Design of Obstacle Avoidance Mechanism of Magnetic Levitation Type Inspection Robot for High Voltage Lines

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Abstract. An obstacle avoidance mechanism is designed for the operation mode and the overall structure of high-voltage power lines inspection robot based on magnetic levitation principle. The mechanism is composed of a planar linkage mechanism and a screw nut mechanism with two degrees of freedom. Through the control of two of the original, the robot has a function of opening the shell and obstacle avoidance. The mechanism is simple and occupies less space with flexible movement, compact structure, to meet the requirements of obstacle avoidance to avoid vibration hammer, clamp, straight line towers and other obstacles effectively which solved the contradiction between the small space in the robot and the obstacle avoidance requirements. Two prime bar linkage relationships is obtained according to static analysis of the mechanism. Finally, by means of Kinematics simulation of the obstacle process through Pro/E software, the feasibility of the institution obstacle scheme is verified.

1. Introduction
The inspection robot of overhead high-voltage transmission line has become the research hotspot in the field of robot at home and abroad\textsuperscript{[1-9]}. In our country, in order to meet the needs of development of smart grid, robots in the field of inspection of the high voltage transmission lines become more and more attractive. However, inspection robots developed at home and abroad mostly adopt wheel-arm composite structure with disadvantages such as large size, heavy body, weak capacity of anti-wind. Most of all, the wheel type mobile mode is with low efficiency and often with the problem of slipping.
In paper\textsuperscript{[10]}, according to above problems, a scheme of magnetic levitation type inspection robot was proposed. The scheme used the magnetic field around high voltage direct current wires to realize the function of magnetic levitation based on ampere force, which could make the robot suspended on the high voltage wires and drive the robot to move by ampere force. The scheme of magnetic levitation type inspection robot could not only greatly improve the robot's cruising speed and eliminate slipping problem but also cancel traditional motor, private servers, transmission device and cantilever structure, which could greatly reduce the weight of the robot. To adapt to the operation mode of magnetic levitation, paper \textsuperscript{[10]} proposed the overall structure of the cylindrical shape of the magnetic levitation inspection robot, which is compact in structure, small in size and strong in wind load resistance.
In engineering application, the high voltage wire is mostly made of steel core aluminum strand, which has the characteristics of sufficient mechanical strength and high tensile strength, etc. For the light-type magnetic high-voltage line inspection robot, the deformation of the high-voltage wire can be neglected within the size range of the body. Aiming at this new type of light-duty maglev inspection robot, a set of planar connecting rod mechanism is designed in this paper, which is used for the magnetic inspection robot to cross the obstacles such as vibration hammer, pressure pipe and overhanging line clamp, so as to improve the inspection range of the robot.

2. Introduction of magnetic levitation type inspection robot for high voltage lines
The robot ontology (the magnetic levitation system is left out, as shown in figure 1) can be seen as two semicircular pellet shells hinged. Cross obstacle mechanism is installed in the shell with the functions of opening body, flipping guide wheel, avoiding obstacles, etc. In the absence of the operation phase, obstacle avoidance mechanism is closed. The robot is moving fast on the high voltage wire under the action of magnetic levitation force and magnetic force. At this point, the guide wheel is located above the high voltage wires, and has no contact or has a contact but no mutual forces, which plays a safety protection role to prevent the robot from accidental falling. When the robot encounter obstacles, the body of the robot is open. Magnetic levitation system cannot make an efficient use of the magnetic field around high voltage lines. At this point, the ampere force is not enough to balance the gravity of the robot and to provide the robot with forward thrust. When the wheel is in the lower level, it also has the effect of balancing the robot gravity and driving forward.

3. The constitution of mechanism
As shown in figure 2, No.1, 3, 4, 6 are the bars, and No.2 is the guide pulley. No.5, 7 are the lead screw nut mechanism. No.5 is the lead screw and No.7 is the nut. The rods are hinged together. The degree of freedom of the mechanism is 2. Servo motor M1 is added to the lead screw 5. Servo motor M2 is added to the hinge between the rod 3 and 4. There is a linkage between the two motors which could control the robot box closed or open and the rotary motion of the guide pulley.

