A Study of Simulation on Relationship Between Young’s Modulus of Cable joints and Interface Pressure Based on Finite Element Method

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Abstract. The interface pressure between cable and cable joint is of essential importance to ensure the electrical transmission safety. As there is no accurate formula to derive the exact interface pressure and the measurement of the interface pressure is quite complicated or may exist errors that cannot be ignored, it is difficult to design a cable joint that can meet all kinds of requirements. In this paper, series of finite element models are established by Ansys. They are based on a 110kV crosslinked polyethylene (XLPE) cable with cross-section area of 1600 mm² which is connected by its cable joint made of silicon rubber. The distribution of the interface pressure value along axis is studied. The relationship between the Young’s Modulus of the material of the cable joint is also analysed according to the models. Facts prove that the value the of interface pressure is changed along axis, and it is bigger in the middle of the cable joint. The interface pressure is directly proportional to the value of the cable joint’s Young’s Modulus. Using finite element method is of instructive significance and can save money and energy in the design of a cable joint.

1. Introduction
High voltage cable joint (Figure 1) plays a key role in connecting cables together to lengthen the cable lines for long distance power transmission. It is usually made by silicon rubber which are variable in Young’s Modulus. According to different materials and installation methods, cable joints can be divided into thermal shrinkage type, wrapped type, pouring type, prefabricated type and cold shrinkage type. However, due to the composite interface and electric field stress concentration within the cable joint, it is generally known that cable joints have become the typical part of operational malfunction and weak points of high voltage distribution lines [1-3].
Among factors which influence the quality of the assembly of cables and cable joints, controlling the interfacial pressure within an appropriate range is of essential importance [4-6]. Because it may not meet the electrical strength requirements and cable insulation strength if the interface pressure is too small, and it may cause difficulties in installation or damage called bamboo joint phenomenon to the cable shown in Figure 1 if the interface pressure is too large.

The interface pressure between cable and cable joints is affected by many factors such as the structure of the cable joints, the interference between the cable and the cable joints, the dimensions and thickness of the cable joints, and the Young’s Modulus of the materials. Because of the variable cross-section of the cable joints, there is no accurate formula to calculate this interface pressure. At present, the main methods of measuring the interface pressure between cable and cable joints are built-in sensor method, photo elasticity method, on-site electrical measurement etc. But all these methods above are complex or exist measurement errors such as damaging the continuity of the structure because of the insert sensor, different from the actual structure of cables, and all needing to produce the cable joints and assemble them with the cables before the measurement process [7]. Therefore, they are not practical for the design stage of the cable joints.

In this paper, we derived the interface pressure and its distribution along axis positions between the cable and cable joint using finite element method, and studied the relationship between the interface pressure and the Young’s Modulus of different materials of the cable joints-silicon rubber. It is helpful for estimating the interface pressure without producing the cable joints before with sufficient measurement accuracy. Therefore, it is useful for the designation of the cable joint in the aspects of structure, size, interference value and so on to create an appropriate interface pressure.

2. Establishment of finite element model

In this study, axisymmetric simulation models are established by using the finite element analysis software Ansys. The models are based on the size of a 110kV crosslinked polyethylene (XLPE) cable with cross-section area of 1600mm² connected by the cable joint matching with the cable which is made of silicon rubber. The model is showed in figure 3.
In this model, we simplified the cable into two parts, the part reflecting the cable-core and the part representing the insulation layer. The cable-core is made of copper. So, its Young’s Modulus of the material is 119GPa and the Poisson’s Ratio is 0.33. The material behaviour of insulation layer is set up referring to XLPE with the Young’s Modulus at 150MPa and the Poisson’s Ratio at 0.5. And through reading papers about silicon rubber cable joints, we found that the Young’s Modulus of materials widely used in cable joints were from 0.58MPa to 1.35MPa [2.8.9]. Therefore, to study the effect on interface pressure produced by different Young’s Modulus of the materials and to give a guidance in practical design process for material selection, the material parameters of the cable joint are set up as silicon rubber with a range of Young’s Modulus from 0.5MPa to 2.0MPa wider than consulted values in data above and the Poisson’s Ratio at 0.5. The Young’s Modulus increase 0.1MPa in each model.

