Chapter 4
Accessories

Contents

4.1 Submarine Cable Joints

The manufacture of a submarine power cable joint[1] requires valuable vessel time, specialised equipment for the manufacturing and deployment of the joint, highly specialized teams on board, and a sufficient long period of suitable weather conditions. The failure of some early installation joints during service shaded the reputation of submarine power cable joints. Failures in the joints were usually caused by poor engineering or inadequate installation procedures. As an example, all shore joints in the first Cook Strait cable connection failed or needed repair. The failures were blamed to inadequate engineering of the transition joints connecting different conductor sizes [1]. However, submarine power cables of today deserve a better

[1] The expression “splice” is sometimes used.

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reputation. In a 1986 Cigré study on the reliability of submarine power cables, the joints account for 18% of the failures, the cables for 82%. Improved engineering methods, better route survey methods, and more sophisticated installation procedures have changed the picture during the past twenty years. With these improvements, the major submarine power cable manufacturers can provide joints of high quality and reliability. Assembled by well-trained teams and supported by adequate vessel equipment, the joints meet all requirements and do not have to be regarded as a weak point anymore. Still it is prudent to reduce the number of cable joints as much as possible because the joint assembly requires extra good weather time.

Submarine power cable joints come in a row of different shapes, which can cause some confusion. There are factory joints, installation joints, repair joints, flexible and stiff joints, both for 1C and 3C cables. The following paragraphs try to eradicate some of the confusion.

4.1.1 Factory Joints

A factory joint connects semi-finished pieces of cable before the armoring is applied. Factory joints are also used when production mishaps require that the production cable length must be cut to remove damaged parts. The flexibility of the joint allows for application of a continuous armoring over the joint in the ordinary armoring machine in the factory.

The manufacturing of a factory joint (cf. Fig. 5.2) starts with the connection of the conductors of the two cable ends. Different welding methods such as TIG, MIG, etc. are used. Friction welding can be used to connect aluminium to copper. Stranded conductors are welded either with a single welding seam across the entire diameter, or wire-by-wire. The choice of an appropriate welding process and suitable filler materials is critically important to producing conductor joint with sufficient mechanical properties. Welding defects such as discontinuities, cracks, porosity, incomplete fusion or penetration, and nonmetallic inclusions must be avoided. Sometimes, the weld quality is checked by X-rays. The tensile strength of the welded joint is of great importance for the installation of submarine power cables. The conductor portion adjacent to the welding is weaker because it is annealed by the welding heat. The strength is often only 70% of the strength of the original conductor. Less frequently, other methods of conductor joints are used, such as flush ferrules to be crimped on the conductor ends, or soldering processes [2].

The electric conductivity of the weld must be sufficiently high to avoid a hotspot in the cable. Still, a local moderate increase of the specific resistivity of the weld materials is uncritical as the heat generated from the excess losses is dissipated efficiently into the adjacent conductor.

Screw connectors are not used for factory joints because they would add up to the diameter and obstruct further manufacturing.

After the conductor joint, the insulation is built up, normally comprising the same structure as the cable insulation. The insulation of the two cable ends is tapered to form conical surfaces. New insulation material is applied between the two tapered cable ends now. A longer interface cone provides a lower axial electric field along the sensitive interface. In most cases, the joint insulation is somewhat thicker than the cable insulation in order to reduce the electric stress.

Factory joints according to the described generic design can be used both for paper-insulated and polymeric cables.

The joint insulation for polymeric insulated cables (XLPE, PE, EPR) is made from tapes of similar material, which are lapped in the gap between the cables. The screens are made from carbon-black loaded polymeric tapes. The joint insulation is cured under heat and pressure so that the tapes melt together and form a homogeneous continuous material without voids. If XLPE tapes are used, the curing time is longer for the cross-linking process. The applied pressure helps to suppress the formation of gas bubbles when the XLPE tape is cross-linking. The interface between cable insulation and joint isolation must not have any voids, gaps, cracks, or contaminations. The preparation of the conductor screen and the transition between the conductor screen in the cable and the screen in the joint is a delicate task and requires the highest carefulness (cf. Fig. 4.1). The adhesion of the joint insulation to the cable insulation is of great importance for the electric strength of the joint.

