the robot as the reference point, the spatial position change of the robot is analyzed by the change rule of the reference point spatial position. The vibration of the reference point lateral vibration, the vertical direction vibration and the horizontal direction (the movement direction of the robot along the high voltage line) are as showed in Figs. 5 (a) ~ (b).

(a)  
(b)  

Figure 5. The vibration amplitude curve of each direction of the center of gravity of the robot

The center of the middle arm drive wheel is in the same vertical plane as the center of gravity of the robot, that is, the inclination angle of the robot is zero. The center of the middle arm drive wheel is in the same vertical plane as the center of gravity of the robot. High-pressure line dancing usually caused by the robot as a whole with the high-voltage line with the side of the swing, fluctuation within the vertical ups and downs, generally does not affect the lateral side of the robot; the lateral inclination of the robot is mainly caused by the wind load acting on the windward surface of the robot. As showed in Figure 6.

Figure 6. The lateral vibration curve of the center of the robot and the center of the middle arm drive wheel

Flexible four-split high-voltage line in the natural wind under the action of the dancing phenomenon, the impact of high-voltage line dancing on the robot from Figure 5, the direction of the center of the robot vibration curve analysis shows that. It can be seen from Figure 5 (a) that the whole center of gravity of the robot vibrates in the lateral direction, that is, the robot oscillates laterally, and the vibration amplitude is about 60mm.

From the analysis in Figure 5 (b), it can be seen that the speed of the center of gravity in the vertical plane is 350mm ~ 600mm under the influence of the flexible high voltage line, and the vibration process Although the vibration amplitude is large, but no mutation, the robot with the high voltage line vibration, the robot will not fall off.
It can be seen from Fig. 6 that the distance between the center of gravity of the center of the robot and the center of the drive arm is the distance between the center of gravity of the robot and the center of the center arm drive wheel, that is, the length of the middle arm \( l_1 = 1860 \text{mm} \). Lateral Inclination:

\[
\theta_1 = \arcsin \frac{\Delta y}{l_1} = 1.54^\circ
\]

By means of ADAMS, the lateral inclination angle \( \theta_1 = 1.54^\circ \) of the robot is consistent with the inclination angle \( \theta < 5^\circ \) of the robot under the action of wind load, and it is proved that the rigid-flexible coupling dynamics of the robot by ADAMS. The accuracy of the analysis results, and the rigid and flexible coupling stability of the robot to meet the work requirements. This paper does not analyze the vibration under interference of wind because the de-icing robot is operating without wind.

5. Conclusion

The robot's soft motion analysis under the condition of flexible high voltage line, the robot's own movement and the wind load will cause the robot and the high voltage line to shake, need the robot has certain stability, to ensure the robot normal work. Firstly, the flexible model of high voltage is analyzed, and the rigid and flexible coupling equations of the robot under flexible high voltage line are established, which lays the theoretical foundation for the rigid and flexible coupling analysis of the robot. Based on ADAMS, the stability of the rigid and flexible coupling of the robot is analyzed. Finally, the stability of the robot is verified by the stability of the robot.

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