Cold Shrinkable Joint for 66-kV and 110-kV XLPE Cables Applied to Practical Transmission Lines

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ABSTRACT In the overseas market of power cable accessories for 110-kV rating or over, prefabricated joints (PJs) of on-site assembly type are very often designated in the purchasing specifications due to their simple installation and high reliability. In particular, one-piece rubber block joints (RBJs) featuring simple structure and easy installation are growing in popularity thereby replacing epoxy-unit type PJs comprised of epoxy unit and rubber stress cone. In the domestic market for 66-kV rating also, the RBJ is known for its high quality, low cost, and short installation time so that it is going to supplant tape-wrapping joints (TJs) now dominating the market.

In view of these market needs, the authors have successfully developed a cold shrinkable joint (CSJ) as a class of RBJ, in which one-piece molded rubber block is expanded at the factory in advance followed by installation on the cable at the construction site [1]. This is the world's first achievement of factory expansion, cold shrinkable joints with ultra-high voltage rating.

This paper reports on the first application of this factory expansion, cold shrinkable joint to practical transmission lines.

1. INTRODUCTION

Among various means to upgrade the quality of cable joints, the use of prefabricated joints (PJs) goes a long way, in which joint components are fabricated in the factory in advance under consistent quality control followed by assembly at the construction site. These PJs are going to prevail in the domestic as well as overseas market of power cable accessories due to their high reliability. In particular, rubber block joints (RBJs) using one-piece molded rubber block for the main insulator are overwhelming the market, armed with simple structure and excellent installation performance.

In the domestic market where efficiency and avoiding waste are earnestly required due to the harsh economic conditions, the RBJ is expected to enable short-time installation and cost reduction, while upgrading the quality and reliability of installation.

Domestically, tape-wrapping type joint (TJ) in which ethylene-propylene rubber tape is wrapped using a taping machine perpendicular to the electric field gradient for insulation is typical of cable joints for 66-kV CV cables, and the joint has a track record of more than 10,000 phases. While the TJ can carry out installation at a pace of three phases per three days, the RBJ that permits installation in shorter time is coming in as a new approach to cost reduction.

When it comes to overseas market, the construction of electric cable networks is being carried out flourishingly in East Asia especially; and exploding growth in the demand for electric power accompanied by economic development sometimes results in a huge construction project that includes a total cable length in excess of 50 km. In these construction projects, demand focuses on prefabricated joints for 110-kV rating which permit easy installation without the need for dedicated apparatuses. Heretofore, the market of prefabricated joints has been dominated by the epoxy-unit PJs that combine epoxy unit and rubber stress-relief cone --a design based on the concept of termination joint. Recently, however, RBJs have inevitably risen in this field since they have fewer components and they are able to finish the assembly work of the main insulating portion simply by mounting the molded rubber block onto the cable insulator. RBJs are simple in structure and permit easy assembly, thus enabling total cost reduction through the cost merit of the reduction of installation time.

We have developed a state-of-the-art RBJ called cold shrinkable joint (CSJ), which is based on a factory-expan-

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Figure 1 110-kV expanded rubber unit with carrier pipe

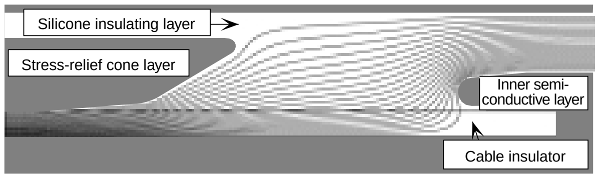


Figure 2 Calculated electric field distribution of rubber unit

sion, room temperature shrinking scheme [1]. In this innovative jointing technology, silicone rubber is used for the one-piece molded rubber block serving as main insulator; and taking advantage of low mechanical stress relaxation, i.e., small permanent set of the material, the rubber block is expanded to a diameter greater than that of the cable sheath using a carrier pipe called spiral core at the factory in advance (See Figure 1); and it is installed on the cable at the site simply by pulling out the spiral core. Thus, customers can elude purchasing the expansion apparatus including hydraulic machinery thereby lessening the burden of initial investment. This fact helps considerably in promoting our sales campaigns advantageously.

