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Analysis of Contact Characteristic of Overhead Line and Suspension Clamp

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Abstract

In this paper, a LGJ150/25 type ACSR transmission line and a CGU-3 type suspension clamp are taken as research objects. A contact model of the conductor and the clamp was established by using finite element method. The effects of sag angle of the conductor, holding force and tension force in section are analyzed. The results showed that the contact area in the middle of the clamp is of belt-like type. The extreme values of tress were observed on the edge of the contact area and near the edge of keeper. In clamp section, suspension angle had the greatest influence on contact stress, and then the clamp force. The tension force in section played a most important role in these affecting factors. In the exit section of clamp, the biggest impact factor was tension force in this section, then the suspension angle, the third was clamp force. The results provide theoretical basis on reducing corona loss, optimization the clamp. Doubtlessly, the conclusion has important theoretical significance and application value.

Keywords: *overhead transmission lines, fretting wear, contact characteristics, finite element analysis, optimization of suspension clamp.*

1. Introduction

There are many kinds of contact in the installation structure of overhead conductor and suspension clamp, mainly including the contact between conductor and clamp, conductor and press plate, and U-shaped screw and press plate etc. The contact vices will relatively slip when the wire is effected by the alternating loads ,such as the wind-induced vibration [1] ,then the wear and tear will be generated in contact area which will lead to fatigue failure [2]. In order to improve the fatigue life of the wire and line fittings, it was necessary to analyze the contact characteristics of the connection between conductor and fitting (such as suspension clamp). According to the existing researches, it is easy to produce wear in the holder section because of the tension of the wire and the clamping force produced by U-shaped screw will lead to a large stress in the contact area of conductor and clamp [3]. In the low bending amplitude, the contact area between the outer layer wire strands and suspension clamp became the critical region of fatigue failure, and the failure of wears fist appears in the contact edge point (LPC) of conductor and clamp [4]. Alain Cardou et.al had analyzed the strain distribution of contact area of the suspension clamp under different suspension angle and wire tension by experiment [5], [6], [7] and finite element method [8], [9], [10] and the maximum tensile strain was found to appear in the contact edge. In this article, LGJ150/25 type ACSR transmission line and CGU-3 type suspension clamp were taken as research objects, the contact model of conductor and clamp was established and the effect of suspension angle of conductor, holding force and tension force in section for the stress distribution of the the clamp contact zone was analyzed by the finite element software ABAQUS under different conditions.

2. The Structural Characteristics and Stress Analysis of Clamps

CGU-3 type suspension clamp is composed of hulls, two U-shape bolts, press plates and two peg boards. The centerline of hulls in the holder section between two U-shaped bolts is

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a straight line, and in the two exit sections is arc. The main structural parameters of the CGU-3 type suspension clamp are shown in Table 1 [12].

Analyzing the parts of the U-shaped blot separately, the schematic diagram of the connection body of U-shaped screw and clamp hulls is shown in Figure 1.

Table1. The structural parameters of CGU-3 type suspension clamp

Clamp type	Applicable conductor diameter (mm)	The height of hanging point H(mm)	The length of hulls L(mm)	The radius of trunking R(mm)	The type of suspension bolt	The distance of peg board (mm)	The failure load （kN）
CGU-3	13.1～21.0	101	220	11.0	M16	18	40

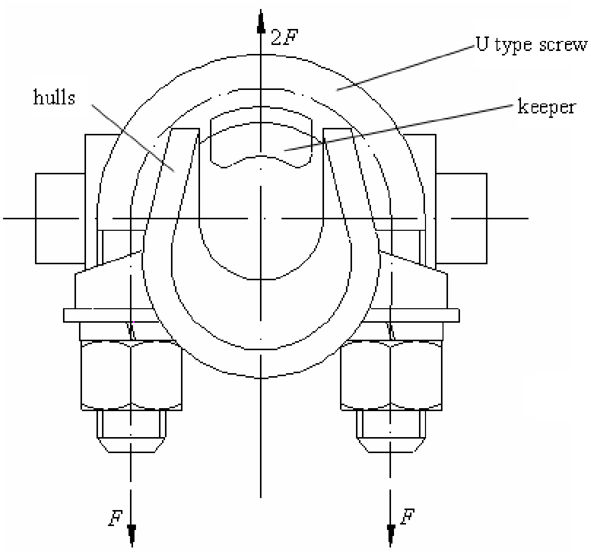


Figure 1. The connection schematic diagram of U type screw and clamp hulls

Assuming that both sides of the U type screw are applied the same tightening torque T_L, then its value equals to the sum of the frictional torque of the spiral vices and the frictional torque between nut annular end face and the supporting surface of connecting members. It can be known from the literatures[11], [13]:

$$T_L \approx 0.2Fd \tag{1}$$

Where the F is the tensile force applied on U type screw produced by nut (N); the d is the nominal diameter of the screw thread (mm).

