The Design and Simulation Analysis of Distribution Network Stripper Structure

Yan Yu¹, Zhanfan Zhou¹, Weidong Liu¹, Shichao Hu² and Xianjin Xu²

¹State Grid of Hunan Electric Power Maintenance Company, Changsha, Hunan Province, 410004, China
²School of Mechanical Engineering, Hubei University of Technology, Wuhan, Hubei Province, 430068, China

*Corresponding author’s e-mail: xxjoyn@126.com

Abstract. Considering the low efficiency of the stripping process and the serious damage of the core in the current distribution network, we propose a novel wire stripper in this paper. The kinematics modelling of the main transmission components in the wire stripper is established, and the opening and closing process of the wire stripper in real working condition is analysed by the kinematics and dynamics simulation. Furthermore, the static strength analysis and the stress distribution are obtained by the ANSYS, which provides theoretical guidance in the optimized design process. The results of motion modelling and static simulation confirm that the structural design of the novel wire stripper is reasonable and feasible.

1. Introduction

Electric power operation is the foundation of the national economy, and the people's life increasingly depends on power demand with the rapid economic development [1]. The real-time disconnection and connection of the drain wire is the joint link to ensure the continuous power supply of the power system, thus the stripping of the conductor insulation layer plays an important role in the work of the distribution network [2-3]. As we know, live working is usually used to improve the quality of the power supply. However, the manual operation still dominates in disconnecting, connecting and stripping processes in China's power sector, which may lead to serious security risks from the poor working environment and the light workload. Therefore, it is imaginable that using automatic mechanical equipment instead of manual work is an effective way to improve efficiency and reduce risk.

For example, Lu and Fu [4] designed a teleportation high-voltage live working robot, which can be used to strip the wire insulation layer and connect the lead wire, and it has a strong applicability in urban live working and complex field environment, but its structural design and control links are more imperfect than modern live working equipment. Li [5] design eda robot automatic wire stripper, the automatic wire stripper consists of the compression feeding device and the ratchet driving device. The double spring mechanical damping is used in the cutting tool end portion to ensure the effective fit of the tool and the wire, but it does not provide precise force to peel the wire. Qi [6] proposed a special wire stripper device for high-voltage live working robots, which is mainly composed of stripping cutters, main trusses, and electric actuators. The one set of cutters cuts annularly along the direction of the wire axis, and the other set of cutters are symmetrically arranged in a circular section of the wire. After the insulation layer is cut along the axis, the cutters arranged along the cross section of the wire...
are subjected to the transverse cutting movement, and then the entire insulating layer is automatically detached, and the cleaning process is very convenient. A multi-manipulator working platform for live working with distribution network is developed in literature [2], the model and the physical object are shown in Figure 1 and Figure 2 respectively. A stripping manipulator is included in the platform with the worm gear and the screw nut structure, and the device can be automatically changed with the diameter of the wire, which is a relatively advanced live working equipment for distribution network in the world. From the above, at present, the distribution network operation field mainly faces the following three major problems: 1. Most of the distribution network operation field relies on manual wear protective clothing for operation with high intensity, and there exist serious safety hazards; 2. Manual operation Guided by experience is in efficient, the wire can not be accurately stripped, and the wire core is often damaged, which seriously affects the power distribution effect; 3. Although a few distribution network machinery and equipment have been successfully developed, but the equipment is cumbersome, whose degree of automation is low and the applicability is poor. Based on the above questions, a multi-functional stripping mechanical mechanism with high degree of automation is designed to solve the problem of core damaged easily in this paper, and the design of structure is compact, light and its layout is reasonable.

\[\text{Figure 1. The model of the multi-manipulator working platform}\]

\[\text{Figure 2. The physical object of multi-manipulator working platform}\]

2. The whole structure of the wire stripper

The whole structure of the wire stripper mainly consists of three parts: the cage-shaped bracket, the link assembly, as well as the actuator and the lead screw. The three-dimensional structure diagram is shown in Figure 3. The cage-shaped bracket is composed of four half-ring brackets, and each of the two half-ring brackets is connected by six cylindrical support columns to form a semi-cage structure. The main function of the cage bracket is to carry and fix the cutter, and the twelve cutters are evenly arranged on the support cylinder of the cage-shaped bracket through the fasteners. After the cage-shaped bracket is completely closed, the cutter begins to cut along the radial direction of the wire until the tool is cut into the insulation layer, and then the wire insulation and wire core are distinguished by the corresponding impedance force control technology [7]. Thus, the tool can be cut into the insulation layer accurately, and then the wire stripper is driven to move along the axis of the lead wire to peel off the insulation layer by the manipulator.
3. Modelling Analysis of the Opening and Closing Movement of Cage-shaped Brackets

The opening and closing movement of the cage-shaped bracket serves as a prelude to the entire stripping process of the wire stripper. Once the opening and closing movement of the cage-shaped bracket is troubled, the entire stripping process cannot achieve normally. Therefore, its normal opening and closing process is very important for the stripper.

