An Automatic Stripping Device for Hot-line Connection of 10 kV Cables

Wu Han1,*
1 Fujian Electric Power Research Institute, FuZhou 350007, Fujian Province, China
*Corresponding Author: e-mail: wu_han@fj.sgcc.com.cn

Abstract. Electricity is an energy that is closely related to people’s daily life, and hot-line connection is often necessary in grid transformation and overhaul. Traditional stripping devices need to be operated manually with tools, which are not only time- and labor-consuming, but also have certain potential safety hazards. In this paper, a special stripping tool that is suitable for 10 kV high-voltage hot-line work is researched and designed based on summary of existing manual stripping devices. This new device is featured by a simple structure, safety, reliability, low operation risk, high efficiency, and a high automation level.

1. Introduction
With the continuous improvement of people's living standards, people's life is increasingly dependent on electricity. The contradiction between grid transformation and people's constant demand for power is increasingly prominent, which brings great pressure to power supply enterprises' fulfillment of service commitments [1]. Therefore, grid companies request the work on distribution lines to follow the principle of “uninterrupted energy” and perform hot-line work as far as possible, so as to improve power supply stability and reliability. Vigorous promotion of hot-line work has become an extremely important core work for all grassroots power supply companies [2].

Hot-line work is a work method for live overhaul and test on high-power electrical equipment. Electrical equipment needs to be tested, checked, and repaired regularly in long-time operation. On this background, hot-line work is an effective measure to avoid overhaul power outage and ensure normal power supply [3]. Common hot-line work items include line connection, line scrapping, installation of electrical inspection grounding ring, installation of lightning protection wire clamp and foreign matter removal of conductor. Generally, the proportion of such items in daily hot-line work is more than 90% [4]. Owing to the difference in the tools and operation process of such live operations, one field operator can master most operations only after going through multiple trainings. Besides, it is very easy to have faults in field operation. A workman must sharpen his tools if he is to do his work well. The design of a convenient and practical automatic stripping device for hot-line connection is of great significance to hot-line work [5].

2. Design of Automatic Stripping Device for Hot-line Connection of 10 kV Cables
Currently, domestic conductors are in accordance with Aerial Insulated Cables for Rated Voltage of 10 kV (GB/T 14049-2008). They have different diameters and insulating layers. At present, the mainstream practice on the stripper market is manual operation, which is not only complex but also requires lots of manpower and material resources. Since different workers have different operation proficiencies, there can be a great difference in stripping efficiency. During stripping and cutting, it is...
necessary to make sure the sheath is peeled successfully while the core is not damaged. In addition, adequate force shall be applied for stripping and cutting, and correct positioning is required to prevent core cutting.

2.1 Structural Analysis and Design
Independent intelligent modules that are subject to infrared remote control are used in the design. The device is driven by motor for automatic operation. The equipment is connected to the mechanical arm via insulating rods for insulation. Operators only need to set up parameters remotely and perform remote start, and then, the entire stripping operation can be realized.

Major components of the mechanical structure: guiding mechanism, driving mechanism, locking stripping & cutting mechanism, and supporting mechanism. Figure 1 shows the structure of the device.

Guiding mechanism: Composed of a front cable guide block and a rear cable guide block, it is used for guidance and positioning of the mechanism that is lifted to the conductor.

Driving mechanism: It is used to drive motor, motor output gear, ring gear and ring gear block. It can drive the locking stripping & cutting mechanism for rotation.

Locking stripping & cutting mechanism: It consists of tool apron motor, two-way ball screw, optical axis, conductor limiting block, stripping knife and waste guiding block. Driven by the driving mechanism, the stripping knife will cut the sheath of the conductor at certain angle first, and then, the sheath will be stripped.

Supporting mechanism: It includes supporting plate and fixing frame. It is connected to a big gear.
During operation, the supporting mechanism is connected to the mechanical arm, and it will move towards the conductor direction under guidance of the driving mechanism.