Under this tightening force, the holding force F_C works in hulls produced by U type screw is:

$$F_c = 2F = \frac{10T_L}{d} \tag{2}$$

In the actual installation process, the torque applied on two ends of the U-shape bolt is not equal, therefore the force generated on the platen is not necessarily along the vertical direction, and the distribution of the holding force can be equivalent to a concentrated stress due to the line contact between platen and U-shape bolt.

3. The Contact Model of Finite Element

The structural parameter of LGJ150/25 type ACSR transmission line is shown in Table 2. In order to get the stress distribution of the contact area between conductor and clamp, a finite element model for CGU-3 type suspension clamp was established according to the actual size. The length of conductor is 500mm and it is symmetrically installed on the clamp. The top of the platen is established into curved surface and its curvature radius is 50mm, while its area is 62 mm^2. The holding force working on the clamp produced by U-shape bolt is calculated according to formula (2), and it is loaded on the platen. The physical model is meshed division by using C3D8R type unit, and the finite element model is shown in Figure 2. As seen in Figure 2, the surface A is the outer surface of the hull hanging shaft, which is used to constraint the rotation of clamp; the surface B is simplily established on the place where the U-shape bolts is installed on the platen, which is used to load holding force; the sufaces C and D are the two end faces of the wire, which are used to load wire tension and overhanging angle.

Table 2. The specification of LGJ150/25 type ACSR transmission line (GB1178-83)

Nominal sectional area of aluminum/steel (mm^2)	Structure number/diameter(mm)		Calculation cross-section area (mm^2)			Outside diameter (mm)	Calculation breaking force(N)	Calculation mass (kg/km)
	Aluminu	Steel	Aluminum	Steel	Gross			
150/25	26/2.7	7/2.1	148.86	24.25	173.11	17.1	54110	601

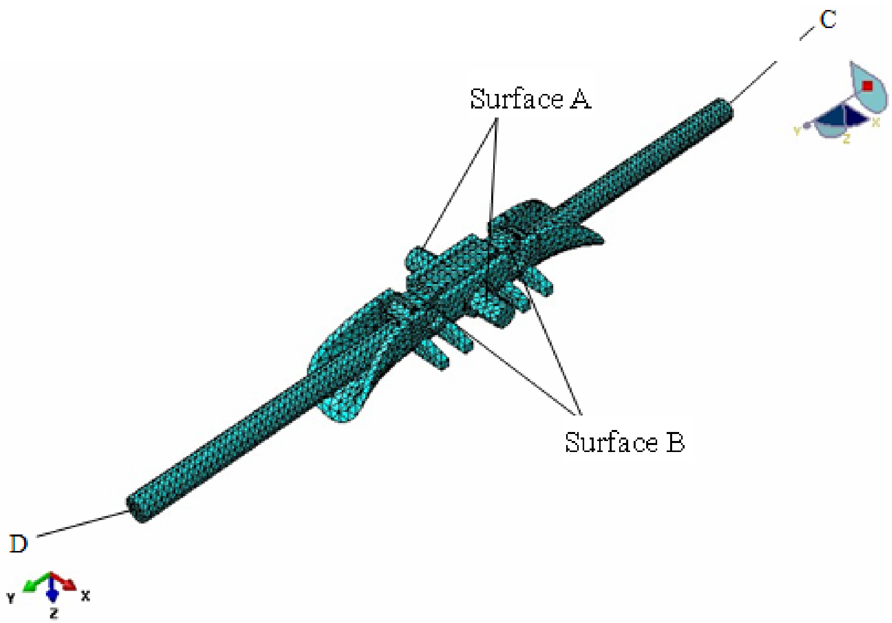


Figure 2. The finite element model of the contact between conductor and clamp

4. Loads and Boundary Conditions

4.1. Material Parameters

The suspension clamp and platen should be manufactured used malleable iron which grade is not less than KTH330-08. Considering the elastic-plastic deformation of the clamp and wire during the calculation process, the clamp hull, platen and wire are endowed with elastic and plastic parameters. The typical stress-strain curve of the malleable iron and the aluminum wire materials are respectively shown in Figure 3 and Figure 4 [14].

