Development of Factory-Expanded Cold-Shrinkable Joint for EHV XLPE Cables

Shozo Kobayashi, Daisuke Muto, Satoru Tanaka, Hiroyuki Iizuka
The Furukawa Electric Co., Ltd.
6, Yawatakaigan-dori, Ichihara, Chiba 290-8555, Japan
Tel. +81-436-42-1713 / Fax. +81-436-42-9341
skoba@ch.furukawa.co.jp

Hiroshi Niinobe
Fujikura Ltd.
42-1, Shintomi, Futtsu-shi,
Chiba 293-0011, Japan
Tel. +81-439-80-1555 / Fax. +81-439-80-1595
hniinove@fujikura.co.jp

Masahiro Suetsugu
Viscas Corporation
4-13-14, Higashi-Shinagawa, Shinagawa-ku,
Tokyo 140-0002, Japan
Tel. +81-3-5783-1855 / Fax. +81-3-5783-1870
m-suetsugu@viscas-j.co.jp

Abstract: We studied the installation process, interfacial property, insulating property, elastic property, and thermal behaviour of joints for EHV XLPE cables, and succeeded in applying cold-shrinkable technology to one-piece premoulded joints using silicone rubber, which has superior elasticity and good insulating properties. One rubber unit is applicable to various cable sizes, allowing it to be used to joint cables of different sizes (e.g., 1800 mm^2 – 800 mm^2).

Keywords: one-piece premoulded joint, EHV, XLPE cable, cold-shrinkable joint, interfacial pressure

Résumé: Nous avons étudié le procédé d'installation, les propriétés d'interface et le comportement thermique d'un joint pour cable XLPE à extra haute tension (EHT). Nous avons réussi à appliquer la techniq ue de rétraction à froid à des joints prémoulés d'une pièce en caoutchouc aux silicones. Ce joint a des caractéristiques d'élasticité et d'isolement remarquables. Le même joint de caoutchouc peut être adapté à diverses sections de cable et permet également la jonction de cables de section différente. (par exemple: 1800 et 800mm^2).

Mots clés: Joint prémoulé d'une pièce; EHT; cables XLPE; joint rétractable à froid; pression d'interface.

1. Introduction

We have been pursuing the ideal application of one-piece premoulded joints to EHV XLPE cables. We studied the quality function deployment of EHV XLPE cable joints and found that factory-expanded cold-shrinkable technology provides an ideal solution for such a joint.

We studied the installation process, interfacial property, insulating property, elastic property, and thermal behaviour of premoulded joints up to 400 kV-class, and succeeded in applying cold-shrinkable technology to premoulded joints using silicone rubber, which has superior elasticity and good insulating properties. With cold-shrinkable technology, a premoulded rubber unit is shipped expanded onto the carrier pipe. The carrier pipe is made of a plastic string and can be removed easily by hand. The user therefore requires no tools for assembly at the jointing site and simply has to pull out the carrier pipe. The required insulating properties of the rubber unit can be tested in the factory, and the expansion process of the rubber unit is carried out in the clean, controlled conditions of the factory. The installation process can thus maintain the high reliability of the insulating properties of the joint.

In a one-piece premoulded joint, the interfacial property is important as a guarantee of quality because the insulating property inside the rubber unit can be tested in the factory. Interfacial pressure is an important parameter of the interfacial insulating property. The interfacial pressure between a one-piece premoulded joint and the cable insulation is caused by the expansion of the rubber. We therefore studied the interfacial insulating property and elastic property of the rubber and found that silicone rubber gives excellent results in terms of both properties, enabling the rubber unit to be expanded up to 300% and to maintain the expanded state for over several years. Because the rubber unit can be expanded up to 300%, the inside diameter of the carrier pipe can be larger than the cable jacket even in case of metallic corrugated sheath. The overall size of the joint including a protection box can be minimized, because additional removal of the cable jacket can be avoided. One rubber unit is applicable to various cable sizes, allowing it to be used to joint cables of different sizes (e.g., 1800 mm^2 – 800 mm^2).

