A NEW INSTALLATION TECHNOLOGY OF MID-VOLTAGE CABLE JOINT USING RTV SILICONE RUBBER ADHESIVE

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ABSTRACT

The installation quality becomes the main reason causing the insulation failure of mid-voltage cable accessories. In this paper, based on the problem analysis during the installation process, a new installation technology of mid-voltage cable accessories by using RTV silicone rubber adhesive was put forward to eliminate the insulation defects in the conventional installation process. By constructing the insulation testing system, the withstand voltage test, partial discharge check, water-resistant test, surface flashover test and bonding pressure test were conducted to verify the feasibility and safety of the proposed installation method. The test results showed that the proposed method can enhance the operation reliability of mid-voltage cable joints and reduce the technical difficulty of on-site installation.

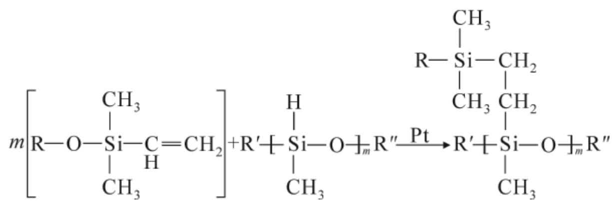
INTRODUCTION

Nowadays, the installation quality of mid-voltage (10-35 kV) cable accessories has become one of main factors affecting the safety operation of mid-voltage cables in distribution system [1]. According to the long-term operation and maintenance experiences of power cables, the main defects causing the electrical breakdown of mid-voltage cable joints are as follows [2-4]: (i) Improper handling of the semi-conductive shielding layer of the power cable causes many insulation defects such as scratches and air gaps. (ii) The sealing performance is not reliable, resulting in the presence of moisture intrusion channels. (iii) After the long-term operation of the accessory insulation, the interface pressure decreases and the control effect of the accessory on the electric field stress decays obviously. At present, it mainly relies on strengthening the project management to avoid the failures, but there is a lack of corresponding on-site technical treatments. Although a kind of two-component cold-bonding adhesive was developed for repairing the sheath insulation of mid-voltage cables, it cannot deal with the insulation defects in the cable body and accessories [5].

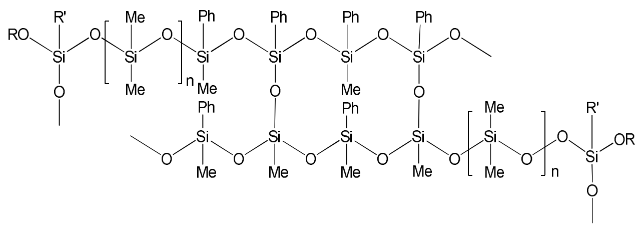
In view of the above problems, this paper proposed an installation technology and insulation testing of mid-voltage cable joint using RTV silicone rubber (SiR) adhesive, which utilized the room temperature vulcanization and adhesion characteristics of RTV to fill the air gap of the insulating interface and ensure the interface pressure and sealing performance. Compared with the traditional technology, this installation technology can significantly improve the insulation performance of the joint, prevent the above defects from causing breakdown of the cable accessory and simplify the technical difficulty of the engineering installation.

RTV ADHESIVE AND ITS COUPLING AGENT

The molecular structure of RTV adhesive and its coupling agent is given in Fig. 1. The two-component RTV is used to control the vulcanization speed through changing the component ratio under different humidities. In order to enhance the adhesion between RTV adhesive and XLPE, the coupling agent was developed by mixing the modified polysiloxane and the azide alkyl siloxane at the ratio of 100:4.



(a) RTV adhesive



(b) Coupling agent

Fig. 1 Molecular structure of RTV adhesive and its coupling agent

MECHANICAL TEST OF CABLE JOINT WITH RTV ADHESIVE

As the adhesion strength of the main insulation and the joint surface by using RTV adhesive is essential to the installation quality, the mechanical test was conducted as shown in Fig. 2 and the results are given in Tab. 1. The average bonding pressure between XLPE and SiR with RTV adhesive is about 0.36 MPa, which is much higher than the obligatory installation critical pressure (0.1 MPa) of cable joint [6].