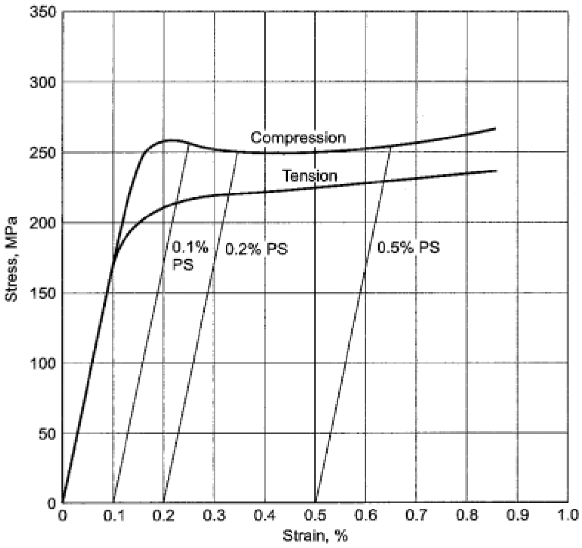


Figure 3. The stress-strain curve of KTH330-08 malleable iron

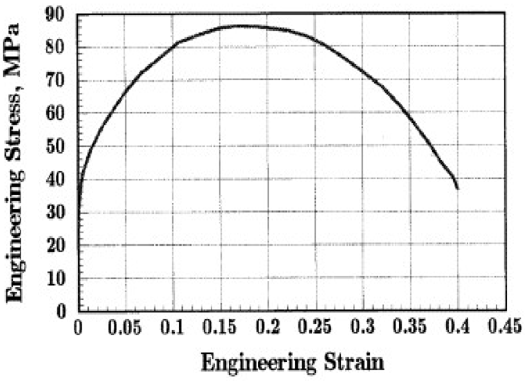


Figure 4. The stress-strain curve of the aluminum wire materials

4.2. Boundary Conditions and Loads

Ignoring the impact of wind loads and ground elevation difference, wire and clamp could only rotate a certain angle around the hull hanging scroll. Thus the DOF along the horizontal and vertical directions were constrained in hanging scrolls, and the DOF rotating around the hanging scroll axis was released. Actually the conductor would sag under the effect of gravity , and the catenary was formed within the span. After considering the overhanging angle was controled at 5°~ 12° [6], when the conductor passed through the flat areas, the overhanging angles applied on conductors were chosen at 8.08°, 8.26°, 9.05° before loading. Since the two ends of the wire were not free end, a certain force was applied at the each end face to reflect the remaining portion effect on the selected segment. In this article, the effect of the end face tension working on the contact region have been researched, and the calculated pull force (UTS) of the two end faces of the conductor were respectively applied on 5%, 10% and 15%.

The holding force was computed based on formula (2), and the screw nut fixed U-shaped were respectively applied on the torques of 2.5N ▪ m, 3.0N • m and3.5N • m. The holding force of the single screw respectively were 562.5N, 1875.0N, 2187.5N.

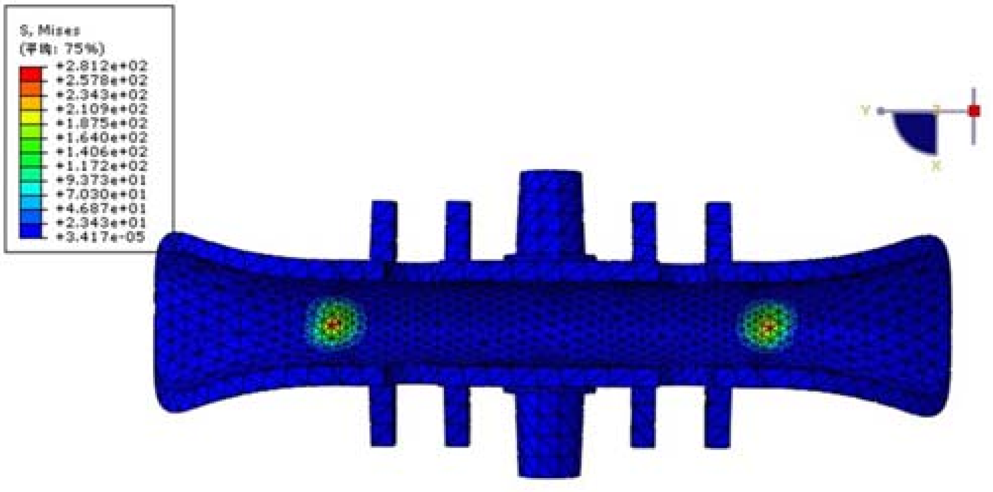
The orthogonal analysis method was used, and the three factors which include wires hanging angle, clamp holding force and wire cross-section tension were selectied; while the level number is 3. The designed analysis program is shown in Table 3.