We have achieved the world's first supply, in the field of ultra-high voltage cables, of one-piece rubber block joints of factory-expansion type using silicone rubber. This paper reports on the technological characteristics of these joints together with their application to practical transmission lines.

2. FACTORY-EXPANSION, COLD-SHRINKABLE, SILICONE RUBBER JOINT

2.1 Characteristics of Cold Shrinkable Joint

(1) Factory Expansion and Low Permanent Set

While cold shrinking technology has been widely used in many applications besides power cable jointing, we have been successful in improving its working efficiency significantly by using silicone rubber.

In the case of one-piece rubber block using ethylene-propylene rubber, the expansion ratio can not be as great as that of silicone rubber due to the limitations of stress relaxation characteristics of the material. Moreover, it is indispensable to use an expansion apparatus including hydraulic machinery at the site --hence, it is called site-expansion type-- since the period of time allowed for maintaining sufficient strain is as short as a few hours. By selecting silicone rubber with excellent stress relaxation characteristics in contrast, we have achieved a factory-expansion type in which the rubber unit is expanded at the factory in advance and, at the site, installation work is completed simply by pulling out the end of a spiral core string that is formed into a cylinder, so that the unit shrinkage is effected at room temperature without using any special tool. This technology can ensure a sufficiently long period of the unit expansion --to a size larger than that of the cable sheath diameter-- even for exported products where product maintenance is extremely difficult after delivery.

(2) Structure Simplification

Simplification of the product structure leads to cost reduction through both material cost and installation cost. In this regard, the CSJ is an integrated rubber unit comprised of inner semi-conductive layer, outer semi-conductive layer, stress-relief cone layer, and silicone insulating layer, thus enabling a great deal of components unification in comparison to epoxy-unit PJs in particular.

In addition, unlike epoxy-unit PJs, one size of CSJ can be assigned to a plurality of cable sizes resulting in a cost reduction. This is because, so long as the inner diameter of a CSJ rubber unit remains within a certain range smaller than the outer diameter of a cable insulator, the unit adheres with sufficient strength to the cable, whereby the unit is expanded and subsequently fitted onto the cable.

2.1.1 Key Design Factors

Key factors in designing a combination of different insulators are to ensure an appropriate interfacial pressure at the interface between the insulators as well as to control an optimized distribution of electric fields. CSJs maintain the interfacial performance between the surface of the cable insulator by making use of their intrinsic contraction force without using any pressurizing apparatus based on spring. If stress relaxation occurs, i.e., rubber slackens due to expansion hysteresis, the interfacial electric performance degrades considerably. Therefore, the material characteristics have to be carefully selected so as to prevent this degradation.

In terms of electric field distribution, it is optimized by means of conductive silicone rubber that is molded integrally with the insulating silicone material. See Figure 2. As can be seen, these materials together with the advanced molding techniques support the foundation of the CSJ technology, based on which the CSJ rubber unit never separates nor tears even when the unit significantly changes its geometry during expansion and contraction.

The carrier pipe or the spiral core poses another important task in the application of factory-expansion to ultra-high voltage cables. Through careful investigations, we have optimized the geometry and molding technique of the spiral core string that offers a sufficient strength to