For voltages up to and including 110 kV also self-amalgamating tapes can be used as joint insulation. These tapes must be applied with well-defined tension. The self-amalgamating process results in a compact insulation material after a few days.

With paper-insulated cables, the insulation of the flexible joint has a similar structure as the cable itself, comprising a conductor screen, the electric insulation, and an insulation screen. The screens are made from carbon-black paper tapes. The paper tapes are pre-impregnated and are applied either manually or with a semi-automatic lapping machine (Fig. 4.2). The joints should be manufactured in humidity-controlled and temperature-controlled rooms.

Fig. 4.1 Application of XLPE joint insulation under clean conditions (Courtesy of ABB, Sweden)

Fig. 4.2 Application of paper insulation for a flexible joint using a semi-automatic lapping machine (Courtesy of ABB, Sweden)

The factory joint also includes a lead sheath over the jointed insulation. The lead sheath is applied as a wide lead tube, which is slid over and parked on one side of the factory joint before the conductor jointing. After the insulation is finished, the lead tube is pushed over the factory joint, swaged down to a tight fit over the joint insulation, trimmed, and soldered to the cable's lead sheath. In case of mass-impregnated cables, the insulation inside the lead sheath can now be treated again to achieve fully saturated paper-oil insulation. Finally, a protective polymeric shrink tube is applied over the lead or other outer layers. Now, the factory joint constitutes an integral part of the power cable core and is ready for further steps in the production line such as armoring. The slight oversize of the factory joint does not impose any obstacle for the further production.

4.1.2 Offshore Installation Joints

The notion "installation joint" or "field joint" describes a joint of the complete submarine power cable including conductor, insulation system, armoring and all intermediate layers.

Installation joints are manufactured on-board of a sea-going vessel, or in the beach area. Depending on the cable and joint design, the manufacturing of offshore installation joints takes between one and ten days after both cable ends are laid up in the jointing shack on-board the vessel. No matter if this is the laying vessel or a separate jointing barge, the joint should be designed to keep the offshore jointing time as short as possible. During the jointing, at least one of the cables is hanging down from the vessel over a laying wheel or a laying chute.[2] In heavy weather this imposes a risk for the jointing crew and the cable. If the required jointing time

[2] One of the cables to be jointed may still be on the turntable on the cable laying vessel.

is short, there are better chances to find a sufficiently long weather window with suitable sea-state. Once the jointing process is started it can be interrupted only by cutting the cable.

4.1.2.1 Flexible Installation Joints

Flexible joints can be used with advantage when a long cable route requires the offshore jointing of subsequent delivery lengths. After the first laying campaign, the vessel would fetch the next cable length at the manufacturer's premises or a storage port. It returns to the cable route and pulls up the end of the first cable over the laying wheel to a jointing shack onboard the vessel. There, the second cable length, which is still onboard the vessel, is jointed to the first cable by means of a flexible installation joint.

The basis of a flexible repair joint is the same procedure as for the factory joint, including the jointing of conductor, insulation, and lead sheath as described for the factory joint. The joint may be slightly thicker than the corresponding cable diameter. Finally, and this is the special attribute of submarine power cable joints, the armoring over the installation joint must be arranged with high tensional strength, yet flexible.

For flexible joints a wire armoring covering the joint section is necessary. The gap between the armoring of the two cable ends can be closed with pre-spiralled wires. These wires are welded to the wires on one side of the joint, twined around the joint, and then connected to the armoring wires on the other side of the joint. A pretension of the joint armoring wires is necessary to maintain the tensional forces in the armoring. The armoring wires can be welded to each other wire by wire, or in various welding patterns to achieve the best possible tensional strength between the cable armoring and the joint armoring. The wires of the joint and the cables can be connected also by screw connectors [3] or by what is known as turnbuckle, a left/right-threaded sleeve to tighten the connection between armoring wires [4]. The use of ring-shaped welding sleeves to connect the wires from the joint to the cable armoring wires provides a good distribution of tensional forces. A welding sleeve makes it also possible to connect cables with different numbers, diameters or shapes of armoring wires. A Swedish manufacturer uses a patented [5] semiautomatic portable armoring machine to provide the joint armoring.