The insulating properties of the rubber were also studied. We carried out AC voltage tests, impulse voltage tests, and long-term tests, and found that the selected silicone rubber possesses excellent electrical properties for use as a cable accessory. The electrical stress of the rubber unit has been optimised by field analysis with respect to deformation of the unit.

We have already completed IEC PQ & type tests up to the 230 kV-class without encountering any problems and have started IEC PQ test up to the 400 kV-class.

2. Cold-shrinkable joint

The cold-shrinkable joint (CSJ), which is shipped from the factory site with its moulded rubber unit expanded, has significant advantages over other premoulded joints [1, 2]. Assembly of the rubber unit as shown in Fig. 1 is easier because the only work required is to "pull out" the string of the carrier pipe. Moreover, since the inside diameter of the carrier pipe is larger than outside diameter of the cable jacket even in case of metallic corrugated sheath, it is possible to avoid removing too much of the sheath.

Moreover, dust-proof packing at the factory site facilitates quality control at the jointing site and reduces the risk of contaminants at the interface.

3. Electrical design of CSJ

3.1 Electrical property of the silicone rubber

The electrical property of the silicone rubber was investigated by using recessed specimens. An AC voltage test, impulse voltage test, and long-term test were carried out [2]. The results of these tests showed that the silicone rubber selected for the CSJ has excellent electrical properties for a cable accessory.

3.2 Electrical design of rubber unit

The electrical field in the moulded rubber unit of the CSJ was optimised by means of computer calculation. The stress-relief configuration was thus optimally designed and the size of the moulded rubber unit was minimized. The design points of the CSJ were limited to the four major points (τ1-τ4) as shown in Fig. 2. An example of electrical field calculation for premoulded rubber unit is shown in Fig. 3.

