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Improvement of Production Process for Medium-Voltage XLPE Cables and Promotion Strategies of Product Qualification Rate

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Abstract: Medium voltage cross-linked cables have been widely used in urban distribution networks, municipal infrastructure, and industrial plant power supply. The mechanical reliability and insulation performance of the products have a profound impact on the operational safety of the power system. In the continuous production process of industrialization, due to the fluctuation of equipment operating conditions, unreasonable process parameter settings, and differences in raw material batches, quality defects frequently occur in medium voltage cross-linked cables, resulting in a decrease in product qualification rate, continuous increase in material loss and rework costs for enterprises. In this study, the focus is on exploring strategies for improving the production process and product qualification rate of medium voltage cross-linked cables, in order to provide reference solutions for similar manufacturing enterprises to reduce production losses and improve product quality.

1. Introduction

Cross linked polyethylene is the main insulation material of medium voltage cross linked cables, which has good electrical insulation performance, mechanical aging resistance and heat resistance. It has become the main cable product of 10-35kV distribution network. At present, there is not much difference in the hardware configuration parameters of most production lines in China, but there is a significant gap in the stability of finished product quality, such as the frequent occurrence of quality problems such as micro pores and bubbles inside the insulation and breakdown during withstand voltage testing [1].Production management personnel attribute quality defects to problems with raw material quality or equipment aging, overly rely on post inspection screening for defective products, and lack systematic improvement measures from the source of the process. Post inspection can only eliminate non-conforming products and is difficult to reduce defect problems at the root. Once batch quality defects occur, it will not only increase the manufacturing cost of the enterprise, but also lead to the flow of non-conforming products into the market. In view of this, this article focuses on exploring strategies for improving the production process and product qualification rate of medium voltage cross-linked cables.

2. Factors affecting the qualification rate of medium voltage cross-linked cables

(1) Factors affecting equipment accuracy and operational stability

The three-layer co extrusion cross-linking production line is mainly composed of a three-layer co extrusion head, a conductor pay off machine, a cross-linked vulcanization tube, and an extrusion host. The equipment operates in coordination with multiple units, and any decrease in accuracy of any unit will cause product quality defects. Firstly, the extrusion host system, barrel, and screw are in a high-temperature operating state for a long time. After the screw wears out, it is easy to change the material conveying flow rate, causing uneven extrusion of insulation material and seriously affecting the thickness of the insulation layer. Secondly, the traction and release system, as well as the tension control device for conductor release, have insufficient accuracy. During the operation of copper conductors, radial displacement and shaking are prone to occur, resulting in the conductor swinging at the core position of the machine head and severe insulation layer eccentricity problems. Thirdly, the temperature and pressure control system components of the vulcanization tube are aging, and the actual temperature and pressure inside the tube are inconsistent with the displayed data on the screen. If the operator produces according to the displayed parameters, it will result in unqualified thermal extension indicators.

(2) Raw material performance and storage control factors

Cross linked polyethylene insulation material and inner and outer semi conductive shielding material are key raw materials for medium voltage cross-linked cables, and fluctuations in raw material properties can cause product defects. Cross linked materials are highly sensitive to moisture, and the internal moisture content of the raw material particles exceeds the standard. After high-temperature extrusion, the moisture evaporates, and bubbles and micropores are easily formed inside the insulation, resulting in breakdown failure during the high-voltage withstand test stage. In addition, there are significant differences in the melt index and crosslinking agent content of different batches of crosslinking materials, which can also affect the performance and quality of raw materials. For example, suppliers may experience reasonable fluctuations in the performance of each batch of raw materials. If the enterprise's process parameters remain unchanged and the extrusion process is not fine tuned according to the incoming material performance, even if batch A products are qualified, batch B products may still experience thermal extension failure.

(3) Process parameter matching and operational specification factors

The main reason for the high incidence of quality defects in the workshop is the unreasonable matching of process parameters and the inadequate execution of on-site personnel operations. In the three-layer co extrusion process, the temperature of each section of the extruder is not set according to the raw material grade. If the temperature is set too high, the polymer material is prone to premature degradation; The temperature setting is too low, the material plasticization is incomplete, the melt flowability is poor, and a large number of particle spots appear on the surface of the shielding layer. In the cross-linking and vulcanization process, the production line speed, vulcanization pressure, and vulcanization speed should be matched with each other. If the temperature and pressure of the vulcanization pipe are not synchronously increased after the production speed is increased, it will lead to insufficient cross-linking reaction and unqualified cable thermal extension index.