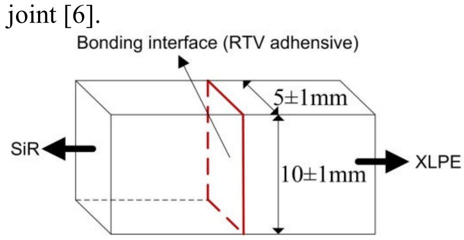


Fig. 2 Schematic of mechanical test

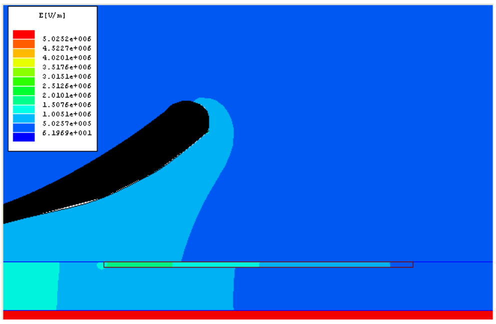
Tab. 1 Results of mechanical test

Testing Number	Contact Area/mm^2	Maximum Tension/N	Calculated Pressure/MPa
1	50	16.7	0.334
2	50	14.6	0.292
3	50	19.4	0.388
4	50	19.2	0.384
5	50	20.1	0.402

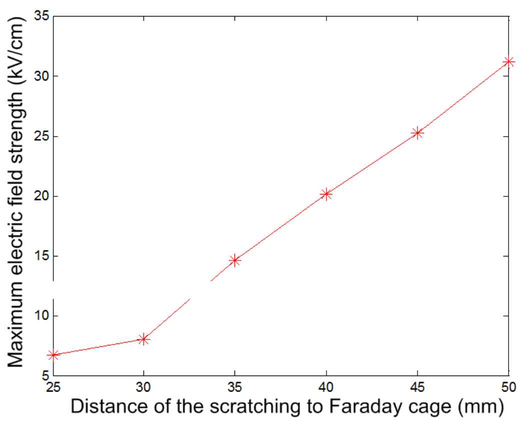
INSULATION TEST OF CABLE JOINT WITH RTV ADHESIVE

Experimental Specimen

Fig. 3 presents the simulation results of effects of the scratching defects on the electric field distribution of cable joint. By using ANSYS software, an 10-cm scratching defect on the main insulation was simulated to obtain the electric field distribution (Fig. 3a) and the relation between the maximum electric field strength and the position of scratching defect (Fig. 3b). It is found that the scratching causes the distortion of electric field distribution and the maximum value appears at the defect, which is mainly affected by the scratching length and its distance to the Faraday cage. With increasing the distance of the scratching to the Faraday cage, the maximum electric field strength shows a sharp increasing tendency.



(a) Electric field distribution with 10-cm scratching



(b) Relation between the maximum electric field strength and the position of scratching defects

Fig. 3 Effects of the scratching defects on the electric field distribution of cable joint

Based on the simulation results, the same scratching defect, with the length of 25 mm, the depth of 1.5 mm and the distance to the Faraday cage of 50 mm, was artificially produced on the cable main insulation. Some of the processed specimens were repaired by using RTV adhesive, and the others were left for the comparison. The cable main insulation with and without using RTV adhesive are shown in Fig. 4.

(a) without using RTV (b) using RTV

Fig. 4 Cable main insulation with and without using RTV adhesive

Interface Breakdown Test

Fig. 5 shows the schematic of interface breakdown test at the interface of XLPE and SiR by using the flat-round electrode pattern with the distance of 5 mm. The specimen dimensions were 20 mm×20 mm×1 mm. The XLPE surface was polished by using 240#, 500# and 1000# abrasive papers. The particle size of abrasive paper is shown as Tab. 2, which makes the surface roughness of 240# > 500# > 1000# [3]. The interface pressure was set at 0.1 MPa by changing the pressure of high-intensity transparent organic glass through the two springs. The AC voltage (50 Hz) was raised at 2 kV/s until the surface discharge occurred at the interface of XLPE and SiR, which is defined as the interface breakdown voltage. Each test was repeated 5 times and the breakdown voltage obtained was the average value.