A picture or illustration of a flexible repair joint would not be very informative as the joint has the same appearance as the adjacent cables.

The completed joint can now be transferred through the ordinary laying equipment of the vessel and passes over the stern laying wheel down into the water. The jointed new cable length is following and the laying operation can be continued. Depending on the cable design, the manufacturing of a flexible joint requires a jointing shack of 4 up to 18 m length on-board, located between the storage turntable and the stern laying wheel.

Flexible cable joints can be made for single-core mass-impregnated cables of any rated voltage. For polymeric single-core cables, flexible installation joints have been used for voltages up to 245 kV. Flexible joints have also been used for three-phase cables up to 150 kV [6].

Cable factories without their own sea harbour can produce submarine cables only in short drum lengths fit for road transport to the next port. In these cases, flexible joints are used to connect a number of drum lengths to the desired submarine cable delivery length, which is an inconvenient and tedious method [4, 6].

4.1.2.2 Rigid Joints

Rigid joints (or "stiff joints") are very different to flexible joints. The name denotes that the joint has a rigid outer casing, most often in the shape of a steel tube (Fig. 4.3). The steel tube serves as a connecting point for the cable armoring wires of each cable end, and as an outer protection to the cable joint inside.

The jointing of the electric systems inside the outer casing can be accomplished in different ways. The cable core ends may be connected with the flexible jointing method as described above. The outer steel casing provides additional mechanical strength and tensional force. In another method, the steel casing allows to use pre-moulded joint sleeves for the electrical parts of the cable. The pre-moulded joint design employs an elastomeric sleeve containing both semi-conducting and insulating layers. This sleeve is bridging the gap between the cable insulation on each side (cf. Fig. 4.4).

The concept of pre-moulded or pre-fabricated joints has become the method of choice for polymeric land cables because of many advantages:

- short assembly time
- accommodates all types of conductor connections such as welding, compression sleeves and screw connectors according to client specifications
- can be pre-tested in factory

The steel casing makes it possible to use pre-fab joints also in submarine applications. Sometimes, an inner casing made of copper or brass is used which encloses

Fig. 4.3 Rigid submarine installation joint in a steel casing for a 1C cable during an on-shore bending test

Fig. 4.4 Pre-moulded polymeric cable joint. The elastomeric joint sleeve on *top*. Conductor connected and insulation prepared for application of insulation sleeve on *bottom*

the pre-fab joint and is soldered to the lead sheath for complete water tightness. Before jointing the conductors of the two cable ends, the pre-fab sleeve is expanded radially and "parked" on an auxiliary support tube on the nearby power cable end. After conductor jointing and preparing the insulation according to the instructions of the supplier, the "parking" sleeve is slid over the insulation gap. The support tube is removed, and the joint sleeve collapses over the insulation gap in a pre-determined position. In this final position, the sleeve keeps a radial pressure onto the underlying insulation surfaces. The radial pressure between the interface surfaces is of critical importance for the dielectric strength of the joint over the total lifetime. In some designs, external spring-loaded elements help keeping that radial pressure up.

In contrast to the taped or tape-moulded joint, the pre-fab joint sleeve can be pre-tested at the manufacturer's premises. The high-voltage factory test, often with partial discharge recording, can detect possible flaws, voids, or particles in the insulation material and confirms the intrinsic dielectric strength of the tested joint sleeve. Naturally, this test cannot unveil a poor installation job.

The core joint is equipped with its own water barrier system (very often a lead sheath). If the pre-fab joint sleeve is very bulky, a copper or brass casing can be used to encapsulate the joint. The copper casing can easily be soldered to the cable lead sheath in order to provide a completely watertight cover for the joint.

For some medium voltage cables, a polymeric water protection is considered adequate and the joint can be covered with a shrink tube.

The jointed core(s) are now encased into the outer metallic casing. The casing has a central cylindrical portion and two conical ends. The partition line of the steel casing may run in parallel with the cable axis connecting two half-shells, or may run around the ensemble connecting two funnel-like parts. The outer casing can also be assembled from more than two parts. The different parts of the steel casing are connected to each other by welding or nuts and bolts. The wire armoring on each side of the joint casing is connected mechanically to the casing by means of clamping flanges or welding (cf. Fig. 4.5).