3.1 The analysis of the principle

In order to normal open and close the cage support, the bending links and straight links are used as the important actuators. The servo motor provides power to drive the screw mechanism to rotate forward and backward, and then the nut mechanism is driven to move up and down in the inner sliding groove of the general support plate, thus the connecting rod can be pushed and straightened in the sliding groove, as shown in Figure 3. The one end of the connecting rod is hinged, the other end of the rod is fixedly connected with the ring support by screws, and the bending link rotates around the support axis, thus the opening and closing movement is completed with the cage support.

3.2 The modeling analysis of opening and closing movement

This section is to analyze the quantitative relationship between the opening and closing angle of the cage support and the angle of the lead screw, as well as the minimum opening angle is analyzed when the cage support and the wire contacted at the limit position. If the opening angle of the cage support greater than its corresponding limit motion position, it can be determined that the mechanism design is reasonable.
The related structure can be simplified in the process of kinematic modelling analysis due to the entire wire stripper is symmetrical in structure. The simplified physical model is shown in Figure 6. The point A represents the upper limit position of the nut mechanism in the chute, and the point B represents the lower limit position. The dotted line represents the position of the connecting rod assembly, and the solid line represents the position relationship between the components at time $t$.

When the cage-shaped bracket is completely closed, the angle between the pair of tortuous links on the same side is $\theta$, the nut mechanism is at the upper limit position, whose distance from the limit position to the support shaft is $h$, and the length of long side to tortuous link is $l$, the length of straight link is $m$, the angle between the long and short sides of the is tortuous links is $\Phi$, the rotation speed of the lead rod is $\omega$, the thread lead of the lead screw is $p_h$. After time $t$, the rotation angle of the lead screw is $\gamma$, the angle between the tortuous links corresponding to the same side is $\delta$, the displacement of the nut mechanism moving up and down in the sliding chute is $a$, the distance from the nut mechanism to the support shaft is $x$, and the angle of the long side of the tortuous link with the axial direction of the lead screw is $\alpha$. Once the nut mechanism is moved to the limit position, the link assembly is moved to the limit position too, subsequently, the opening and closing of the cage-shaped bracket reach the limit. The geometric relationships are as follows:

$$\gamma(t) = \omega t$$  \hspace{1cm} (1)

$$x(t) = h + a$$  \hspace{1cm} (2)
\[ a = \frac{\gamma}{2\pi} p_h \]  

At time \( t \), the position distance \( x \) between the nut mechanism and the support shaft, the long side \( l \) of the tortuous link, and the side length \( m \) of the straight link, three of which meet the cosine theorem:

\[ x^2 = m^2 + l^2 - 2ml \cos \alpha \]

Where \( \alpha \) is the angle between the long side of the tortuous link and the axis of the lead screw. It can be deduced that

\[ \alpha = \arccos\left(\frac{m^2 + l^2 - x^2}{2ml}\right) \]

At the same time, it can be obtained that:

\[ \delta = 2\pi - 2\alpha - 2\phi \]

The opening angle of the cage-shaped bracket is \( \beta \) at time \( t \), then there exist:

\[ \beta = \delta - \theta \]

In practice, where \( \phi = 75^\circ \), \( l = 97\text{mm} \), \( m = 100\text{mm} \), \( \theta \) is 120\(^\circ\), \( p_h \) is 1.25\text{mm}, \( h \) is 107\text{mm}. The relationship between the opening angle \( \beta \) of the cage-shaped bracket and the rotation angle \( \gamma \) of lead screw can be obtained from equation (1) to equation (7):

\[ \beta = \frac{\pi}{2} - 2\arccos\left[\frac{0.0194 - (\frac{\gamma}{1600\pi} + 0.107)^2}{0.00194}\right] \]

Any opening and closing posture of the cage-shaped bracket can be achieved by controlling the rotation angle \( \gamma \) of the lead screw. The relationship between \( \beta \) and \( \gamma \) is plotted as a function relationship as shown in Figure 7.

![Figure 7. The relationship between \( \beta \) and \( \gamma \)](image_url)

It is showed that the curve of the relationship between \( \beta \) and \( \gamma \) is not pass the origin as the lead screw is screwed into the nut mechanism several times. The actual angle between the lead wire and the limit position of the cage-shaped bracket is 10.17\(^\circ\) and 24.25\(^\circ\) respectively in the Figure 4 and Figure 5. From Figure 7, it can be seen that the maximum opening angle of the cage-shaped bracket reaches 188.5\(^\circ\) which is larger than the limit angle between the wire and the cage-shaped bracket. To enhance the applicability of the wire stripper to lead wires of different diameters, the limit opening angle of the cage-shaped bracket is larger than the limit angle between the cage-shaped bracket and the lead wire.
3.3 Simulation of opening and closing motion to cage-shaped bracket
The software of ADAMS [10] is used to simulate the process of the opening and closing movement of cage-shaped bracket, and then the three-dimensional structure model of the wire stripper is imported into the ADAMS. The motion sub-constraint between the components in the wire stripper is completed in the ADAMS, the positive and reverse driving force is applied to the screw respectively, and the driving force is set as the default value of the software. The simulation time is set as 15s, and the number of simulation step size is 0.1. The kinematics and dynamics curves of the tortuous links and the straight links during the opening and closing process of the cage-shaped bracket are obtained respectively, as shown in Figure 8, Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13.

