Development of Cold-Shrinkable Straight-Through Joints for 22-kV XLPE Cables

by *Hideo Takei* [*], *Kazutoshi Mochizuki* [*], *Koichi Yokosuka* [*], *Kouzou Takahashi* [*2], *Isao Takaoka* [*2], *Toyoaki Tashiro* [*3], *Hideo Kawahara* [*4] and *Yoshinari Hane* [*2]

ABSTRACT In the electric power distribution field of these days, cable joints are required to be low in cost, easier to install, take less time to install, and applicable to more space-limited places. Against this background, the authors have developed cold-shrinkable straight-through joints for use specifically with 22-kV XLPE (cross-linked polyethylene) cables. The developed joints and accessories proved, through the initial and long-term evaluation, to have satisfactory performance, offering outstanding ease of installation.

1. INTRODUCTION

Straight-through joints for 22-kV XLPE cables now used in electric power companies come generally in three types -- slip-on type, prefabricated-composite type, and taping type; and they are specified in Electric Utility Standard 1998. The current situation of the electric power distribution field requires that cable joints be low in cost, easier to install, take less time to install, and applicable to more space-limited places, resulting in an urgent need for developing a new type of joint.

In response to such a need, Furukawa Electric has been developing, jointly with Tokyo Electric Power Co., cold-shrinkable straight-through joints that would meet the above-mentioned requirements. This paper presents an overview of the process of developing the new joints, which not only meet such requirements but also have satisfactory performance including ease of installation.

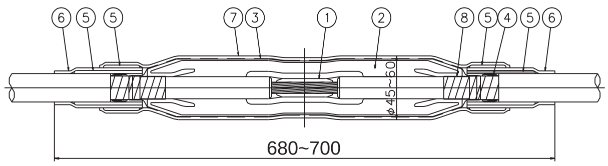
2. DESIGN OF NEW STRAIGHT-THROUGH JOINT

2.1 Target Specifications

Table 1 shows target specifications. Because the development program had started before the relevant standards -- High Voltage Tests on Cross-linked Polyethylene Insulated Cables and their Accessories for Rated Voltages from 11 kV up to 275 kV (JEC-3408-1977) and Electric

Table 1 Target specifications

Item		Target performance
Partial discharge at commercial frequency voltage		10 pC or less at 17 kV
Long-term withstand voltage at commercial frequency		57 kV/3 hrs.
Lightning impulse withstand voltage		
	Normal temperature	-230 kV/3 times
	High temperature	±165 kV/3 times
DC withstand voltage		-64 kV/1 hr.
Temperature cycling		105°C/3 hrs x 3 times
Short-circuit current loading		24 kA/2 sec.
Waterproofness		98 kPa at outer pressure x 1 hr.
Load cycling	In air	27 kV at 90°C conductor temp. 8 hrs. ON, 16 hrs. OFF/30 cycles
	In water	Same as for "in air" with joints immersed in water
Installation work		Reduced skill level and ease of installation



① Connector
② Insulation layer of splice body
③ Shielding layer
④ Tin-plated soft copper wire
⑤ Sealing mastic
⑥ Waterproof tube (Small)
⑦ Waterproof tube (Large)
⑧ Adhesive cross-linked polyethylene tape

Figure 1 Structure of cold-shrinkable straight-through joint

[*] Tokyo Electric Power Co.
[*2] Silicone Products Development Team, Power Cable Accessories Div.
[*3] Engineering Sec., Production Dept., Power Cable Accessories Div.
[*4] 2nd Engineering Sec., Distribution Cables & Accessories Engineering Dept., Power Cable Accessories Div.

Utility Standard 1998-- were published or amended, the design intended to meet the old standards --JEC-209 and Electric Utility Standard 1979. However, it is also applicable to the new standards mentioned above.

The design adopted cold-shrinkable method working on site to make the installation work more efficient and less skill-oriented, so that the site work is improved in terms of elimination of flame tools and adjustment of insertion force. The structure of the developed product is shown in Figure 1.