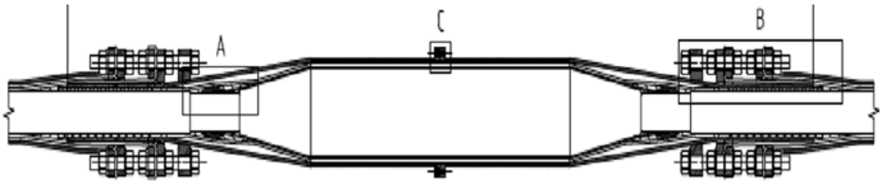

Fig. 4.5 Copper and steel casing for a pre-moulded joint

In Fig. 4.5, the soldering of the copper casing to the cable lead sheath can be seen at “A”, and the partition of the steel casing at “C”. The casing constitutes a strength member connecting firmly the armoring layers of each cable side (at “B”). For less demanding applications such as shallow waters, a casing made from polymeric materials may be used. Special attention must be paid to the transition between the layers of the cable and the corresponding layers of the joint as the manufacturing, transport, installation, and service can impose high mechanical stresses on all parts of the joint.

In order to avoid sharp cable bends at the transition between the stiff joint casing and the flexible armoring of the submarine cable, bend restrictors in the shape of conical rubber sleeves enclose the cable at the exit of the steel casing (cf. Fig. 4.3).

Rigid joints cannot be transported through the ordinary cable gantries or deployed with the ordinary vessel laying equipment because of their stiffness and increased diameter. Complicated crane arrangements are necessary for the deployment of rigid joints.

All these facts seem to make the rigid joint the inferior choice of installation joints for submarine power cables. Indeed, the flexible joint as outlined in the previous chapter has the advantage of simple design and easy installation. But the advantages of pre-fab joint sleeves and the good mechanical protection provided by the steel casing may outweigh the use of extra components. At the end, assembly time on board the vessel is very precious.

While rigid joints have been used for submarine LPOF cables, they are not being used for today’s MI d.c. cables. As there are no pre-fab MI cable joints available, the joint insulation must be made by on-site lapping anyhow. Rigid joints can therefore not provide the advantage of quick assembly and factory pre-testing for mass-impregnated cables.

Rigid installation joints are used for almost all 3C cables (cf. Fig. 4.6). Inside the joint case, the three cable cores are split and jointed individually. Each cable core joint is encapsulated in its own water-proof inner casing, which can be made from pre-formed copper tubing to be soldered to the lead sheath of the cable. The functional separation of inner casing (water protection) and outer steel casing (tensional forces, armoring) allows for more possibilities in the design process. The outer casing also can accommodate a splice box for optical cables, which might be incorporated into the power cable.

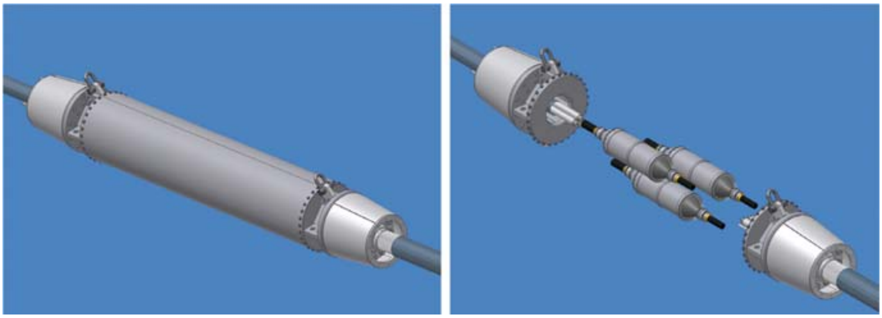

Fig. 4.6 Rigid joint casing with three pre-moulded joints inside (Courtesy ABB, Sweden)

4.1.3 Miscellaneous Joint Designs

Fluid-filled submarine power cables require joints with a continuous fluid duct in the hollow conductor. A tubular sleeve is often included into the duct to provide support before welding. The cable cores are frozen down by liquid nitrogen to prevent oil outflow.