The interface breakdown voltage with and without using RTV adhesive is shown in Tab. 3. Under the condition of without using RTV adhesive, the interface breakdown voltage can be found to increase with the decrease in the surface roughness of XLPE. It is consistent with the significance of polishing operation during the conventional installation process. The smaller grit of abrasive paper can make the better resistance to the interface discharge, even interface breakdown. However, when using the RTV adhesive for all the specimens, the interface breakdown voltage is almost the same no matter the surface roughness of XPLE is. Meanwhile, the interface breakdown voltage under the condition of using

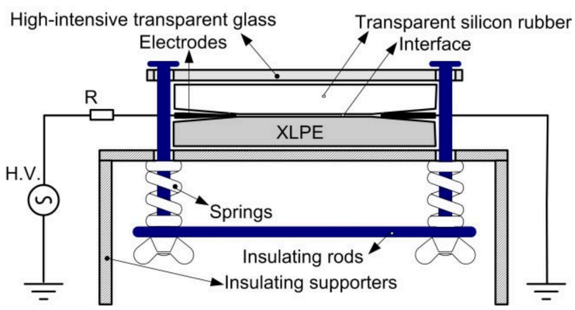


Fig. 5 Schematic of surface breakdown test at the interface of XLPE and SiR

RTV adhesive is much higher than that of without using RTV adhesive. Therefore, the RTV adhesive can effectively repair the mechanical defects on the main insulation during the installation process of cable joint, which improves the insulation reliability of power cable system.

Tab. 2 Particle size of abrasive paper

Abrasive Paper	Particle Size (μm)
240#	35-57.5
500#	20-14
1000#	5-7

Tab. 3 Interface breakdown voltage with and without using RTV adhesive

Specimens	Without Using RTV Adhesive	Using RTV Adhesive
unpolished	3.35	3.82
240#	3.60	3.88
500#	3.65	3.85
1000#	3.72	3.88

Partial Discharge (PD) Test

Installation procedure of cable joint by using RTV adhesive

The installation procedure of cable joint by using RTV adhesive is as the following four steps.

Step 1: According to the specified dimension of the cable accessory manual, it is successive to strip the sheath, steel strips, under sheath and inter-core filler, then to remove the copper shield and outer semi-conductive layer, and finally to clear the main insulation, crimp the copper connecting rod and the copper shielding net.

Step 2: The coupling agent should be coated evenly on the main insulation surface of cable joint, which is required to completely cover the main insulation. It is paid attention to make the covering area of semi-conductive layer on both sides less than 1 cm.

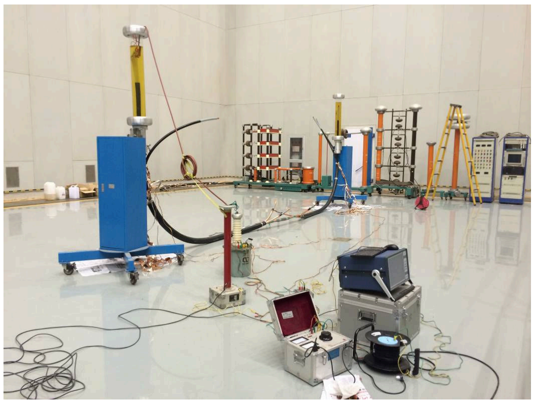
Step 3: The curing time of coupling agent is about 20 minutes. Following this, the RTV adhesive is evenly coated on the surface of coupling agent layer.

Step 4: After about 15 minutes of coating the RTV adhesive, the subsequent installation is completed on the cold-shrink joint at the predetermined position without the silicone grease, the connection of shielding net as well as the guard treatment of cable joint. The complete vulcanization of RTV adhesive is generally controlled about 30 minutes.