Figure 8. Speed curves of the link assembly during the opening process of the cage-shaped bracket

Figure 9. Acceleration curves of the link assembly during the opening process of the cage-shaped bracket

Figure 10. Speed curves of the link assembly during the closing process of the cage-shaped bracket
It can be seen that the curves are continuous, and the simulation curve of each member are generally demonstrated the symmetrical relationship, it also indicates that the motion of the structure is relatively stable, and the animation of the entire motion process can be clearly demonstrated in ADAMS. In a certain perspective, it is reflected that the design of stripper structure is reasonable and feasible.

4. Static analysis of the tortuous
The design of the structure should be satisfied the static properties and the motion laws. In the design of the wire stripper structure, the tortuous links is the main structural force receiving unit, it is easy lead to the failure of its strength. Thus, the tortuous links structural strength should be checked. The aluminum alloy material has the advantages of light weight, good strength and high cost performance,
therefore, the aluminum alloy (6061-T651) is selected as the material of the tortuous links and the cylindrical supporting shaft, and the mechanical properties of the material are shown in Table 1.

| Material       | Density ρ kg/m$^3$ | Elastic modulus $E$/GPa | Poisson's ratio $\mu$ | Yield strength $\sigma$/MPa |
|----------------|--------------------|------------------------|-----------------------|-----------------------------|
| 60061-T651     | 2750               | 72                     | 0.33                  | 110                         |

The entire stripper structure is symmetrical in the working space, therefore it can be simplified to analyze the force between the tortuous links and the support shaft on the one side. The finite element model is shown in Figure 14. When the restraint is applied to the components, the two ends of the support shaft are first fixed, the frictional contact between the tortuous links and the support shaft is defined, and then the load is applied along the axial direction of the short side of the tortuous links. The maximum tensile force of the tortuous link is estimated about 40N through the kinetic analysis, the analysis result is obtained as shown in Figure 15. The maximum shear stress occurs at the contact surface of the tortuous links and the supporting shaft, and the maximum stress between them is 14.96Mpa, which is less than the yield strength of 110Mpa of aluminium alloy. Therefore, this structural design is completely reasonable.

5. Conclusion
A novel wire stripper for distribution network is designed, and the kinematics modelling is established and its kinematics simulation and statics simulation are analyzed. Moreover, it is confirmed that it is an effective way to use the straight link and the bent link as the dynamic actuators, the static strength simulation analysis also shows that the design of the key structural parts of the stripper is reasonable and feasible, and there is a large optimization space.

Acknowledgments
This research was financially supported by the China National Science Foundation (Project No. 61375092).

References
[1] Yu Y, Xu X, etc. (2018) Mechanism Design of Electric Robot of Distribution Network for Cut off or Connection of Leading Wire. In: Earth and Environmental Science. Chengdu. pp. 22-32.
[2] Yu Y, Xu X, etc. (2018) Development of Live Working Robot for Distribution Network. In: Earth and Environmental Science. Cheng Du. pp. 41-51.
[3] Zhang H. (2018) Design of Robotic Arms for Live Working Robots. Research and Design, 34: 70-73.

[4] Lu S, Fu Me, etc. (2005) DWR-I teleportation high-voltage live working robot. Journal of Shanghai Jiao Tong University, 6: 911-913.

[5] Li J, Li D, etc. (2011) Development of automatic stripper for high-voltage live working robots. Manufacturing Automation, 33: 111-114.

[6] Qi H, Han L, etc. (2019) Design of special stripping device based on 10KV high voltage live working robot. Mechanical Engineering and Automation, 2: 107-109.

[7] Chen H. (2018) Joint space impedance control based on torque sensor. Manufacturing of Machine, 657: 30-33.

[8] Yang S, Wang B. (2015) The method of Lightweight structural design and optimization for lightweight manipulators. China Mechanical Engineering, 27: 2575-2580.

[9] Liang M, Li Z. (2017) Optimization design of mechanical arm structure based on flexible multi-body dynamics. China Mechanical Engineering, 28: 2562-2566.

[10] Gong P, Hu R, etc. (2014) ADAMS virtual prototype from entry to proficiency. Mechanical Industry Press, Beijing.