4. Obstacles analysis
In the front of the tangent tower, the vibration damper is usually arranged to cushion the impact of levitated high voltage line swing on the linear clamp. The structure of the vibration damper and the pressure line clamp has been standardized, and the line clamp protrudes 3-5mm above the high voltage line. The vibration damper is suspended under the high voltage line through the line clamp, which hinders the robot's progress. The tangent tower pulls the high voltage lines with large span vertically through insulator strings and wire clips, which could slow down the swagging caused by large span and insufficient tension. The insulator strings are directly above the high-tension wires, which hinders the robot's inspection of high voltage wires.
5. Structure analysis of obstacle crossing mechanism

5.1. Geometrical relation

To simplify the obstacle avoidance mechanism, the motion diagram is shown in FIG. 3. At any moment, the mechanism has a certain relative geometric relation:

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\begin{align*}
\cos \alpha &= \frac{l_x^2 + l_y^2 - l_z^2}{2l_xl_z} \\
\cos \beta &= \frac{l_x^2 + l_z^2 - l_y^2}{2l_xl_z} \\
\cos \gamma &= \frac{l_x^2 + l_z^2 - l_y^2}{2l_xl_z} \\
\cos (\alpha + \beta) &= \frac{l_x^2 + l_z^2 - l_y^2}{2l_xl_z} \\
\end{align*}
\]

(1)

In the equation, \(l_x\) is the relative distance between the nut and the hinge \(E\). \(n_x\) is the rotate speed of the lead screw \(l_z\). The torque is provided by servo motor \(M_1\). \(p\) is the thread pitch.

According to the above equation, we can confirm that the function relationship between \(\gamma\) and \(l_x\) is \(\gamma = f(l_x)\). The linkage between servo motor \(M_1\) and \(M_2\) can ensure the function relation between \(\gamma\) and \(l_x\), which means that the movement of the mechanism and the posture of the robot are determined solely. In the process of the mechanism from closing to opening, the corresponding relations between \(l_x\), \(\beta\) and \(\gamma\) are calculated by Matlab software as follows:

| \(l_x\) | 50.0704 | 51.5506 | 53.0308 | 54.5110 | 55.9912 |
| \(\beta\) | 2.1478 | 9.8719 | 13.5195 | 16.1597 | 18.2491 |
| \(\gamma\) | 44.6557 | 73.0230 | 88.1879 | 100.4266 | 111.3005 |
| \(l_x\) | 57.4714 | 58.9516 | 60.4318 | 61.9120 | 63.3922 |
| \(\beta\) | 19.9727 | 21.4287 | 22.6770 | 23.7575 | 24.6989 |
| \(\gamma\) | 121.5191 | 131.5956 | 142.1268 | 154.3366 | 180.0000 |
Note: $l_\beta$ is the relative distance between the nut and the hinge $E$. $\beta$ and $\gamma$ are the degrees of the angles.

At any moment, the corresponding relation between $l_\beta$ and $\gamma$ is drawn by Matlab software as figure 4.

As long as servo motor $M_1$ and $M_2$ is controlled and the linkage between $l_\beta$ and $\gamma$ satisfy the relationship shown above, the relative motion of the mechanism can be determined and the guide wheel can be kept upright.

5.2. Preparations before crossing obstacles
The robot slows down before encountering obstacles and stops in front of them. The motor $M_1$ drives the lead screw to rotate. At the same time, the other motor $M_2$ makes $l_2$ and $l_3$ rotate relatively according to the linkage relation $\gamma = f(l_\beta)$. Three groups of obstacle avoidance mechanisms distributed in the robot slowly open, making the robot always in a state of dynamic balance. The mechanism changes from closing state to open state. At this point, the bar $l_2$ and $l_3$ are both on the same line and in the self-locking state. Screw-nut pair also has self-locking function. The function of two self-locking mechanisms enables the obstacle avoidance mechanism to maintain its original posture under the action of gravity. On the one hand, the guide pulley is in good contact with the high voltage line, so that gravity can provide the positive pressure of the wheel and the line. The friction of the high voltage line provides the driving force forward when the regulating wheel rotates. On the other hand, the appropriate posture combined with the action of the obstacle crossing mechanism is conducive to the crossing of the obstacle.

5.3. Crossing the anti-vibration hammer
As is shown in Figure 3 Diagram of mechanism, in $\Delta EFG$ composed of rod 7, the high voltage line and the anti-vibration hammer, if the distance between the center of the hammer and rod 7 is longer than the radius of the hammer, it can be guaranteed that the hammer will not interfere with the movement of the robot, thus the robot can cross the anti-vibration hammer.