Under certain circumstances, the free flow of impregnating fluid through the joint is not wanted, e.g. in steep passages of the submarine cable. In these cases, stop joints can be devised, which have a solid conductor weld, closing both the central oil duct and the inter-wire spaces. Conical epoxy resin spacers inserted into the insulation wall stop the oil passage in the insulation. These stop joints can also prevent unwanted movements of copper particles with the oil [4].

Many transition joints have been designed to connect submarine cables of different kinds. Submarine cable links sometimes comprise different conductor sizes to match different thermal conditions along the route. Small size differences can be jointed with flexible joints. For large size differences, the use of a rigid joint is preferred because it provides a protection against mechanical stress, which can be detrimental to the sensitive transition of the highly stressed conductor screen.

Some submarine 150 kV HVDC projects with extruded cables have copper conductors in the submarine portion and aluminium conductors in the land section (Estlink, NordE.ON). The transition between the different cables was accomplished by purpose-made pre-fab joints with two-metal screw connectors. The transition joint connected a 1000 mm^2 Cu submarine cable conductor to a 2000 mm^2 Al land cable conductor.

In some submarine HVDC cable links the near-shore cable is a fluid-filled cable, while the submarine cable is a mass-impregnated cable [7]. Also here transition joints can be constructed to connect cables with different insulation systems and different conductor design. Transition joints between paper-insulated cables and extruded cables are known from on-shore applications but no case of submarine use is known.

Table 4.1 Application and properties of various joint concepts

	Flexible joint	Rigid joints, tape-insulated	Rigid joints, pre-fab
1C mass-impregnated	Yes, all voltages	Yes, but no advantages	No
1C paper-insulated	Possible	Possible	No
1C extruded cables	Up to 145 kV. In few cases 245 kV.	Common up to 110 kV	Yes
3C paper-insulated	Possible	Yes, but no advantages	No
3C extruded cables	Possible	Yes, but no advantages	Yes
Conductor joint	Welded only	Welded only	Welded, compression or screw
Need for special deployment arrangement on cable vessel	No	Yes	Yes
Space for optical joint box	1C cable: No	3C cable: Yes	3C cable: Yes

Trifurcation joints connecting a three-core cable to three single-core cables are known for land applications but no submarine use is known. Probably trifurcation joints have been used as beach joints to connect 3C submarine cables to 1C land cables.

A bifurcation joint has been manufactured for the NorNed project; it connected a two-core HVDC cable in the southern part of the cable route to two single-core cables in the northern part.

The large variety of submarine cable joints may cause some confusion. Table 4.1 lists those joint concepts described here and their most important properties.

4.1.4 Beach Joints

Sometimes, the submarine cable can be connected to an overhead line or a substation directly at the landing point, but in many cases the cable route continues onshore. A beach joint between the submarine and the land cable can be necessary for different reasons:

– The cable termination is too far from the shoreline to pull in the submarine cable all the way.[3]
– Thermal conditions require a larger conductor size onshore than offshore. It would be imprudent to dimension a long submarine cable for the thermal needs of a short beach section.

[3]The longest pull hitherto has been made when the Swedish end of the Baltic Cable was pulled from the sea more than 4 km onshore to the cable-to-air transition yard.

– In many projects the submarine cable is 3C while the land cable system consists of three single-core cables. The transition joint is usually erected in the shoreline

The design and installation of beach joints may require special attention. The location for the beach joint should be selected carefully if there is a choice. A dry jointing house or tent offering protection from wind and airborne sand, salt, and droplets, is necessary for the assembly of a joint. The safest place is on dry land, sufficiently far away from the splash zone. The higher the location over the water table, the easier it is to keep the joint pit dry. A location beside a road would facilitate transport of equipment and minimize impact on the environment.

The manufacturing of the beach joint in the splash zone generates further difficulties. The jointing pit must be excavated into the near-shore seafloor, secured by a cofferdam and pumped dry. The cable ends must be guided through the cofferdam walls. Equipment and crew must be given a dry clean environment. Alternatively, the joint can be erected on a lofty platform. In either case, the work preparations are even worse when tidal current threaten the stability of the arrangements twice a day.