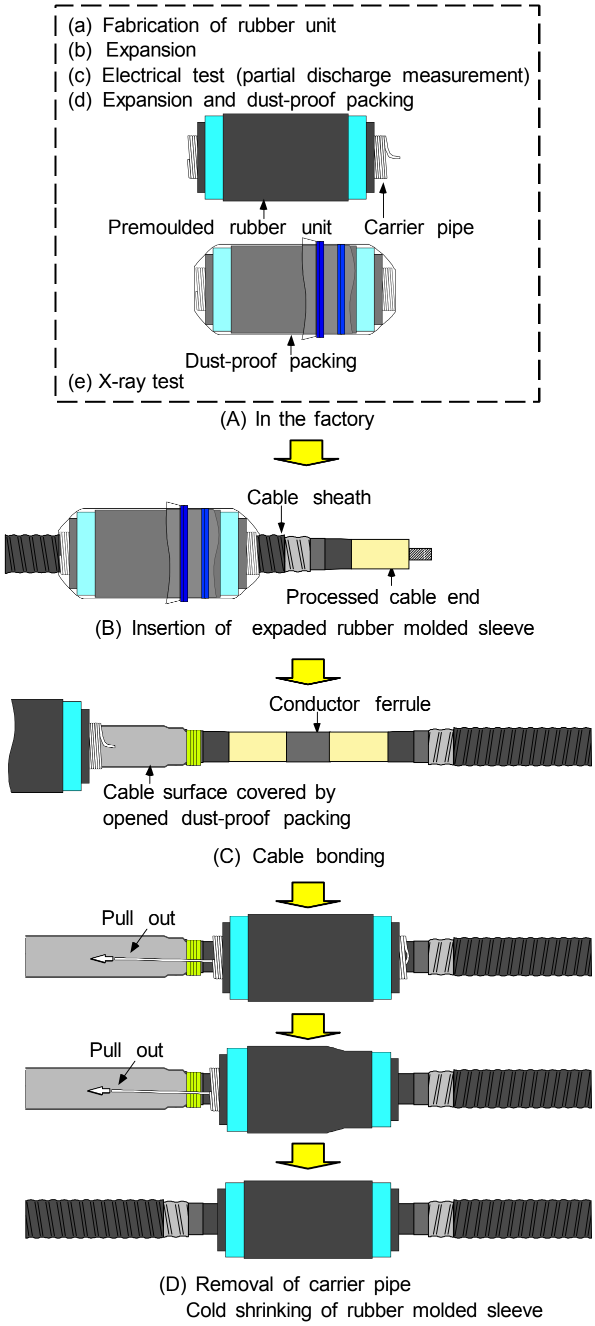

Fig. 1 Assembly of Cold-Shrinkable Joint

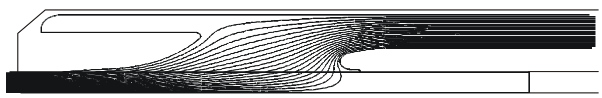

Fig. 3 Example of Electrical Field Calculation for Premoulded Rubber Unit

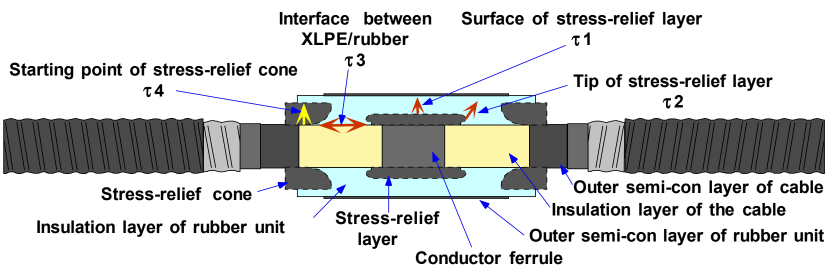

Fig. 2 Electrical Design of Rubber Unit of CSJ

4. Interfacial design of CSJ

Interfacial design is the most important aspect of any cable joint. It is well known that the stability of interfacial dielectric performance in premoulded joints is mainly affected by interfacial pressure [3, 4]. Therefore, the insulation property of the interface, the elastic property of the silicone rubber, and the interfacial pressure characteristics of the CSJ were studied.

4.1 Insulation property of the interface

The insulation property of the interface between XLPE and silicone rubber was studied using the models shown in Figs. 4 to 7.

Interface model tests: Using the models shown in Figs.4 and 5, electrical break down tests even at lower interfacial pressures well below 0.02 MPa were performed [2]. The structures of the specimens were designed by field calculation as shown in Fig. 5, allowing us to simulate electric stress distribution similar to that of cable joints in these models. The XLPE sheets applied to these models had a smooth surface or scrubbed rough surface to simulate actual cable joints. The tests were also carried out with and without oil, which would not be contained in either the XLPE or silicone rubber at the interface, to elucidate the effect on the electrical properties. As a result of these tests, it was found that a satisfactory interfacial property of almost double the required value for 400 kV cable could be obtained even at the lower interfacial pressure and without the use of oil. These results were obtained for both the AC and lightning impulse tests.

66 kV-class CSJ model tests: The dependence of interfacial pressure on the electrical properties was also confirmed using the 66 kV-class CSJ models shown in Figs. 6 and 7. This time, several XLPE cables having different outside diameters were applied to simulate the interfacial pressure range from 0.04 MPa to 0.18 MPa.

The model in Fig. 6 enhances the interfacial properties between XLPE cable and the moulded rubber unit. The model in Fig. 7 represents the properties at the starting point of the stress relief cone. The results of both AC and lightning impulse tests were shown in Figs. 8 to 11. The results showed that even at the lower interfacial pressure of 0.04 MPa, the breakdown stress had a high value equivalent to that at the higher interfacial pressure of 0.18 MPa.

Overall, we reached the conclusion that the lower elasticity of silicone rubber can provide a better interfacial insulation property even in the case of lower interfacial pressure, and that a CSJ with a moulded rubber unit consisting of silicone rubber will not require an interfacial pressure of more than 0.04 MPa for application to the EHV XLPE cable.