2.2 Design

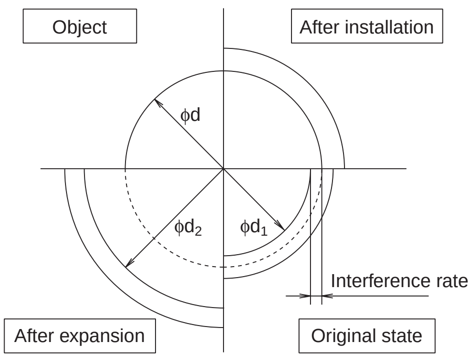
2.2.1 Installation Method

Components of cold-shrinkable joints are expanded in factory and shipped as expanded fitted on inner core, that is expansion support. Then on the site, shrinking and installation is completed simply by pulling out the inner core without using heat or insertion force, thereby eliminating any special tools for expansion or shrinking.

2.2.2 Basic Concept of Cold-shrinking

Cold-shrinkable products have to meet not only electrical but also mechanical requirements when installed by the on-site shrinking method mentioned above. Figure 2 illustrates diameter changes during cold-shrinking.

Interference rate for installation on the object is one of the most important elements that control the product performance, since this induces interference pressure. In addition, sufficient clearance with respect to the object is needed from the standpoint of ease of installation. Thus, proper selection of cold-shrinkable material properties is essential to make these two elements compatible with each other. Suitable combinations of these elements will lead to unification of applicable cable sizes and usable cold-shrinkable splice bodies as well as elimination of reducer, thereby contributing a great deal to cost down due to components number reduction.



ϕd: Outside diameter of object
Outside diameter of cable insulation or finished cable
ϕd_1: Inner diameter of original cold-shrinkable tube
Inner diameter of original cold-shrinkable tube to ensure required interference pressure with respect to the object
ϕd_2: Inner diameter of expanded cold-shrinkable tube
Inner diameter with a clearance for passing over the object

Figure 2 Diameter changes during cold-shrinking

2.2.3 Materials

(1) Splice body

In the cold-shrinkable technology, stress relaxation characteristics including permanent elongation set and their temperature dependence are major design parameters to be considered from the standpoint of quality assurance in terms of diameter expansion period and long-term performance after installation. Although ethylene-propylene rubber (EP rubber) is mainly used for jointing materials nowadays, silicone rubber is superior to EP rubber in these mechanical properties. See Table 2. We decided, therefore, to use silicone rubber for the splice body, a major insulating component, based on our evaluation that the material is suitable for cold-shrinkable products.

(2) Waterproof protective cover

It is required to assume that the cold-shrinkable joints are used fully immersed in water. Since silicone rubber is inferior to EP rubber in the water-imperviousness at full water immersion irrespective of its high hydrophobic properties, we decided to use EP rubber for the waterproof cover of cold-shrinkable joints.

2.3 Detailed Design of Splice Body

2.3.1 Electric Field Design

The electrical stress of every portion of joint shown in Figure 3 was calculated by electric field analysis, and dimensions of the splice body were determined by optimizing such stresses as follows.

Table 2 Material properties of silicone and EP rubbers

Item	Silicone rubber	EP rubber
Ultimate elongation	790%	750%
Tensile strength	10 MPa	9.3 MPa
Hardness (JIS-A)	34	60
Tear strength (JIS-A)	21.5 N/mm	11.8 N/mm
Permanent elongation set at 100%	2.6%	32.4%
Dielectric breakdown strength	20 kV/mm	20 kV/mm

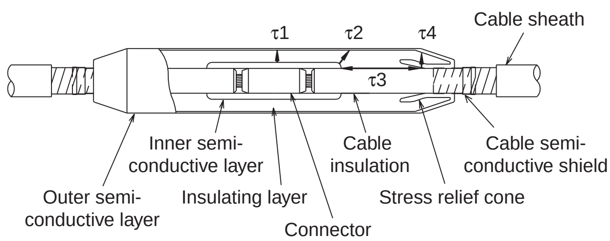


Figure 3 Structure of splice body and its electrical design

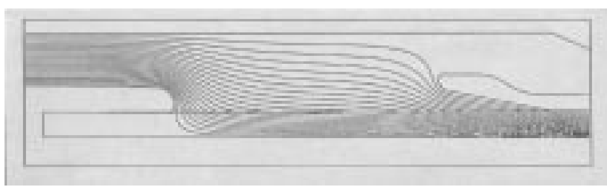


Figure 4 Result of electric field analysis for designing splice body

τ1: Stress at the level portion of the inner semiconductive layer
τ2: Stress at the end portion of the inner semiconductive layer
τ3: Stress along the XLPE/rubber interface
τ4: Stress at the rising portion of the outer semiconductive layer

Figure 4 shows the result of electric field analysis over the dimensioned splice body, which optimizes the stress balance.