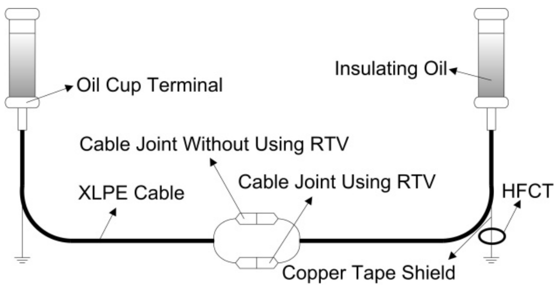
Therefore, the air gaps caused by the scratching of main insulation and the fracture between the outer semi-conductive layer and the main insulation can be automatically repaired by the RTV adhesive. Meanwhile, the good adhesion can be achieved on the interface of the main insulation and the joint, which refrains from the moisture intrusion and the decrease in the interface mechanical pressure.

PD testing system

The PD testing system of cable joint is shown in Fig. 6. A two-phase intermediate joints were connected with two three-core 10 kV cables (3×240 mm^2). One end of the cable was connected to the test equipment through the oil terminal, and the other end was immersed into the oil terminal to achieve insulation. The metal sheath of the cable was grounded at both ends. Once the test voltage was applied on the cable system, the PD detection was respectively conducted by using the pulse current method and the electromagnetic coupling method of high-frequency current.



(a) PD testing laboratory



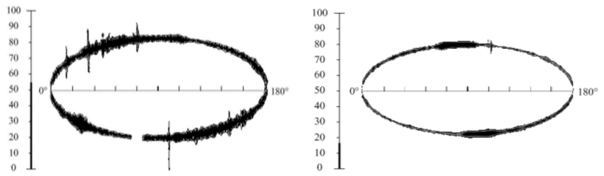
(b) Schematic of PD test

Fig. 6 PD testing system of cable joint

Characteristic analysis of PD signals

The PD signals were measured by connecting the input impedance in series with the coupling capacitor and in parallel with the cable. Firstly, a 50 pC square wave generated by a square wave box was applied to the high voltage end of cable system, which is used to calibrate the PD measuring system. Then, the square wave box was taken away to measure the background noise. Finally, when the test voltage was respectively raised to 6 kV, 10 kV and 15 kV, the PD measurement was carried out to obtain the PD characteristics of cable joint with and without using RTV adhesive, as shown in Fig. 7 and Tab. 4.

The PD signals based on the electromagnetic coupling method of high-frequency current were measured by using the high-frequency current transformer (HFCT). The high frequency characteristics of PD signals of cable joints with and without using RTV adhesive were obtained, as shown in Fig. 8. For the cable joints without using RTV adhesive, the internal discharges can be detected in the cable joint due to the scratching of main insulation. For the cable joints with RTV adhesive, there is no discharge in the cable joint.

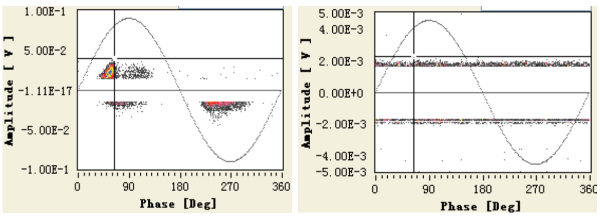


(a) Without using RTV (b) Using RTV

Fig. 7 PD signals of cable joints based on pulse current method with and without using RTV adhesive

Tab. 4 PD quantity of cable joint with and without using RTV adhesive

Test Voltage /kV	PD Quantity /pC	
	Without Using RTV Adhesive	Using RTV Adhesive
6	54.5	15.9
10	278	20.4
15	659	121



(a) Without using RTV (b) Using RTV

Fig. 8 PD signals of cable joints based on electromagnetic coupling method of high-frequency current with and without using RTV adhesive

Withstand Voltage Test

In order to verify the effects of RTV adhesive on the withstand voltage of cable joint affected by the water (moisture) injection, the water ingress system of cable system was constructed, as shown in Fig. 9. The tap water was artificially injected from the water inlet pipe into the cable system (including both XLPE cable and cable joint) through the conductor. When the water flowed out from the water return pipe, the cable system was taken away from the water ingress system and connected to the oil terminals, as shown in Fig. 6.

The AC voltage was applied to carry out the withstand voltage test of cable joints with and without using RTV adhesive. The step-up voltage method was adopted to apply the test voltage on the cable, as shown in Fig. 10. The voltage was raised with the step voltage of U_0 (8.7 kV) and kept for 1 minute at each step. When the breakdown occurred in the cable system, the applied voltage was recorded as the withstand voltage (U_{ws}).