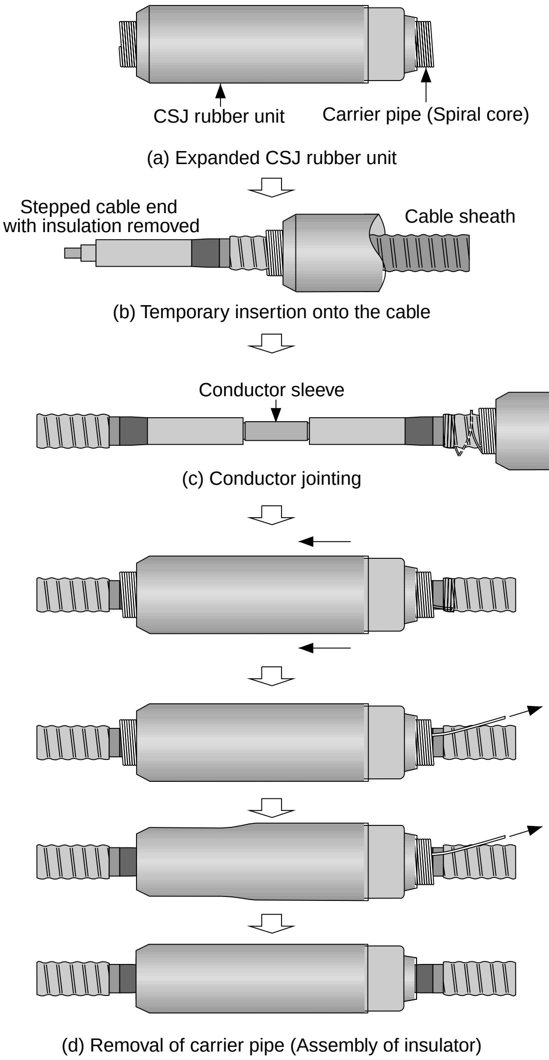


Figure 3　Assembly procedures of CSJ

Figure 4　110-kV rubber unit inserted onto cable

Figure 5　Assembled CSJ for 110-kV XLPE cable

Figure 6　66-kV rubber unit inserted onto cable

support the great contraction force associated with expansion as well as an excellent property for core withdrawal.

2.2 Assembly Method of CSJ

The simplicity of assembling the rubber unit to form the insulator is no doubt the most distinguished advantage of factory-expansion type CSJs using silicone rubber. See Figure 3.

Generally speaking, the most critical operation in jointing work is the assembly of insulator. PJs are commonly considered to be stabilized in quality necessitating fewer quality control measures on site, since they are assembled on site using insulators electrical characteristics thereof are verified at the factory before shipping. Among PJs, CSJs with one-piece rubber block insulation, in particular, are believed to be extremely free from interference by foreign inclusions and external injuries to cause electrical degradation, since they have fewer components and the assembly is completed in short time. Because the expansion work is finished at the factory before shipment, only the interface between the cable insulator and the insulator unit has to be taken care of not to be interfered by unexpected elements at the time of assembly on site. See Figures 4, 5, and 6. It can be said that the CSJ technology has approached an ideal state of consistent quality control encompassing the factory and the site. See Table 1.

2.3 Installation Process

The one-piece insulator enables the reduction of installation hours in addition to the simplification of constituting components thus leading to the material cost down. For example, whereas epoxy-unit type PJs of 110-kV rating for overseas specifications take about eleven days per

Table 1 Comparison of PJ, TJ, and CSJ in structure and installation method

Item	110-kV epoxy-unit PJ	66-kV TJ	66~110-kV CSJ	Evaluation of CSJ
Structure (insulation)	Epoxy-unit with metallic electrode	EP rubber tape	One-piece silicone rubber unit	• Simple structure and easy installation • Unlikely to contain foreign inclusions and external injuries
	EP rubber stress relief cone			
	Compression device			
Assembling method	Rubber stress relief cone is pressed against epoxy unit by compression device	Rubber tape wrapping by taping machine	Shrinkage of rubber unit at room temperature and spiral core removal	
Interface pressurizing	Compression force of spring	Tape wrapping tension	Compression force of rubber	
Installation hours	11 days/3 phases	3 days/3 phases	66 kV(domestic): 2 days/3 phases 110 kV(overseas): 3~4 days/3 phases	• Short-time installation • Cost reduction in both material and work
Cost	Many components	Taping machine needed	Few components; short installation hours; special apparatus not needed	