2.3.2 Interference Pressure Design

The inner pressure of cable is calculated as 3.7×10^4 Pa, or 4.9×10^4 Pa allowing for a margin of safety, using Boyle-Charles law and neglecting expansion of cable for a maximum cable temperature difference of 105°C (-15°C ~90°C). This inner pressure is to be counteracted by the interference pressure of splice body due to interference, so that sufficient interference pressures are maintained to suppress interface gap even after an elapse of 30 years.

The interference pressure of splice body is calculated by the following equation, in which the body is considered as a circular cylinder under inner pressure with its both ends open.

$$P = \frac{(b^2 - a^2)}{(1-\nu)a^2 + (1-\nu)b^2} \times \frac{\delta}{a} \cdot E$$

where, P is the interference pressure, a and b are the inside and outside diameter of original tube, ν is Poisson's ratio, δ is the diameter interference, and E is Young's modulus.

2.4 Design of Inner Core

The splice body and the waterproof tube are maintained and stored mounted on the inner core, enabling easy installation by cold-shrinking on site without using any special tool. Thus, the inner core plays an important roll in implementing cold-shrinking.

2.4.1 Material

Although the inner core is an important component that influences expansion-holding and cold-shrinking, it eventually turns into waste when installation is finished. Accordingly, we selected polypropylene and polyethylene for its material, which have appropriate strength to maintain expanded products as well as recyclability after use.

2.4.2 Strength of Inner Core

The inner core has to be designed to ensure a sufficient mechanical strength so as to withstand the pressure due to products expanded to the required diameter. Hence, we calculated the hoop stress of the expanded product which generates the product's inner pressure, and determined the supporting strength of the inner core to withstand this pressure.

Calculation of hoop stress

σ_θ = modulus x elongation due to expansion

Calculation of the inner pressure of product generated by expansion

$$P_a = \frac{(k^2 - 1)}{(k^2 + 1)} \times \sigma_\theta$$

$$k = b_e / a_e$$

where, a_e is the inside diameter after expansion, b_e is the outside diameter after expansion, and P_a is the generated inner pressure. Further, a_e and b_e are calculated assuming that the cross section of cold-shrinkable tube remain the same before and after expansion.

Calculation of the supporting strength of the inner core

$$P_b = \frac{2 \times t \times \sigma_{pp} / S}{D}$$

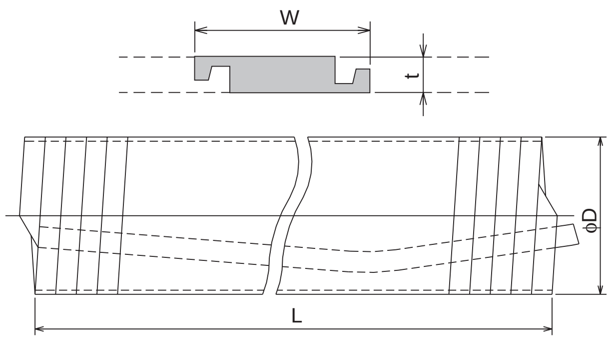


Figure 5 Structure of inner core and cross section of core ribbon

Photo 1 Splice body (right) and waterproof tube (left) before expansion

Photo 2 Splice body (right) and waterproof tube (left) after expansion

where, t is the thickness of inner core ribbon, σ_{pp} is the yield stress of inner core ribbon, S is a safety factor, and D is the inside diameter of inner core.

2.4.3 Structure of Inner Core

The inner core comprises a core ribbon having L-shaped edges, which is formed into a pipe under optimal welding conditions such that the core keeps expanded products properly but collapses easily at on-site shrinking without using any special tool. See Figure 5.

3. EXPANSION TECHNIQUE

An expansion apparatus which expands cold-shrinkable products and transfers them onto inner cores has been developed, enabling easy expansion without causing slightest damages thanks to its low friction resistance. See Photos 1 and 2.