Figure 4.7 illustrates the beach joint area for a double HVDC extruded cable circuit. Two pairs of HVDC cables are pulled in from offshore through pipes into land. The protection pipes are terminated in beach holding devices that are bolted into the concrete floor of the joint pit.

Fig. 4.7 Beach joints of two pairs of extruded HVDC cables

4.2 Cable Terminations

The submarine cable, when landed onshore, is normally connected (jointed) to an underground cable close to the beach. The underground cable continues to a substation, where it is terminated with a standard onshore cable termination. The substation can be a few meters or many kilometres from shore.

The onshore cable termination is not specifically designed for submarine cables but for underground cables.

4.2.1 On-Shore a.c. Cable Terminations

Onshore a.c cable terminations are equal for submarine and underground cables in most respects. Standard terminations for a.c. submarine cables are available from a row of manufacturers:

– *Open-air terminations* to connect the cables to overhead lines or the busbars of an air-insulated substation. The insulator may be of porcelain or polymeric. The creepage length over the insulator sheds is specified between 25 and over 40 mm/kV depending on the expected salt and pollution load. Expected salt storms close to shore also require special attention to the corrosion protection of the metal work of the termination. It is recommended to replace standard aluminium grades to highly corrosion resistance grades. Also, specified wind loads for near-shore terminations might be more stringent.
– *GIS terminations* to connect the cables to gas-insulated switchgear. This type of cable terminations is well-known from land cable applications up to the highest voltages. GIS terminations have standardised sizes in order to make them compatible to switchgear from other manufacturers. GIS terminations are based on a stress relief cone on the extremity of the cable insulation. The stress cone is inserted into a conical receptacle inside the GIS compartment. In some GIS terminations, the stress cone matches the inside of the conical receptacle perfectly (plug-in type), and these terminations are completely oil-free. Other designs contain a small amount of dielectric fluid to fill the gap between the stress cone and the inside of the conical receptacle.
– *Transformer terminations* are generally identical or very similar to GIS terminations. However, for submarine cables they are rarely used, as substation planners want to have circuit-breakers between the submarine cables and the transformer.

4.2.2 On-Shore d.c. Cable Terminations

So far, only cable-to-air terminations have been devised for submarine d.c. cables. The stress control in d.c. termination must rely at least partly on resistive elements,

Fig. 4.8 Indoor HVDC cable terminations for mass-impregnated cable (*left*) and extruded cable (*right*). Small oil reservoir cylinder is attached to the stand of the left termination

as pure capacitive elements would be not suitable with d.c. The design is adapted to the type of submarine d.c. cable.

The terminations used for extruded submarine HVDC cables up to 150 kV are identical to on-shore cable terminations for the same cable technology. They have a polymeric insulator and are completely oil-free. Terminations for extruded HVDC cables are erected indoors.[4] The termination shown in Fig. 4.8 has a field-grading element that is made of a resistive material with non-linear resistivity. This material becomes more conductive when subject to higher electric stress. Owing to this property the field grading element has the ability to relieve highly stressed parts inside the termination.

LPOF cable terminations for d.c. use are designed very similar to their sisters for a.c. use. However, the stress cone and the external insulator might have a different design to control the d.c. stress. The stress cone is made from impregnated paper, which is either pre-formed in the factory or shaped on-site during the erection of the termination. The termination also constitutes the oil-feeding entry point into the cable.

The terminations for mass-impregnated HVDC cables are similar to the LPOF cable terminations except the oil-feeding system. While the LPOF cable termination must take care of the thermal "breathing" of the entire cable (or at least half of the length of it), in the mass-impregnated system only the expansion of the small oil

[4]It is yet not known how the cable terminations for the Trans Bay HVDC project (under construction) will be arranged.

volume inside the termination must be taken care of. For this purpose, a relatively small oil expansion vessel of a few hundred litres is enough and can be mounted on the termination stand without external pipework (cf. Fig. 4.8).