There are various cables for 10-kV overhead lines on the market. The stripping device in this design needs to meet the stripping requirements for overhead cables having different diameters. Common specifications of 10-kV cables: 10-kV overhead cables can be classified into three types based on material: JKYJ copper core XLPE insulated overhead cable, JKLYJ aluminum core XLPE insulated overhead cable and JKLGYJ ACSR core XLPE insulated overhead cable. The dimension is within 25 - 300 mm² in general. The device in the design is able to suitable for the most common cables with the dimension of 70 - 240 mm², the external diameter of 18.40 - 26.80 mm, and the insulating layer thickness of 3.4 mm and 2.5 mm respectively on the market. The insulating layer thickness of 3.40 mm is dominated on the market, and it is taken as an example in the design.

Figure 2 displays the schematic diagram of the stripping & cutting mechanism of the designed device.

![Fig. 2 Schematic Diagram of Stripping & Cutting Driving Mechanism](image)

1- Driving motor; 2- Motor of locking mechanism; 3- Clamping block 1; 4- Two-way screw; 5- Tool; 6- Clamping block 2; 7- Driven gear; 8- Big gear; 9- Pinion; 10- Cable

The clamping block, tool and cable in our design are shown in Fig. 3 below. The clamping blocks on two sides of the tool fixing block make side-to-side movement for clamping. For the 26.8-mm cable, the clamping status is shown in Fig. 3A. In this case, the tool cutting depth is 3.4 mm, and the sheath can be stripped. By adjusting the clamping block, it reaches the position in Fig. 3B. At this time, the cable is 18.4 mm. But since the sheath is in the tangential direction of the tool cutting edge, the blade will move together with the clamping block, and the cutting depth is also 3.4 mm.

![Fig. 3 Clamping block mechanism](image)

Stripping is realized when the clamping block mechanism rotates around the cable. After that, the clamping mechanism is adjusted so that the tool retreat by 2 mm, and rotate around the cable to cut off the sheath. Its structure is shown in the figure below.
The stripping & cutting force needed for tool during stripping & cutting depends on the material being stripped & cut and the feed amount of stripping & cutting. Its calculation equation is shown as below:

\[ F_f = 25Df^{0.8}K_p \]  

where \( K_p \) represents material coefficient; that of XLPE is 0.97; \( D \) is the stripping & cutting depth; \( f \) refers to the feed amount of stripping & cutting.

In the design, the cable cutting depth is \( D = 3.4 \text{ mm} \), the feed amount of stripping & cutting is \( f = 0.5 \text{ mm/r} \), and the stripping & cutting force is:

\[ F_f = 225Df^{0.8}K_p = 25 \times 3.4 \times 0.5^{0.8} \times 0.97 = 47.36 (N) \]  

The tool is fixed on the clamping blocks, which move along the screw that has two-way thread, so that two clamping blocks can move towards the cable center, guaranteeing uniformity.

The pitch diameter of thread of the screw (\( d_2 \)) shall comply with the following equation

\[ d_2 \geq \sqrt[3]{\frac{FP}{\pi \varphi [p]}} \]  

where \( P \) refers to the pitch; \( F \) is the maximum working load; \( h \) is the thread working height; \([p]\) is the allowable pressure of material; \( \varphi \) is taken as 1.2 - 3.5 in general, and it is set at 1.4 in the present work.

Thread working height is \( h = 0.5P \); according to mechanical design manual, \([p]\) is 21 MPa. Thus, the original equation is transformed into

\[ d_2 \geq \sqrt[3]{\frac{FP}{0.5 \pi \varphi [p]}} = \sqrt[3]{\frac{47.36}{0.5 \times 3.14 \times 1.4 \times 21 \times 10^5}} = 1.01 \text{ mm} \]  

The dimension of the roller screw is taken as \( d = 8 \text{ mm} \).

The distance between the design tool and the pinion is \( l = 75 \text{ mm} \), and the torque needed for the pinion is:

\[ M = FL = 47.36 \times 0.075 = 3.55 \text{ N\cdotm} \]

We chose Deli DGX42RS775-DCV-35 DC planetary reducer motor with the torque of 4.9 N\cdotm.