Table 3 Results of initial performance tests

Item	Results
Partial discharge at commercial frequency voltage	No occurrence
Long-term withstand voltage at commercial frequency	Good
Lightning impulse withstand voltage	
Normal temperature	Good
High temperature	Good
DC withstand voltage	Good
Temperature cycling	Good
Short-circuit current loading	Good
Waterproofness	Good

Table 4 Results of load cycling tests

Item		Results
30 cycle test	In air	Good
	In water (normal temperature)	Good
180 cycle test	In hot water at 60°C	Good

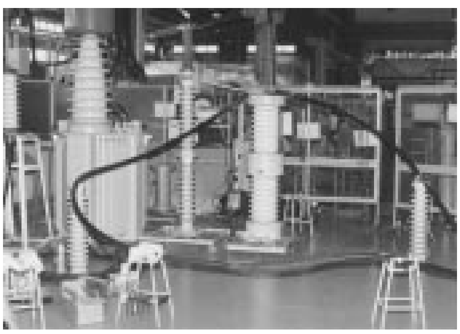


Photo 3 Load cycling test

4. EVALUATION OF PRODUCT PERFORMANCE

4.1 Initial Performance

Table 3 gives the test results of the developed product for the initial performance, showing that every test item meets the target specifications. In particular, the result of lightning impulse withstand voltage test at high temperatures, which was specified in consideration of the IEC specifications, was found to be equivalent to that of at normal temperatures.

Moreover, long-term withstand voltage test at commercial frequency and lightning impulse withstand voltage test were conducted on the specimens that underwent temperature rise test and short-circuit current loading test, and their breakdown voltages were equivalent to those of initial state, thus confirming excellent performance.

4.2 Long-term Performance

In addition to load cycling test in air with 30 cycles, test in water with 30 cycles as well as test in hot-water with 180 cycles for 6 months were also conducted, and satisfactory

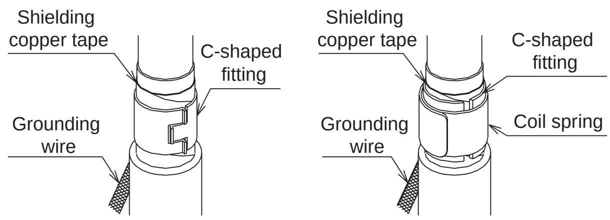


Figure 6 Structure of solder-less fittings

Table 5 Evaluation items of solder-less grounding fitting

Evaluation item / Test item	Test results
Basic performance	
Contact resistance	To be measured every 25 cycles of normal mode test
Temperature rise	To be measured every 25 cycles of normal mode test
Normal mode performance	
Heat cycle and sheath current loading	Conditions of conductor heat cycle Conductor temperature: 90°C 4 hrs. ON - 4 hrs. OFF/ cycles Conditions of sheath current loading Sheath circulating current: 16 A 1 hrs. ON - 1 hrs. OFF/ 500 cycles
Failure mode performance	
Large current loading	Loading current: 650 A 2 sec ON - 1 min. OFF/ 3 cycles

Table 6 Test procedures for fittings

Evaluation item	Test item
Normal mode performance	Basic performance→Normal mode performance
Failure mode performance	Basic performance→Failure mode performance → Normal mode performance

results were obtained. Residual performance was evaluated subsequently for withstand voltage at commercial frequency and lightning withstand voltage, and it was confirmed that the performance was comparable to that of initial state. See Table 4 and Photo 3.

5. Development of Accessories

5.1 Grounding Fitting

5.1.1 Structure and Evaluation Method of Solder-less Grounding Fitting

The structure of grounding fitting was studied to make it solder-less and the installation work easy using no flame tools. Figure 6 shows the structures of two types of the fittings thus studied. Tables 5 and 6 show the items of the evaluation test and the test procedures, respectively.

5.1.2 Evaluation Results

Two types of solder-less fittings and a conventional soldering samples were evaluated in addition to a bare cable shielding material, using new cables. Satisfactory results were obtained as shown in Figures 7 and 8, in which resistance changes during the normal mode and failure mode tests are seen to be small compared with those of the bare cable shielding material.

When it comes to installed cables, it should be noted that the same tests as for the new cables have to be carried out to confirm their reliability.

5.2 Fixing Fitting for Joint

The length of the fixing fitting for joint was set to be the same as for the existing tray, considering the interval of supporting fittings in the manhole.

Joints were clamped by the three-core bundling method, since the joint diameters were diversified according to the cable size due to the jointing method based on cold-shrinking.

Furthermore, plastic covers were provided to protect the joints. See Figure 9.

5.3 Verification of Improved Installation

Compared with the existing slip-on type joints that are most frequently used, the developed product reduces the installation time by 17-28%.

