Construction and analysis of puncture clamp model for 10KV insulation line based on finite element

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Abstract. At present, the puncture clamp has been widely used in the cable branching technology. However, due to the complicated installation process, the clamping force is too large during installation, resulting in cable damage and reduced life. If the clamping force is too small, it may cause poor contact or even cause fire. In this paper, the 3D solid model of the puncture clamp is established by using SolidWorks 3D software. Then the finite element analysis model of the puncture clamp is established in the finite element analysis software ANSYS Workbench, and the static analysis and exploration of the puncture clamp are obtained. The results show that the puncture blade and the conductor on the puncture clamp have the greatest contact stress and the maximum amount of deformation of the bolt, while the bolt meets the required strength. The results can be used to further optimize the structural design of the puncture clamps, refine the installation specifications and guide the installation.

1. Introduction

The insulated puncture clamp can be electrified to achieve power distribution without power failure, without the cable stripping the insulation layer and without the exposed conductor, thus obtaining an increasingly wide application.

When the outdoor power transmission line needs to be branched, insert the branch cable into the cap of the puncture clamp, and then determine the specific position of the puncture wire clamped on the main line. At this time, the nut can be tightened with a torque wrench, and the puncture blade will pierce the rubber step by step. When contacting the conductor in the cable, when the contact between the piercing blade and the conductor inside the cable reaches the pre-designed optimal position, the torque nut will also reach the maximum value and break off, and the piercing clamp will be installed. At present, some enterprises at home and abroad have tried to develop insulated puncture clamps with electric fire installation tools, which fundamentally solve the problems of safety shortage, complicated operation, time-consuming and labor-intensive, low installation quality and high quality in the installation of puncture clamps, and can improve construction. The efficiency of personnel and the safety and reliability of their construction process. In this process, understanding the force of the puncture clamp work, controlling the puncture process and the clamping force of the blade to the cable, so as not to damage the distribution cable, but also ensure good electrical conductivity, it becomes a key technology problem [1-4].
In this paper, the 3D solid model of the puncture clamp is established by using SolidWorks 3D software. Then the finite element analysis model of the puncture clamp is established in the finite element analysis software ANSYS Workbench. The displacement distribution and stress distribution characteristics of the puncture clamp are used. Further analysis was carried out, which provided guidance to ensure the design and installation reliability of the puncture clamp.

2. Model construction

2.1. Model structure and parameters
Take the aluminum stranded wire of the 10KV single-core JKLYJ insulated aerial cable 240/150 as an example. Its basic physical properties are shown in Table 1:

| Crosssectional area (mm²) | Conductor diameter (mm) | Semiconductive shield thickness (mm) | Thin insulation (mm) | Ordinary insulation (mm) | Thick insulation (mm) | Pulling force (kN) |
|--------------------------|------------------------|-------------------------------------|---------------------|--------------------------|----------------------|-------------------|
| 150                      | 14.6                   | 0.6                                 | 19.6                | 22.6                     | 24.4                 | 21033             |
| 240                      | 18.4                   | 0.6                                 | 23.4                | 26.4                     | 28.2                 | 34680             |

The puncture clamp housing is made of engineering plastics (the density is 1140kg/m³, the modulus of elasticity is 896MPa, the Poisson's ratio is 0.41), and the torque bolts and nuts are made of high-strength No.35 steel (the density is 7850kg/m³, elastic modulus is 2.12E+5MPa, Poisson's ratio is 0.31), the puncture blade is made of copper alloy (the density is 8300kg/m³, the elastic modulus is 1.1E+5MPa, the Poisson's ratio is 0.34), and the wire is made of aluminum stranded wire (the density is 2700kg/m³, elastic modulus is 6.8E+4MPa, Poisson's ratio is 0.34), other parts are structural steel (the density is 7850kg/m³, the elastic modulus is 2E+5MPa, the Poisson's ratio is 0.3) [5].

2.2. Construction of geometric models

![Physical installation diagram.](image)

The geometric model of this paper is modeled by 3D software SolidWorks. Mainly analyzes the force analysis of each part under static conditions, so the wire is stripped. The physical object is shown in Figure 1. The solid model is saved in x_t format and imported into Ansys Workbench to add materials to the material library. The mechanical engineering material performance data of high-strength No. 35 steel and engineering plastics respectively give different material properties to different parts. There
are generally six classification methods for finite element model meshing. This analysis uses hexahedral element meshing. The unit is used to construct a three-dimensional solid structure. Since the minimum dimension in the assembly is 2 mm of the blade thickness, the blade is freely meshed and the cell size of the mesh is 0.9 mm, the main line and the sub-wire network. The grid size is 7 mm, and the mesh size of other parts is 3.5 mm, which means that the finite element model can be obtained. As shown in Figure 2, the assembly finite element model has a total of 436,360 nodes and 147,750 single elements [5-10].