Table 2 Comparison of 110-kV PJ and CSJ in installation process

Days	Epoxy-unit PJ	CSJ
1	Cable cutting; preparation for cable straightening	Cable cutting; shaving outer semi-conductive layer
2	Cable straightening	Assembly; waterproofing
3	Shaving outer semi-conductive layer; cable processing for phase 1	Assembly; waterproofing
4	Assembly for phase 1	(Assembly; waterproofing)
5	Assembly and waterproofing for phase 1	-
6	Shaving outer semi-conductive layer; cable processing for phase 2	-
7	Assembly for phase 2	-
8	Assembly and waterproofing for phase 2	-
9	Shaving outer semi-conductive layer; cable processing for phase 3	-
10	Assembly for phase 3	-
11	Assembly and waterproofing for phase 3	-

Note: 110-kV CAZV cable is exemplified. Likely to change depending on installation conditions.

Table 3 Comparison of 66-kV TJ and CSJ in size and installation days

	TJ	CSJ
Size in mm (entire length x outer diameter)	L 1190 × ϕ135	L 800 × ϕ135
Installation days *1	3 days / 3 phases	2 days / 3 phases

Note *1: 66-kV CV-T cable is exemplified. Likely to change depending on installation environments.

Figure 7 Assembled CSJ for 66-kV XLPE cable

three phases for installation, CSJs take three to four days per three phases. See Table 2.

In the case of domestic 66-kV joints, while conventional TJs used to be assembled at a pace of three days per three phases, it was further shortened to two days per three phases through the adoption of the one-piece rubber block structure and the optimization of the work process. Moreover, as shown in Table 3, the length of the outer casing is shortened by 400 mm in comparison to TJs, so that increased applications to manholes are expected where the offset dimensions are under tight limitations. See Figures 7 and 8.

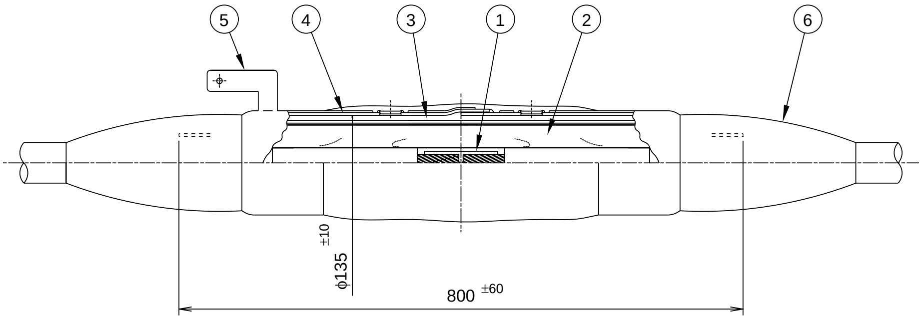
Figure 9 shows the structure of a 110-kV CSJ for comparison.

2.4 Electric Performance of CSJ

Tests are carried out in accordance with customers' specifications at the time of delivery. In terms of 110-kV specifications, CSJs have passed the type tests in conformity to the IEC standards under the presence of the third-party agency. See Table 4 [1]. As for 66-kV specifications, they have passed the test items stipulated in accordance with JEC-3408 standard including a long-term test for one month as shown in Figure 10. See Table 5.