(4) Production environment and process detection factors

The environmental conditions and process testing capabilities of the cross-linking production workshop have a significant impact on the qualification rate of finished products. Cross linked extrusion belongs to polymer thermal processing, and there is a lot of dust in the workshop environment. After the dust falls into the discharge position of the machine head, it is easy to embed between the semi conductive shielding layer and the insulation layer, thereby forming conductive

impurity points and increasing the risk of partial discharge. At the level of process inspection, many enterprises focus on the completion of finished products as the focus of quality inspection, with less frequency of inspection in the production process. In addition, online thickness measuring equipment is not regularly calibrated, and operators adjust the process according to incorrect data, making it difficult to detect insulation thickness deviation in a timely manner.

3. Improvement of production process and strategy for enhancing product qualification rate of medium voltage cross-linked cables

(1) Optimization of temperature control process for three-layer co extrusion extrusion

1) Establish a temperature control database for different grades and levels

Led by our company's technical department, we will determine the temperature ranges for the feeding section, compression section, homogenization section, head body, and die head of the extruder, in order to prevent the application of a single set of temperature parameters to all raw materials. In specific operations, the first step is to consult the physical property report provided by the raw material manufacturer, record in detail the allowable processing temperature and melt index, select the same brand of raw materials for small machine testing, and gradually adjust the temperature of each section; Secondly, it is necessary to clarify the upper and lower limits of the optimal temperature for this brand and synchronously input them into the workshop process system. For example, for a certain 10kV cross-linked insulation material, the feeding section temperature is set to 90-95 ℃, the compression section temperature is set to 100-110 ℃, and the head mold temperature is set to 115-122 ℃. A semi conductive shielding material is configured, and the processing temperature needs to be reduced by 5-8 ℃ to avoid oxidation of carbon black inside the shielding material[2].

2) Control the entire process of temperature rise, standby, shutdown, and cooling of equipment

Most degradation impurities do not occur during normal production stages, but rather during prolonged standby and heating phases. Enterprises have clear regulations on equipment heating: when the equipment is turned on and heated up, each section of the barrel should be kept at the set temperature for 40 minutes to ensure a uniform temperature field inside the barrel and prevent poor plasticization caused by local low temperatures. At the same time, if the temporary shutdown time of the production line exceeds 20 minutes, operators should perform cooling operations, lower the temperature of the barrel and machine head, and avoid materials staying inside the high-temperature barrel for a long time; Before resuming production, the temperature should be raised again to the process temperature. After the insulation is completed, the material that has been degraded by heat in the barrel should be discharged. After observing that there is no yellowing or coking phenomenon, the conductor coating production can be carried out.

3) Increase the linkage monitoring of melt pressure

The change in melt pressure of the extrusion host can reflect the plasticization state. The company incorporates the extrusion melt pressure into the on-site process control indicators, and each extrusion host operation interface is marked with the material melt pressure range. In production practice, when the melt pressure exceeds the upper and lower limits, the system automatically prompts the operator to investigate hidden dangers, check whether the screw is worn, whether the temperature is offset, and whether the raw materials are damp. Production can only be carried out after the melt pressure returns to a reasonable range.

(2) Die matching and extrusion flow process improvement

1) Implement a system for calculating and selecting mold stretching and compression ratios

The technical department completes the selection calculation of mold cores and sleeves for different conductor cross-sections and insulation thickness specifications, outputs a standardized

mold selection list, and distributes it to the workshop. The stretching ratio is controlled within the cross-linked polyethylene process range, and the stretching ratio of the insulation layer of medium voltage cables is controlled between 1.2-1.6; The stretching ratio of the semiconductor shielding layer is controlled between 1.1-1.4. Taking the 10kV-3 × 300mm ² cable as an example, the measured outer diameter of the conductor is 20.6mm, and the nominal insulation thickness is 4.5mm. The technical personnel set the inner diameter of the mold core to 21.0mm and the inner diameter of the mold sleeve to 32.4mm according to the calculation results, and calculated the tensile ratio to be 1.42 [3].

2) Standardized mold assembly and gap calibration process

The quality of mold assembly can easily cause eccentricity, and enterprises need to clarify the assembly operation process: firstly, before assembling the mold, use a special copper shovel to clean the residual carbide material inside the mold core and mold sleeve, and use metallographic sandpaper to polish the mold mouth simultaneously. It is strictly prohibited to use steel files to polish the mold; Secondly, after the mold core and mold sleeve are assembled in place, tighten the clamping bolts in stages and use diagonal alternating tightening to avoid mold displacement. After assembly, closely observe the flow of molten material around the mold mouth. If the discharge flow rate is inconsistent, it indicates that the mold is offset and the fastening bolts need to be adjusted again until the discharge speed of molten material around the mold mouth is consistent. Then, insert the conductor for trial production.