2.3. Loads and constraints
Regardless of the influence of wind load and ground height difference, the tensile force of the main line generally takes 20% of the cable breaking force. 20% × 34680 = 6935 N The tension on both sides of the main line is 6935 N. The other end of the sub-line adopts a frictionless constraint, and there is a vertical downward gravitational acceleration g, and finally the pre-tightening force of the bolt. The relationship between the twisting moment and the pre-tightening force of the bolt of the puncture clamp is checked as follows: [11-12]:

\[ T = \eta \cdot F \cdot D \]  

\( T \) is the tightening torque, the unit is Nm; 
\( \eta \) is the tightening torque coefficient; 
\( F \) is the pre-tightening force, the unit is N; 
\( D \) is the nominal diameter of the bolt, the unit is m.

Therefore, the clamping force of the bolt is 18750 N.

Boundary conditions: There is no friction constraint on the ends of the main line and the cable at one end of the branch line, and the initial condition is the gravitational acceleration g.

3. Results and analysis
As shown in Figure 2, the overall mesh division diagram of the main line, the sub-line and the puncture clamp, and Figure 3 is the mesh division diagram of the blade of the minimum thickness, the correlation coefficient is 100, and the grid size is 0.9 mm. As shown in Figure 4, the overall structure deformation cloud diagram, it can be seen that the deformation of the entire assembly is the main line and the bolt, the other parts are relatively small, and the side of the sub-wire is minimally deformed.
Figure 4. Overall structure deformed cloud.

Figure 5. Overall displacement cloud diagram of bolts.

Figure 6. Bolt overall stress cloud.

Figure 7. Overall displacement of the blade cloud.
Figure 8. Stress map of the blade contact.

It can be seen from Figure 5 that the deformation of the nut is much larger than that of the nut and the deformation of the upper spacer iron block is more obvious. The maximum deformation is 0.255 mm. It is known from Figure 6 that the positional stress of the polished rod is the largest, and the maximum is 866.37MPa, so the Dangerous part is the bolt polished rod part. Figure 7 is the overall displacement cloud diagram of the blade, and Figure 8 is the stress cloud diagram of the blade contact area. The blade and the main line contact area have the greatest stress.

Figure 9 shows the displacement of the main conductor. Under static conditions, the leftmost deformation of the main conductor is not obvious, but the change on the far right is much more obvious and the deformation from the left to the right is larger and larger. The maximum displacement on the left side is about 0.64 mm, and the maximum displacement on the rightmost side is almost zero. Figure 10 is a force cloud diagram of the main conductor. In addition to the puncture clamp, the force of the left and right symmetry is relatively small, and the stress of the puncture clamp is 60.37MPa.

Figure 9. Displacement of the main wire cloud.
Figure 10. Stress clouds of the main lines.

Figure 11 shows the bolt displacement cloud diagram. The displacement from the bolt tail to the nut is gradually increased. The maximum displacement is about 0.25 mm for the bolt head. The minimum deformation is about 0.18 mm for the bolt tail and the deformation of the bolt is the largest part of the entire assembly. From Figure 12, the maximum screw stress can be obtained, and the maximum stress at the dangerous part is 514.3 MPa, which is less than the yield strength and meets the requirements.

Figure 11. Bolt displacement cloud.

Figure 12. Bolt stress cloud.
Figure 13 is the overall displacement cloud diagram of the puncture blade. The overall displacement of the blade is relatively small compared with other parts. The maximum is only 0.047mm. It can be seen from Figure 14 that the stress of the entire component tip is the largest, reaching a maximum of 973.81MPa, and it is the maximum stress of the entire assembly. Therefore, it is necessary to make the puncture clamp to the optimal position when designing and installing the puncture clamp, so that the puncture clamp can maximize its function.

**Figure 13.** The overall displacement cloud of the puncture blade.

**Figure 14.** Stress map of blade.
4. Conclusions
This article in the light of the structure and mechanical performance requirements of the puncture clamp, based on the finite element method, the static analysis of the puncture clamp is carried out, the torque bolt and the puncture blade are analyzed. The contact stress between the puncture blade and the conductor is the largest. The bolts are calculated to meet the requirements. The three-dimensional model construction and the finite element analysis model establishment and analysis methods used in this paper are largely applicable to the analysis of the puncture clamp. The static characteristics of the puncture clamp are presented to the designer and installer, so that the designer and installer understand the force of the puncture clamp during the installation process, in order to control the puncture process and the clamping force of the blade to the cable, so that the clamp can be installed in an optimal position, ensuring reliable connection, saving man-hours, safety and efficiency, and It can ensure good electrical conductivity without damaging the distribution cable. At the same time, it can improve the level of safety operation and maintenance and the level of insulation, and reduce the failure rate caused by the insulation performance of the T-cable after using the clamp.

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