In the model, to ease the calculation difficulty and accelerate the convergence, the insulation layer is tied to the cable core. The contact relationship between the insulation layer and the cable joint is interference fit. The amount of the interference is constant at 4.5mm in radial direction. The models of these three parts are built according to the actual dimensions before assembling. To reflect the interference fit, we tick the button for automatic shrink fit. According to Saint-Venant’s Principle [9], it will not influence the stress if we fix a bottom surface. Thus, one of the bottoms of the cable is in displacement in these models as the boundary condition to eliminate the rigid body displacement.

After all these settings, the model is meshed. The size of each element should not be too large or too small, or the interface pressure value may be inconsistent with actual ones. After many times of attempts, the whole model is shown in figure 4.

**3. Results of simulation**

The distribution of the interface pressure in cable joint with Young’s Modulus of 2.0MPa is shown in figure 5 as an example.
As the pressure around the edges is quite small contrasted with the main part of the model, to display a clearer distribution of the interface pressure, after cutting up both ends of the cable joint, the main part’s interface pressure is shown in figure 6.

The values of relationship between interface pressure and axial positions of some different Young’s Modulus cable joints are extracted from some model and shown in figure 7.

From the results shown above, because the structure of the cable joint is symmetric, the interface pressure is also symmetric along the middle. It can be known that interface pressure is gradually changed along the axis, and it is bigger in the middle part of the cable joint and smaller at the two ends, but the maximum value is not in the exact middle. It can be inferred that it is because the cable joint is thicker in the middle but the connection part is right in the middle and it is weaker than the main part.
of the joint. As the minimum value appears at the two ends of the cable joints, and the interface pressure here is one of the important parts in the cable joint, it is needed to pay extra attention to the design of the cable joint at the two ends of it.

What we can also find in this figure is that the variety of the interface pressure along axis is lighter in the cable joints with smaller Young’s Modules than cables joints with larger Young’s Modulus. This law is instructive in the structure design in the aspect of difference in thickness.

In order to study the influence caused by the Young’s Modulus and the interface pressure, there is a line chart that drawn to figure change of the maximum value of the interface pressure and the minimum one of each model with different Young’s Modulus. The results are shown in figure 8.

![Figure 8. Interface pressure of cable joints with materials with different Young’s Modulus.](image)

From this chart, we can know that the maximum value and the minimum value of interface pressure are both directly proportional to the Young’s Modulus of the materials. This change indicates that if the size of a cable joint is limited to a certain range, it is possible to change the interface pressure by selecting a different material with different Young’s Modulus. It also defined an optional range of material selection for this certain kind of cable joints.

4. Conclusions

In this paper, axisymmetric simulation finite element model is established. Through finite element method, the interface pressure caused by interference fit of the cable and cable joint is calculated. The conclusion can be drawn as follows:

The interface pressure between 110kV cable and this certain kind of cable joint is gradually changed along axis. And the middle part of the pressure is bigger than that of the ends. But the maximum value is not right in the middle. The variation of the interface pressure along axis is smoother in the models with smaller Young’s Modulus of cable joints. These conclusions can be referred in the structure design of cable joints.

The calculation results show that both the maximum one and the minimum one of the interface pressure value between the cable and its cable joint is directly proportional to Young’s Modulus of the materials of cable joints. This means if the size of cable joints is limited to a certain range, it is a feasible method to control the pressure by selecting different kinds of materials of different Young’s Modulus.

Numerous disciplines such as Elastic Mechanics, Electrical Science, and Material Science are involved in the design of cable joint. There is no accurate formula that can reflect the whole design in all factors accurately. So finite element method is a more economical method that can query the needed parameters of an exact product and can also help to optimize product design without producing it before.

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