4.2 Elastic property of silicone rubber

The elastic property of silicone rubber was studied to understand the long-term interfacial pressure property of the CSJ using a sheet sample. Fig. 12 shows an example of the expansion rate calculation for the CSJ. To realize a factory-expanded cold-shrinkable joint, the rubber must have an excellent elastic property that can maintain the interfacial pressure after several years of expansion over a carrier pipe at a higher expansion rate.

Permanent set property: The long-term permanent set property was studied and the master curve of permanent set was obtained. If the permanent set property is unsatisfactory, the inside diameter of the rubber unit becomes larger and sufficient interfacial pressure cannot be obtained. Fig. 13 shows an example of the excellent permanent set property of silicone rubber. Using the master curve, it is possible to calculate the permanent set of a certain expansion rate and temperature.

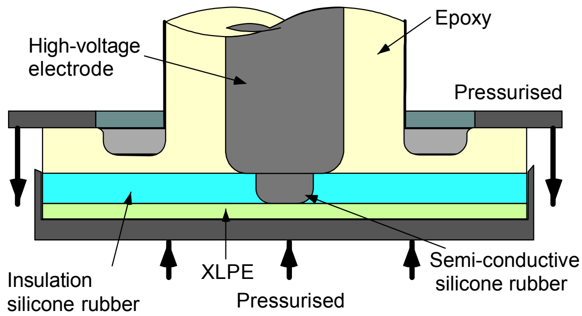

Fig. 4 Sample Setup Modelling Electric Stress Distribution at τ4

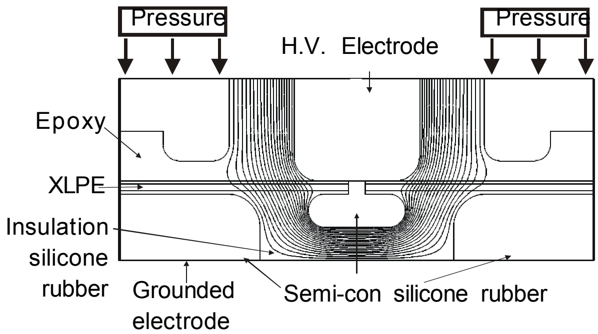

Fig. 5 Sample Setup Modelling Electric Stress Distribution at τ3

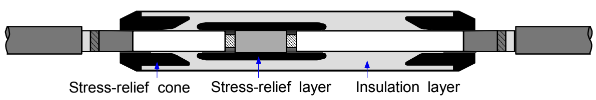

Fig. 6 66 kV-Class CSJ τ3 Model to Evaluate the Dielectric Strength of τ3

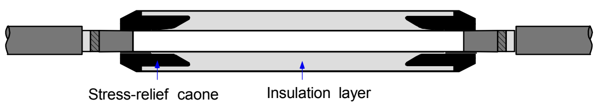

Fig. 7 66 kV-Class CSJ τ4 Model to Evaluate the Dielectric Strength of τ4