Moreover, the working cable length required was reduced to 80% of that of slip-on straight joints due to the

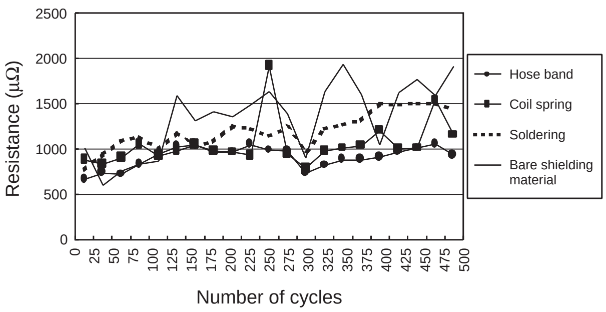


Figure 7 Results of normal mode test

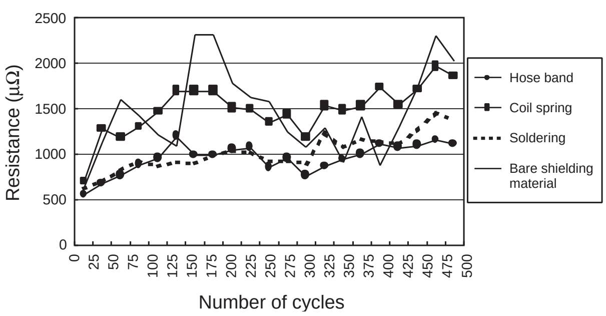


Figure 8 Results of failure mode test

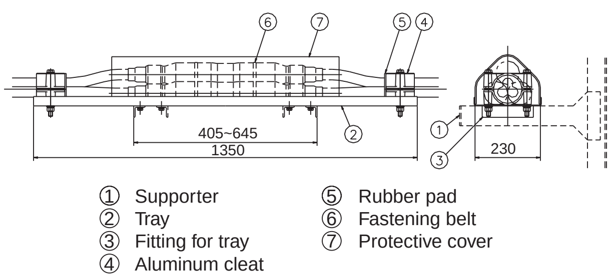


Figure 9 Fixing fitting and cover for the joint

Table 7 Required time and cable length for installation

Type of joint	Installation time	Cable length
Slip-on straight joint Cable length	180-210 min	2500 mm
Cold-shrinkable straight joint	150 min	2000 mm

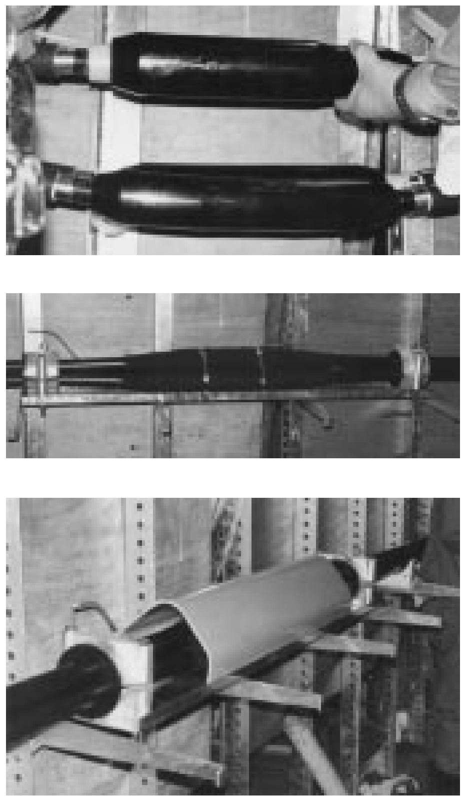


Photo 4 Installation of cold-shrinkable joint

reduction in parts number as well as upgrading of installation techniques and procedures. See Table 7 and Photo 4.

6. CONCLUSION

In an effort to develop a new type of straight-through joint for 22-kV XLPE cables, the authors developed cold-shrinkable straight-through joints based on factory expansion, which not only meet the target specifications but also improve installation work significantly. The following improvements have been achieved.

1) Upgrading of ease of installation
2) Sufficient and stabilized electrical performance
3) Reduction of installation time
4) Reduction of working cable length required
5) Cost reduction

REFERENCES

1) Mochizuki et al.: Development of a New Type of Straight-through Joint for 22-kV XLPE Cables, 344, Electric Power and Energy Div., IEEJ Conference, 1999. (in Japanese)

Notes

1) Manuscript received on November 22, 1999.
2) Printed on January 21, 2000.
3) To be published in Furukawa Review No.19, April 2000.