4.2.3 Offshore Cable Terminations

Submarine power cables connected to offshore installations such as oil and gas production platforms, or OWP must be terminated in a harsh environment. The adverse climate and restricted space allow the use of open-air terminations only for moderate voltage levels. The cables are often terminated directly into encapsulated switchgear by means of GIS terminations, polymeric plug-in connectors, or transformer terminations.[5] Again, these components are standard components from land cable applications. However, they must be corrosion proof and comply with the product and safety standards that rule onboard the platform. These standards may be more stringent than equivalent standards onshore. Also, the erection and installation of the terminations may be subject to much stricter rules compared to those that apply for onshore work.

4.3 Other Accessories

A number of accessories are used for the structural integration and safe fixation of submarine power cables. The following lines give but a rough overview on the large variety of products.

4.3.1 J-Tubes

It is industrial practice to guide power cables up to stationary platforms through J-tubes, named for their J-like shape. The bow of the J is down on the seafloor and the upper end of the J is beneath or above the lowest platform deck. The lower opening is called bellmouth for its shape and is normally directed outwards from the platform legs. The bellmouth can be underneath or slightly above the seafloor. During the installation, the cable is pulled through the bellmouth up to the platform by means of a pulling wire. In order to guarantee a smooth installation, the bow radius should be noticeably larger than the minimum bending radius of the cable, and the tube diameter at least 2.5 times the cable diameter. It is cheaper to add some material to the construction than to get stuck with a cable and an expensive cable vessel scheme during the installation. Normally, there is one power cable in each J-tube, but numbers of two and four have been used.

[5]The terminations of extruded HVDC cables on offshore platforms are usually placed inside the valve cubicles.

While most J-tubes are left open at the bottom, some are plugged around the cable in order to keep anti-corrosion fluid inside.

The thermal conditions of the power cable inside the tube should be given special attention. In the water-filled J-tube, convection contributes to the heat flow between the cable and the tube wall. Convection is depending on the size of the annular gap and is difficult to grasp mathematically. The conditions get worse in the upper air-filled part of the J-tube where the air can get trapped inside the tube. Sufficiently large openings on top and bottom of the air column create a chimney effect and improve the situation considerably. However, openings close to the splash zone are not liked by corrosion specialists.

Some central platforms in OWP's have giant J-tubes that accommodate a large number of incoming cables from the individual chains of turbines. It can get crowded and warm inside.

4.3.2 Hang-Off

The gravity weight of vertically suspended cables on stationary or floating platforms is carried by hang-offs. A hang-off is a sophisticated connection flange between the cable armoring and the platform structure (cf. Fig. 4.9). The flange contains a clamping device for the armoring wires of the power cable to carry the mechanical load. The cable core with lead or copper sheath and protective plastic sheath is extending through the hang-off and continues upwards towards the cable termination.

Fig. 4.9 Hang-off for a three-phase cable connecting an offshore wind turbine

4.3.3 Bending Protection

As any flexible product, a submarine power cable is sensible for overbend and fatigue where there is a discontinuity in bending stiffness. This situation can be found at a cable entrance into a rigid joint enclosure cable, entrances to fixed structures such as hang-off, or cable glands into floating structures. Overbends may occur, or repeated bending may cause severe fatigue in the cable construction. Bending stiffeners are elastomer sleeves that engulf the power cable close to the entrance into a rigid structure. The conical shape of the bending stiffener provides a gradual increase of bending stiffness and defines a gentle bending curve for the flexible cable (Fig. 4.10). The bending stiffener must be designed for the specific case.

A bending restrictor consists of a number of interlocked polymeric or metal shells around the cable allowing for a certain bending angle for each interlocked shell. The bend restrictor defines a minimum bend radius regardless of the cable load. As it has a stepwise bending stiffness adding to the cable bending stiffness, there may be a discontinuity of bending stiffness anyhow. With improper design, the sharp-bend problem will just be re-located to the end of the bend restrictor.

Fig. 4.10 Bending stiffener (*right hand*) together with a diverless subsea cable connector (*left side*). (Courtesy of Trelleborg, UK)

4.3.4 Holding Devices

Various clamping devices can be used to secure submarine power cables in beach areas, along steep underwater slopes, in areas of strong currents, and elsewhere.

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