At this point, the following relationship needs to be satisfied: $H = (l_2 \cos \delta - l_1) \sin \delta > R$.

As for the pruding of the clips above the anti-vibration hammer, the servo motor $M_2$ should be driven to decrease the angle $\gamma$ between $l_2$ and $l_3$. Then the guide trolley will rotate and keep a certain distance from the high-voltage line. Another two wheels will drive the device to move forward for a certain distance. After the guide trolley cross the obstacles, the servo motor $M_2$ should be driven to increase the value of $\gamma$ to 180°. The guide wheel returns to the high voltage line to complete the obstacle avoidance action of the first wheel, and the latter two obstacle avoidance wheels complete the cross of the vibration damper in the same way.

5.4. Crossing the tangent tower
For the insulator strings and line clamps above the high voltage lines, the similar action can be used to complete the obstacle avoidance. After opening the obstacle crossing mechanism, a total of three sets of obstacle avoidance wheels which are in the front, in the middle and in the rear of the device will cross the tangent tower in turn. First of all, the front wheels will rotate and the guide trolley will get away from and diverge from the plane composed of the high voltage line and the insulator strings. The middle wheels and the rear wheels will drive the robot to move forward. Then the front wheels cross from the side of the insulator strings. After the front wheels completely bypass the obstacle, the obstacle avoidance mechanism of the front wheels reversely turn the guide trolley. And the front wheels will return to the high voltage lines to complete the obstacle avoidance motions of the front
wheels. The middle wheels and the rear wheels will carry on the same action to cross the obstacle until all obstacle avoidance actions are completed.

6. Kinematics simulation

6.1. Kinematics simulation of obstacle-crossing process
For the typical motion of the robot obstacle-crossing, crossing line clamp, the mechanism simulation model of the Pro/E software to carry out kinematics simulation. First of all, 3D model of the robot should be established by the 3D modelling function of the Pro/E software. Secondly, we should carry out assembly in component mode and apply motion pairs relatively to every joint. The servo motors are added to lead screw and joint motor. After setting the corresponding parameters, the obstacle avoidance process can be simulated. The obstacle avoidance process of the front wheels is shown in figure 5. The middle wheels and the rear wheels follow the same actions to avoid obstacles.

![Figure 5. Obstacle avoidance motion simulation of front wheel.](image)

The kinematics simulation of the obstacle crossing motion of the clamps on the tangent tower further proves the correctness and feasibility of the scheme. And the obstacle crossing motion is simple, efficient and can be completed quickly.

![Figure 6. Pro/E motion simulation analysis of double motor linkage.](image)

6.2. Kinematics analysis of the key positions
In the whole obstacle crossing motion of the robot, when the shell is opened, the guide trolley must be kept upright to make sure the robot in a state of dynamic balance. The linkage between two motors is the most critical, which directly affects whether the robot can make follow-up actions. Kinematics
analysis should carry out on the linkage relation $\gamma = f(l_g)$. Pro/E software is used to carry out kinematics simulation to analyse the move distance of the nut $l_g$ and the angle $\gamma$. Then we can get the relationship shown in figure 6.

The result of motion simulation analysis is consistent with the result of Matlab simulation in figure 4, which verifies the correctness of the linkage relationship. As long as the servo motor $M_1$ and is controlled to make sure that $l_g$ and $\gamma$ meets the above leakage relationship, the obstacle crossing mechanism will have a certain relative motion.

7. Conclusion

Through the structural analysis of the obstacle crossing mechanism and kinematics simulation of the obstacle crossing motions, the correctness and feasibility of the obstacle crossing mechanism is determined. The mechanism is designed according to the special structure of magnetic levitation type inspection robot. It has two degrees of freedom and has various characteristics such as flexible operation, less steps to cross obstacles. When the robot is crossing the obstacles such as splicing sleeves, vibration dampers, linear clamps and so on, the mechanism runs smoothly. The two self-locking mechanisms are the core of the whole design. The obstacle avoidance scheme of reversing guide wheel solves the contradiction of small internal activity space and large space required for obstacle avoidance, which is innovative to a certain extent.

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