3) Dynamic matching of extrusion flow rate and production line traction speed

The flow rate of the three-layer co extrusion three extruders must match the traction line speed to avoid loose or overly tight wrapping. Enterprises need to change the fixed method of single screw speed and focus on controlling extrusion flow. Technicians use weighing method to calibrate the actual discharge flow rate of extruders at different speeds, and establish a comparison table of "traction speed screw speed theoretical extrusion flow rate". When adjusting the traction speed of the production line causes a change in the production rhythm, the operator should adjust the screw speed of the three extruders according to the reference table. For example, if the traction speed is increased from 8m per minute to 10m, the rotational speed of the insulation extrusion host, inner shield, and outer shield host should be adjusted according to the reference table, rather than arbitrarily adjusting according to the wrapping state.

(3) Adjustment of crosslinking vulcanization constant temperature and pressure stabilization process

1) Establish a vulcanization process matrix

The technical department sorted out the specifications of medium voltage cables and divided them into large section, medium section, and small section levels based on the integral of the conductor cross-section. Different section levels were matched with corresponding temperature and nitrogen pressure ranges for the vulcanized pipes. Among them, the large cross-sectional conductor has a large thermal capacity, and the conduction speed of heat to the inside of the cable is slow, so the requirement for vulcanization temperature is high. Taking the production of 10kV grade cables as an example, when the traction speed is set to 7.5m per minute, the temperature in the heating zone of the small section conductor vulcanization tube is 275-285 ℃, and the nitrogen pressure is 0.85MPa; The sulfurization temperature of the large cross-section conductor rises to 285 to 295 ℃, and the nitrogen pressure increases to 0.92-1.0MPa [4].

2) Eliminate the problem of temperature control virtual display in vulcanization tubes

The enterprise dispatches equipment maintenance personnel to verify the thermocouples in each heating section of the vulcanization tube. Portable standard temperature measuring instruments are used to compare the measured temperature of the thermocouples with the system displayed temperature. If the temperature difference between the two exceeds 5 ℃, the thermocouple

temperature measuring element needs to be replaced in a timely manner. For the segmented heating zone of the vulcanization tube, it is not only necessary to monitor the total displayed temperature, but also to record the actual temperature of the inlet, middle, and outlet sections of the vulcanization tube. If the temperature of a certain zone deviates from the set value, equipment personnel need to check the status of the heating coil; For the nitrogen stabilization system, compare the pressure of the stabilization system before each shift starts to ensure that the actual nitrogen pressure is consistent with the process requirements, and avoid insufficient cross-linking reaction caused by insufficient pressure inside the pipe.

3) Perform cross-linking degree tracking verification

After changing the cross-sectional specifications of the conductor, technicians take samples and conduct thermal extension tests to test the cross-linking effect. If the thermal elongation exceeds the standard, immediately raise the vulcanization temperature and take another sample for testing until the thermal elongation index is controlled within the standard range. It is prohibited to produce continuously at full load after changing specifications, and to stop the machine only after batch inspection of non-conforming products in finished products. If different batches of insulation materials are used for production, even if the cable specifications remain the same, technicians need to take samples for re examination of thermal extension and fine tune the vulcanization conditions according to the content of crosslinking agents in the raw materials.

(4) Qualitative process optimization of segmented gradient cooling

1) Divide into multiple cooling and temperature control zones

The technicians divided the entire cooling pipeline into a first stage pre cooling section, a second stage cooling section, and a third stage final cooling section. When the cable leaves the vulcanization tube and the temperature of the insulation body reaches 250 ℃, it cannot be directly cooled by cold water at room temperature. The water temperature in the first stage pre cooling section is controlled at 75-80 ℃, and the high-temperature insulation slowly releases heat to prevent rapid cooling and solidification of the surface, while the interior remains in a high-temperature state, resulting in significant stress; The water temperature in the secondary cooling section drops to 45-55 ℃ and continues to dissipate smoothly; The third level final cooling section adopts room temperature water cooling to ensure that the cable temperature is reduced to 40 ℃ before winding. When the enterprise is renovating the cooling system, each cooling circuit should be equipped with an independent temperature controlled heat exchange device, and the water temperature setting range of each section should be recorded on the process card. The operator should check the cooling water temperature against the process card, and if the water temperature deviates from the range, adjust the cooling water flow of the heat exchanger.