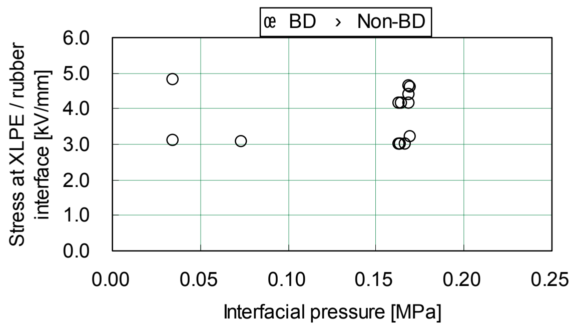

Fig. 8 AC Voltage Test Results for 66 kV-Class CSJ τ3 Model

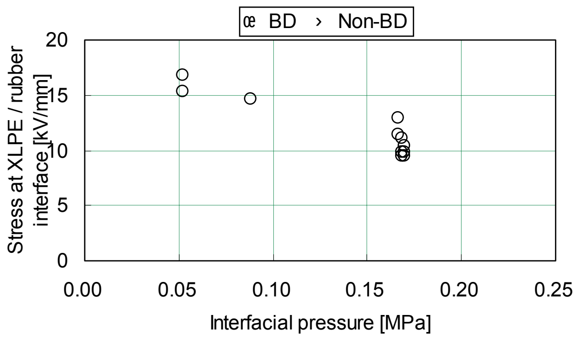

Fig. 9 Impulse Voltage Test Results for 66 kV-Class CSJ τ3 Model

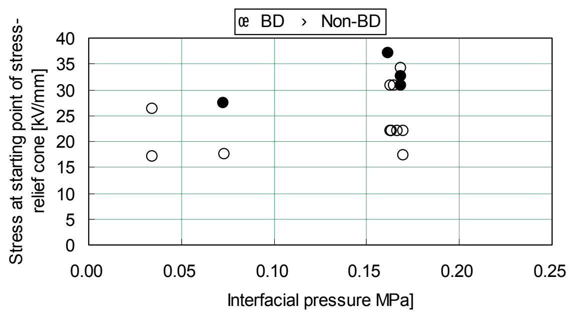

Fig. 10 AC Voltage Test Results for 66 kV-Class CSJ τ4 Model

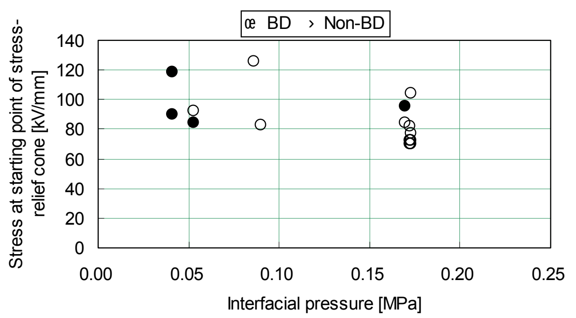

Fig. 11 Impulse Voltage Test Results for 66 kV-Class CSJ τ4 Model

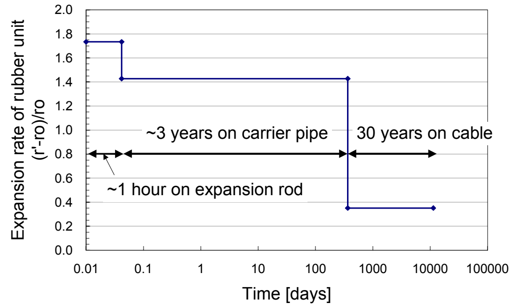

Fig. 12 Example of Expansion Rate Calculation

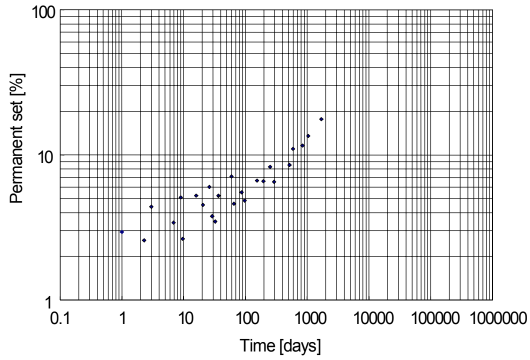

Fig. 13 Example of Permanent Set Property of Silicone Rubber
(expansion rate: 250%, temperature: 25°C)

<u>Stress vs. strain property</u>: To estimate the interfacial pressure of the CSJ, it is very important to understand the stress vs. strain property of silicone rubber because the CSJ is subjected to a high expansion rate for a long period. Therefore, the stress vs. strain property of silicone rubber was studied carefully. After numerous measurements, the dependency of the stress vs. strain property on the history of expansion was elucidated.

<u>Stress relaxation property</u>: The stress relaxation property is indicated by the permanent set and the change in the stress vs. strain property. After measuring many cases of stress relaxation property for long periods, the selected silicone rubber shows an excellent elastic property for a factory-expanded cold-shrinkable joint.