The gear is designed as per tooth surface contact fatigue strength, which needs to comply with the following equation:

\[ d_1 \geq \sqrt{\frac{2K_mT_1}{\varphi_d \cdot u + 1} \cdot \left( \frac{Z_{z_2}Y_{z_2}Y_{z_2}}{[\sigma_f]} \right)^2} \]  

Gear is made of 45# steel that is subject to thermal refining with the accuracy of Class 8. Based on calculation:

\[ d_1 \geq 45.55 \text{ mm} \]

According to the mechanical design manual, the dedendum bending fatigue strength shall meet the following modulus requirement:

\[ m \geq \sqrt{\frac{2K_mT_1}{\varphi_d \cdot Z_{z_1}^2} \cdot \frac{Y_{z_1}Y_{z_1}}{[\sigma_f]} \left( \frac{Z_{z_2}Y_{z_2}Y_{z_2}}{[\sigma_f]} \right)^2} \]
Based on calculation: $m \geq 1.98 \text{ mm}$

In the final design, for pinion, the number of teeth is $z_1 = 25$, modulus $m_1 = 2 \text{ mm}$; for big gear, the number of teeth is $z_2 = 50$, and the modulus is $m_2 = 2 \text{ mm}$.

2.2 Introduction to Hardware Circuit

The master chip of the stripping hardware is SPARTAN-6 FPGA chip. Two motors are controlled by the L298N motor driving chip. It is equipped with infrared receiving and transmitting control terminals outside. Receiving and transmitting are performed with 38k and 56k infrared modulation respectively to establish communication between the receiving and transmitting control terminals and the ground remote control terminal. Besides, the positions and speed statuses of two motors are identified by two optical coupling sensors respectively. In addition, external presetting is performed with dial switch to make it convenient for automatic and manual rotation. The structure is shown in Figure 5:

![Fig. 5 Schematic diagram of the hardware circuit](image)

2.3 Stripping Process

When the equipment is turned on, it will enter reset state, so regardless of motor state before startup, both the big motor and the small motor will rotate to the “on” state and stop. At this time, the cables that need to be stripped can be put into the slot.

It will enter working state when the work start command in the 38k infrared signal is identified. At this time, the small motor will start closing. When the tool contacts the cable, the big motor will start rotating for formal stripping.

During work, the optical coupling sensor of the big motor will count the number of turns. When the number of turns complies with the preset number of turns in automatic rotating state, the equipment will enter tool retracting state.

In tool retracting state, the equipment will rotate forward for one turn to isolate the sheath, and then, it will rotate backward to make sure the clamping mechanism is in completely open state. At this time, the entire stripping process is finished.

3. Conclusions

The automatic stripping device for hot-line connection of 10 KV cables in the design consists of guiding mechanism, driving mechanism, locking stripping & cutting mechanism, and supporting mechanism. The FPGA chip is used for control of two motors and infrared transmission control to achieve automatic stripping. In this process, no additional manual intervention is necessary. Featured
by light weight, small volume, high degree of automation, simple operation, high reliability, and flat notch, the device can adapt to different overhead cables. With this device, the cable sheath can be stripped quickly, so it has significant practical value and promotion value.

Acknowledgements
State Grid Fujian Electric Power Company Science and Technology Project: Research on Key Technologies of Intelligent Electric Fire Catching Robot (Phase I) (52130419002B).

References
[1] Feng, T.S. (2020) Discussions on work safety of 10kV overhead power line. J. Architectural Engineering Technology Design., 26: 110-115.
[2] Wang, H.S. (2019) Installation and Operation of 10kV Overhead Distribution Line. J. Encyclopedia Forum., 8:331-337.
[3] Niu, C. (2015) Exploration of hot-line connection method for cable joint of 10kV live overhead line. J. China Science and Technology Review., 10: 128-132.
[4] Xu, S.J., Xia, Y.Q., Du J., etc. (2020) Design on the live working robot system. J. Technology Innovation and Application., 4: 112-115.
[5] Ling, S., (2017)Wu Shaolei and Feng Yu. Design of a portable automatic device in cutting & jointing live fire operated under electrification on overhead distribution line. J. Mechanical Engineer, 4: 331-335.