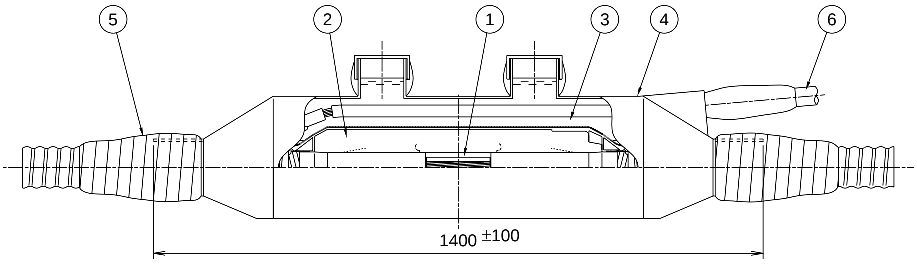
3. CONCLUSION

A factory-expansion, cold shrinkable joint (CSJ) of one-piece rubber unit type has been developed for 66-kV and 110-kV ratings as a class or prefabricated joints, success-



No.	Name of parts
6	Anti-corrosion layer
5	Grounding wire lug
4	Outer casing
3	Waterproof compound
2	Rubber unit
1	Conductor sleeve

Figure 8 Structure of CSJ for 66-kV XLPE cable



No.	Name of parts
6	Bonding wire
5	Anti-corrosion layer
4	Outer casing
3	Waterproof compound
2	Rubber unit
1	Conductor sleeve

Figure 9 Structure of CSJ for 110-kV XLPE cable

Table 4 Electrical Characteristics of 110-kV CSJ in accordance with IEC 60840

Item	Characteristics
Partial discharge	When loaded with AC 112 kV for 10 seconds followed by gradual lowering down to 96 kV, no partial discharge should be observed at room temperature
tan δ (high temperature)	Loading voltage: AC 64 kV Conductor temperature: 95~100°C Specified value: 0.001 or less
AC heat cycle test	Loading voltage: 128 kV Temperature rise: Room temperature to 95~100°C (Heater: 8hr ON / 16 hr OFF) After 20 times, partial discharge should be measured at room- and high-temperatures
Lightning impulse test	Loading voltage: ±550 kV, 10 times each Conductor temperature: 95~100°C After loading, no breakdown should occur when AC 160 kV is applied for 15 min
Water immersion heat cycle test	Water depth: At least 1 m from joint upper end to water surface Water temperature: Room temperature ±10°C to 95~100°C High temperature duration: At least 5 hr Heat cycle: 20 times
Post water imersion test DC withstand test	Loading voltage: 20 kV Loading time: 1 min
Lightning impulse withstand test	Between parts: ±75 kV, 10 times each Each part to earth: ±37.5 kV, 10 times each

fully passing the tests in accordance with JEC-3408 and IEC standards.

With this new joint using silicone rubber of excellent

Figure 10 Long-term test of 66-kV CSJ

Table 5 Electrical Characteristics of 66-kV CSJ in accordance with JEC 3408-1997

Item	Characteristics
Long-term loading or commercial frequency withstand voltage	65 kV (8 hr ON /16 hr OFF cycle) Conductor temp. of room temp.~90°C: 25 times room temp.~105°C: 5 times or, 130 kV·1hr at room temp. for conductor
Lightning impulse withstand voltage	±485 kV, 1 hr at room temperature for conductor
Lightning impulse withstand voltage for anti-corrosion layer	-40 kV, 3 times
Watertightness	98 kPa, 1hr

Table 6 Track record of 66-kV and 110-kV CSJ

Destination	Cable size	Quantity (phase)
Domestic electric power companies	66 kV 325 mm^2	18
	66 kV 325 mm^2	9
Overseas electric power companies	110 kV 800 mm^2	6
	110 kV 400 mm^2	12
	110 kV 400 mm^2	18
	110 kV 630 mm^2	12
	110 kV 300 mm^2	30
	110 kV 400 mm^2	9
	110 kV 400 mm^2	6

stress relaxation property, the following has been realized.

(1) Simplification of installation equipment, improvement of installation efficiency, and shortening of installation hours at the site
(2) Downsizing of joints
(3) Cost down in both material and installation

Using the advantages of easy and short time installation, we have received orders of more than 100 phases in the first half of 2000 as shown in Table 4. In the future, applications are expected to expand to high-voltage areas.

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