4.3 Interfacial pressure characteristics of CSJ

The actual interfacial pressure of the CSJ was measured in several cases using cables on which pressure sensors had been installed. In each case, the measured values were almost equal to the estimated values.

The interfacial pressure characteristics of the CSJ immediately after the installation and during a heating cycle test were also studied.

<u>Interfacial pressure immediately after installation</u>: The interfacial pressure immediately after installation was measured. Fig. 14 shows the interfacial pressure behaviour of a 110 kV-class CSJ immediately after installation. This 110 kV-class rubber unit was expanded for 1 year and installed on

a test cable. The interfacial pressure reached saturation within 5 minutes and become almost stable after 2 hours. The value of the interfacial pressure was almost the same as that calculated from the permanent set and elasticity properties of silicone rubber.

Interfacial pressure during heating cycle test: By passing an alternating current through the cable conductor, the conductor temperature was raised to 90°C. Heating was applied for 8 hours followed by 16 hours of natural cooling. Fig. 15 shows the conductor temperature and the corresponding interfacial pressure of a 66 kV-class CSJ during the heating cycle test. From the figure, it can be seen that the interfacial pressure increases with increasing conductor temperature. It was assumed that the increase in interfacial pressure was caused by thermal expansion of the rubber and waterproof compound inside the protection box.

Long-term characteristics of interfacial pressure: Fig. 16 shows the long-term trend of the interfacial pressure of the 66 kV-class CSJ subjected to the heating cycle. The drop in interfacial pressure is very small. It can be estimated that 30 years after the installation of a rubber unit, the interfacial pressure will drop by about 20% from that at the early stage of installation.

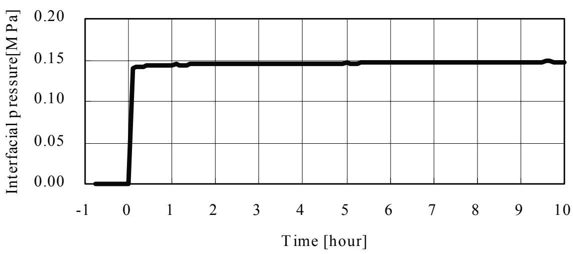

Fig. 14 Interfacial Pressure Behaviour of 110 kV-Class CSJ Immediately after Installation

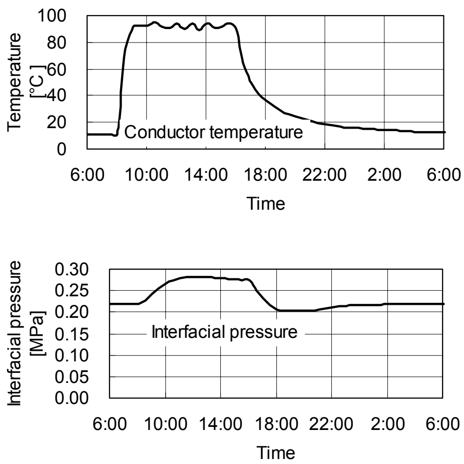

Fig.15 Conductor Temperature and Corresponding Interfacial Pressure of 66 kV-Class CSJ during Heating Cycle Test

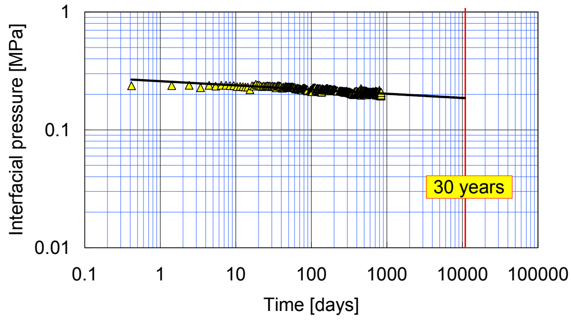

Fig. 16 Long-Term Trend of Interfacial Pressure of 66 kV-Class CSJ

5. Development of 400kV-class CSJ

We have already completed IEC PQ & type tests up to the 230 kV-class without encountering any problems. And then, 400 kV-class CSJ has been developed and confirmed to have enough electrical properties for an AC and impulse voltage tests required for IEC spec. Fig. 17 shows the assembly of premoulded rubber unit for 400 kV-class CSJ. We have already started IEC PQ test up to the 400 kV-class.