The results of cable joints with and without using RTV adhesive after the withstand voltage test are shown in Fig. 11. It can be obtained that for the cable joint without using RTV adhesive, the breakdown occurred when the test voltage was raised to $5U_0$ for 10 s. Based on the cable anatomy, the breakdown point was found at the

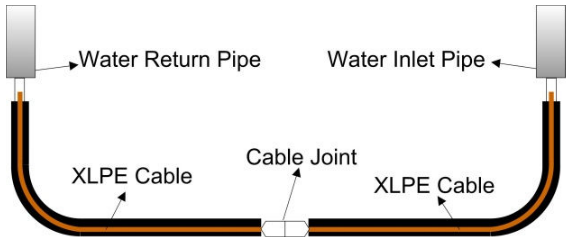


Fig. 9 Water ingress of cable joint

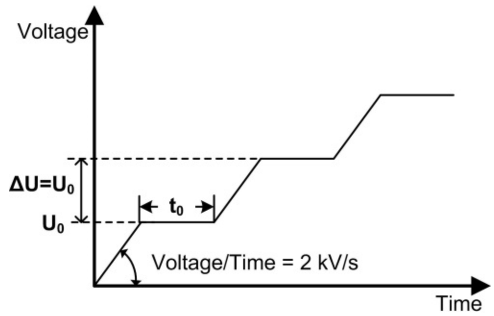
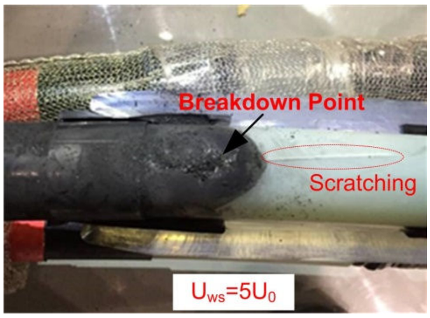
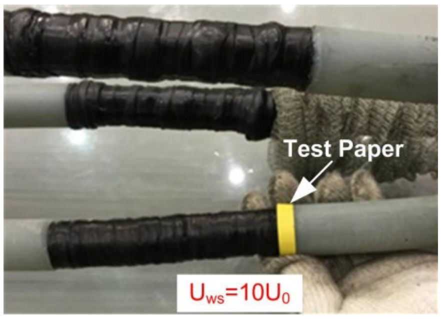


Fig. 10 Step-up voltage method



(a) Without using RTV



(b) Using RTV

Fig. 11 Cable joints with and without using RTV adhesive after the withstand voltage test scratching of the cable main insulation, as shown in Fig. 11a. By using the test paper to the main insulation surface, the paper colour was changed to reveal the existence of water components. However, for the cable joint with using the RTV adhesive, the breakdown cannot occur when the test voltage was raised to 10 U_0 for 10 minutes. After the cable anatomy, the tracks of discharge or insulation failure cannot be found and the colour of test paper was not changed to reveal that there was no water injected into the cable joint, as shown in Fig. 11b. Therefore, the RTV adhesive can effectively restrict the water/moisture ingress to enhance the insulation reliability of cable system.

CONCLUSIONS

This paper puts forward a new installation method of mid-voltage cable joint by using RTV silicone rubber adhesive in order to eliminate the insulation defects in the conventional installation process. By conducting the mechanical and insulation tests, the bonding pressure, interface discharge voltage, the PD characteristics and the withstand voltage under the water ingress were obtained to analyze the insulation reliability of cable joint with and without using RTV adhesive. Main conclusions are as follows.

(1) The proposed installation method can effectively enhance the mechanical and insulation properties of mid-voltage cable joint, which is beneficial to the operation reliability of cable system.

(2) It is suggested that the polishing treatment in the conventional installation process can be neglected, which remarkably simplifies the working time and procedures of cable installation.

(3) The cable joint installed by the proposed method can restrict the typical problems during the cable operation, such as the water/moisture ingress and the decrease in interface pressure of the joint and main insulation.

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