2) Control the water level of the cooling water tank and the immersion status of the cables

Equipment management personnel should adjust the height of the internal guide wheels of the cooling trough in a timely manner to ensure that the cables are submerged in the cooling water from the pre cooling section to the final cooling section, avoiding local rapid cooling caused by cable exposure on the water surface and affecting the uniformity of insulation layer cooling. At the same time, it is necessary to regularly clean the scale in the cooling tank. The scale adhering to the heat exchange tube wall will affect the heat exchange efficiency. The enterprise should arrange a dedicated person to regularly remove the scale from the cooling tank and heat exchanger to prevent the cooling water temperature from losing control due to the decrease in heat exchange capacity. In addition, operators should closely monitor the quality of cooling water, configure water treatment devices to control the hardness indicators of cooling water, and regularly replace some circulating water.

3) Set the static and sampling detection steps after cooling

After the cable is cooled and coiled, it cannot be immediately sampled for insulation

performance testing. The insulation material after high-temperature cooling needs sufficient stress release time. Enterprises should clarify the operating rules: after the completion of the cross-linking cable winding, it should be left in the workshop environment for 4 hours, and after the internal stress of the insulation is released, samples should be taken for thermal shrinkage and thermal extension tests. If urgent testing is required due to tight production tasks, technicians should place the samples in a constant temperature chamber before conducting the test[5]. Sampling and testing of hot cables should not be performed to avoid affecting the authenticity of the test results.

4. Analysis of the Implementation Effect and Benefits of the Improvement Plan for Medium Voltage Cross linked Cables

(1) Comparison of product defect rates before and after process improvement

After implementing process improvement measures in the medium voltage cross-linked cable workshop, the mold calculation and selection, temperature control by grade, vulcanization process matrix, and gradient cooling management actions were fully executed, and production data for six consecutive months were continuously recorded. Before the implementation of the improvement, the comprehensive defect rate of medium voltage cross-linked cables in the workshop was 3.68%, with the main defects being unqualified thermal extension, insulation bubbles, shielding layer defects, and excessive insulation eccentricity. After the implementation of process improvement, the comprehensive defect rate decreased to 1.01%. See Table 1:

Table 1 Comparison of product defect rates before and after process improvement%

Defect Type	Before Improvement	After Improvement
Unqualified thermal elongation	1.04	0.22
Insulation bubble	1.73	0.38
Shielding layer defect	0.24	0.16
Excessive insulation eccentricity	0.67	0.25
Overall Defect Rate	3.68	1.01

(2) Product electrical performance and stability improvement effect

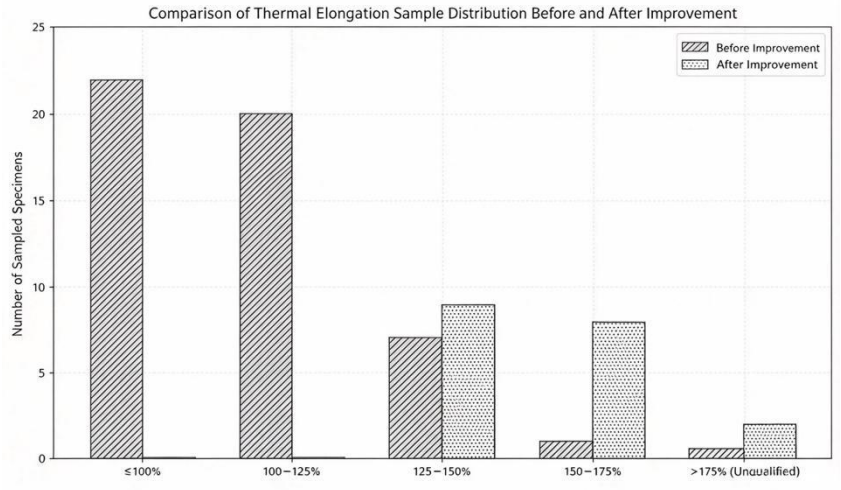


Figure 1 Comparison of Sample Distribution of Thermal Elongation Rate

Before the process improvement, the thermal extension test data in the workshop had high dispersion, and the quality of products in the same batch was uneven, resulting in poor product stability; After the process improvement, the uniformity and stability of the cross-linking reaction significantly increased, and the thermal elongation data was in the qualified range. The unqualified

samples were cleared. Figure 1 shows the comparison of the distribution of thermal elongation samples before and after the process improvement. The insulation eccentricity has been reduced from a maximum of 12% to 8%, which is better than the national standard control requirements; The frequency of abnormal partial discharge and voltage breakdown in cables has significantly decreased, and the overall electrical stability and safety of the product have been improved, resulting in a significant improvement in market quality reputation.

5. Conclusion

In summary, during the production and manufacturing process of medium voltage cross-linked cables, product quality defects may be closely related to the application and operation procedures of mechanical equipment, as well as the manufacturing process. Technical and production management personnel should start from the application of production technology and production process control, and control the quality of different production links in order to continuously reduce product defect rates and stabilize the physical quality of medium voltage cross-linked cable products.

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