6. Jointing cables of different sizes

The CSJ interfacial design technique makes it possible to apply one rubber unit to various cable sizes, allowing it to be used to joint cables of different sizes.

A load cycling test of the CSJ jointing 154 kV 1800 mm^2 and 800 mm^2 cables, including thermo mechanical tests was carried out to reveal the stability of the CSJ. Table 1 shows the conditions of the load cycling and thermo-mechanical tests. Figs. 18 and 19 show a view of 154 kV-class CSJ and the test circuit for the load cycling and thermo-mechanical tests, respectively.

The thermo-mechanical behaviours applied to the CSJ simulated the yearly and daily displacements of a cable system. The displacements were applied by power cylinders and were superposed on the load cycling test.

All of the tests listed in Table 1 were completed without encountering any problems.

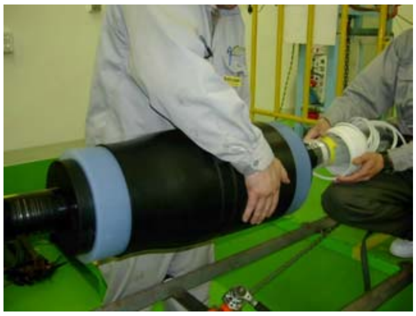

Fig. 17 Assembly of Premoulded Rubber Unit for 400 kV-class CSJ

Table 1 Conditions of Load Cycling and Thermo-mechanical test

Cables	154 kV CV 800mm^2 154 kV CV 1800mm^2
CSJ	Size of protection box Length: 1020mm Outside diameter: 260mm
Load cycling test	JEC-3408 Voltage: 145 kV Conductor temperature: 90°C X 25 days 105°C X 5 days Heating: 8 hours Natural cooling: 16 hours
Thermo-mechanical test superposed to load cycling test	Initial shape of offset Length of offset: 2450mm (1800mm^2 side) 2050mm (800mm^2 side) Width of offset: 640mm Thermo-mechanical behaviour A (Simulating yearly displacement) Displacement: 118mm Number of times: 30 times Expansion: 4 hours Maintainance: 4 hours Contraction: 16 hours Thermo-mechanical behaviour B (Simulating daily displacement) Displacement: 29mm Number of times: 11000 times Expansion: 2 minutes Contraction: 2 minutes Thermo-mechanical behaviours A and B were superposed (e.g., max. stroke: 118mm + 29mm =147mm).
Impulse voltage test after load cycling test	(+)(-) 1035 kV for 3 times
Partial discharge measurement after impulse voltage test	Voltage: 190 kV Period: 10 minutes
Inspection of rubber unit	After all the tests were finished, the protection box was opened and rubber unit was inspected.

7. Conclusion

We are the first manufacturer in the world to have successfully developed cold-shrinkable joints with a silicone rubber unit for EHV XLPE cables. We have already completed IEC PQ & type tests up to the 230 kV-class without encountering any problems and have started IEC PQ test up to the 400 kV-class.

The interfacial design has been studied carefully, and the high performance of the CSJ has been revealed. Our newly developed CSJ is expected to dominate the market for EHV cable accessories.

Fig. 18 View of 154 kV-class CSJ Subjected to Load Cycling and Thermo-mechanical Tests

Fig. 19 Test Circuit for Load Cycling and Thermo-mechanical Tests

8. Acknowledgment

The authors wish to thank the suggestions of Tokyo Electric Power Company for load cycling and thermo-mechanical tests.

9. References

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10. Glossary

CSJ: Cold Shrinkable Joint