THE COMPACT JOINT WITH INTEGRATED SHEAR BOLT CONNECTOR; 
A NEW APPROACH TO FUNCTION INTEGRATION IN MEDIUM VOLTAGE JOINTS

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ABSTRACT

The design of medium voltage joints for polymeric cables has been improved several times during the last decades. Remarkable development steps are represented by the tape joint, the heat-shrink joint and the cold-shrink joint. All these solutions have in common that the connector is installed separately, followed by the rebuilding of the insulation, the earthing system and the outer protection. A new step is done now by integrating a shear bolt connector into a silicone rubber insulated joint. In order to establish appropriate design criteria specific investigations on silicone rubber interfaces were carried out.

INTRODUCTION

During the last years the mechanical connection technique using shear bolts has become widely accepted mainly in Europe as a simple and reliable method to connect the cable conductors in medium voltage joints and terminations. Main advantages are an application range fitting well with the range of modern elastomeric accessories, its applicability for copper and aluminium conductors and the use of standard tools. In case of solid conductors the shear bolt connector offers a better functional reliability than a standard crimp connector.

Therefore the integration of such a connector into a prefabricated joint body is seen as a next logical step in medium voltage joint design. By designing the insulating system closely around the mechanical connector a further joint length reduction becomes achievable. In order to access the shear bolts through the joint insulation openings have to left open and a solution to close and insulate these openings is required. So the technical challenge was to design an appropriate insulating plug system that withstands the electrical stresses without consuming too much additional space. Some results of the related research and development efforts are presented in this paper.

Furthermore the reduction of the total joint length requires an effective electrical stress control system at a minimum interface length between cable and joint insulation. Here the design is based on the proven stress control system of the CELLPACK slip-on joint family CONTRAX [1]. Compared to this the mould-in-place integration of the stress control elements reduces the number of single components and simplifies the installation of the joint.

DESIGN OF THE COMPACT JOINT

The insulating body of the compact joint (fig. 1) consists of the following main components (fig. 2):
- Mechanical connector with shear bolts
- Conductive inner layer (faraday cage)
- Joint insulation made of silicone rubber
- Stress control elements integrated, made of refractive silicone material
- Insulating plug system for shear bolt access

This body, surrounded by a tinned copper mesh stocking for screening and earthing purposes, is finally embedded in a mechanically robust, polymeric housing with openings for the cables and for the insulating plugs (see figures 10 to 15).

Fig. 1 The insulating body of the compact joint with integrated shear bolt connector
INVESTIGATIONS ON PARAMETERS INFLUENCING THE PERFORMANCE OF THE PLUG INTERFACE INSULATION

Interface Pressure

Test set-up and test procedure. Planar model with tip electrodes (fig. 3). Tip (needle) electrodes made of aluminium foil are placed with a gap distance of 10 mm between two silicone rubber plates (thickness 2 mm). The interface pressure is controlled by an inflatable balloon. The balloon is partially filled with insulating oil to avoid a partial discharge inception inside.

Cylindrical model (fig. 5). A silicone rubber tube with a wall thickness of 2 mm is mounted on an insulating rod (polyamide) with low strain. The surface at both ends of the tube is coated with conductive paint except of a ring with a width of 10 mm. A second silicone rubber tube is placed on top with a pre-defined strain. The interface pressure is controlled by applying different strain values for the SR-tube 2. The resulting interface pressure at a certain diameter was obtained by inflating SR-tube 2 with pressurised air. Because of the fact that a lubricant is required for the interface in the cable joint a proven lubricant was used for the interfaces in these tests as well.

Planar model with ring electrodes (fig. 4). To one of the silicone rubber plates two concentric ring electrodes are applied with conductive silicone. The gap distance between the electrodes is 10 mm.

1 Cellpack type GM1
**Test results.** Tip electrodes (fig. 6). When the interface pressure is zero the AC breakdown voltage of the set-up is equal to the value measured in air. The microscopic gap between both silicone rubber plates is still sufficient to get a typical air breakdown that is not significantly influenced by the silicone rubber surfaces.

With increasing interface pressure the breakdown voltage increases until it approaches a nearly constant value. It is observed, that at low pressure the breakdown channel always follows the interface. At higher pressure the breakdown channel increasingly runs through the solid insulating material parallel to the interface. The value of the breakdown voltage becomes similar to values measured in a single-insulation system with an extremely non-homogeneous field.

**Planar ring electrodes and cylindrical ring electrodes (fig. 7).** For these configurations the breakdown voltage versus the interface pressure shows a similar dependency as for the tip electrodes. The difference is that the absolute values for the same pressure are higher. This can be explained by the higher homogeneity of these two electrode arrangements compared to the tip electrodes.

**Time (Electrical Ageing)**

It is known from previous investigations that silicone rubber insulation systems are little affected by electrical ageing processes as long as no partial discharges are present, e.g. in cavities [2]. Own investigation with the above mentioned electrode arrangements have shown that this is also valid for interfaces between silicone rubbers. For the tests the voltage rising speed was varied. The measured values were fitted with the commonly used Inverse Power Law (see figures 8 and 9).

For both arrangements (tip electrodes and planar ring electrodes) there is a slope change in the curves plotted in a diagram with a double-logarithmic scale. In the range of $n = 12$ to $16$ there are partial discharge occurrences before breakdown. In the subsequent range the breakdown occurs without preceding discharges. The breakdown voltage does almost not depend on the stress time. For two tests a silicone oil (GM2) was used as lubricant and microscopic interface filler. The shape of the curves is similar but the breakdown...
values are lower. It is assumed that micro cavities in the interface are the reason for this behaviour. It is known that silicone oil quickly migrates into silicone rubber so that micro cavities remain unfilled.

Fig. 9 Lifetime curves of interfaces (planar ring electrodes)

INSTALLATION OF THE COMPACT JOINT

The installation of the compact joint requires only few installation steps and is done in a short time. The cable ends are prepared as usual. Main difference to other products is the short cutback dimension and that there is no parking position for the joint body required. The joint is easily pushed onto the cable ends even at the maximum cross section (range from 95 to 240 mm² for 24 kV), guided by an integrated slip-on aid (figure 10). After tightening and breaking off the shear bolts (fig. 11) the openings of the joint body are closed with silicone rubber plugs (fig. 12). These are protected by a non-removable cover in the outer housing of the joint (fig. 13). After that the slip-on aids are removed strip by strip. The copper mesh stocking is put over the screen wires of the cable and fixed by means of constant-force springs. For closing and sealing of the cable entries into the housing EPDM rubber sleeves and mastic tapes are applied (fig. 14).

Fig. 10 The joint is slipped onto the prepared cable ends

Fig. 11 The shear bolts are tightened until they break off

Fig. 12 The insulating plugs are pushed into the openings of the joint

Fig. 13 The insulating plugs are protected by a non-removable cover

Fig. 14 Earthing connection and closing of cable entries
CONCLUSIONS

Using the appropriate design criteria for silicone-silicone rubber interfaces a breakdown strength and an insulation behaviour similar to a single dielectric situation can be achieved:

- Based on the results of the investigations for the material around the plug openings a strain of 10% was chosen.
- The maximum electrical stress in the opening area is moved away from the interface into the silicone rubber insulation by an optimised electrode design.
- To avoid partial discharge inception the plug interface microstructure is filled with a non-migrating, durable lubricant already used in existing products.

The success of these design rules has been proven by electrical testing.

On the basis of the presented research results it was possible to achieve a new milestone in the development of medium voltage joints.

REFERENCES