Table 3. The orthogonal analysis program

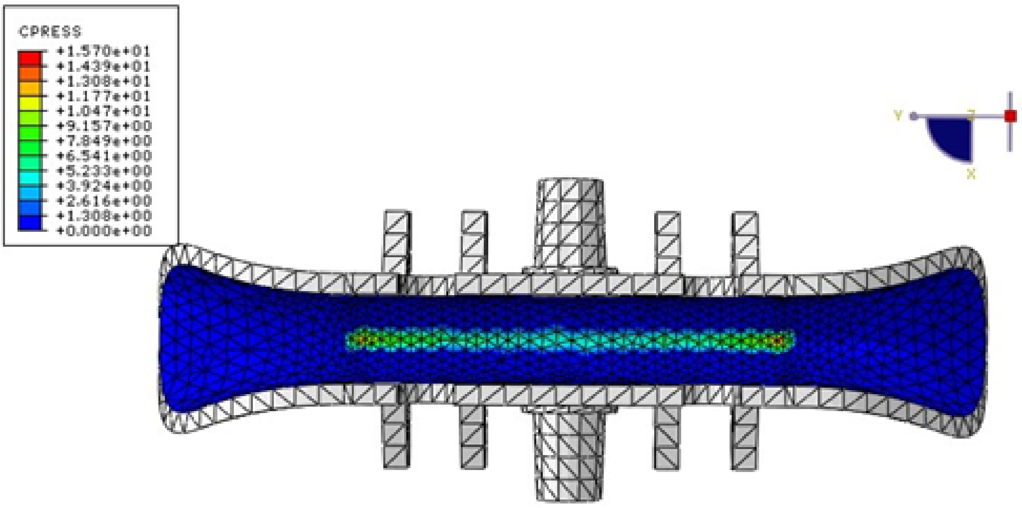
Program	Wire hanging angleβ(°)	Holding force F(N)	Cross-section tension T(N)
1	8.08	1562.5	5411
2	8.08	1875.0	8116.5
3	8.08	2187.5	10822
4	8.26	1562.5	8116.5
5	8.26	1875.0	10822
6	8.26	2187.5	5411
7	9.05	1562.5	10822
8	9.05	1875.0	5411
9	9.05	2187.5	8116.5

5. Results and Analysis

The equivalent stress nephogram and pressure stress nephogram of the clamp contact area obtained by calculating are shown in Figure 5. As seen in Figure 5，the shape of the conductor and wire clamp contact area was a strip in the middle of the wire clamp, while the compressive stress extremum was appeared in the edge of the contact region (LPC) and the press plate.



a) Equivalent stress nephogram of contact area

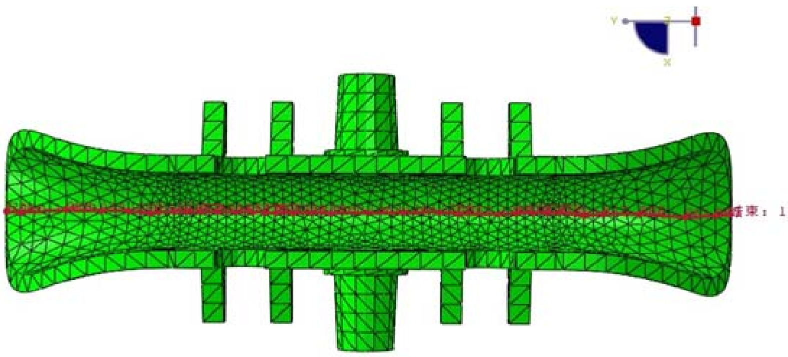


b) Pressure stress nephogram of contact area

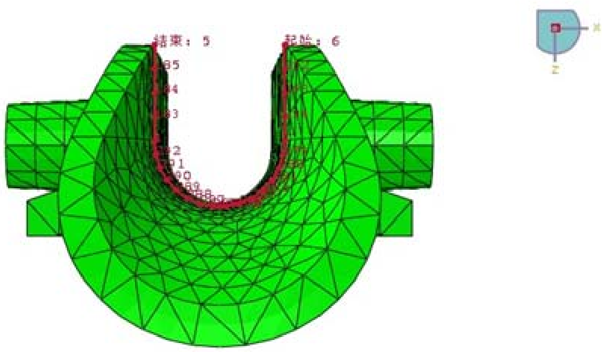
Figure 5. Stress distribution nephogram of contact area

The path one was formed by a sequence of nodes along the clamp axial, while the path two was formed by a sequence of nodes along the radial direction of clamp LPC. The distribution of the two paths are shown in Figure 6.

The stress distributions of the contact area along the path 1 under 9 test schemes are shown in Figure 7. As seen in Figure 7, under the 9 test schemes, the pressure stress of contact area along the axis direction of wire clamp had the same trend and distribute symmetrily in a center. The contact stress near the edge of the directly contact area (LPC)between wire and clamp was larger, but the contact stress at the center of the clamping segment was smaller. Distanced the edge of the hull in 60 mm, there was extreme stress value in clamp corresponding to the edge of the press plate. Affected by the tension of both ends and the dangle angle of the clamp, the wires in the clamp appeared a certain degree of bending, which leaded to the contact stress concentrated on the edge of the contact area, while the positive pressure acted on the wire changes suddenly on the edge of the press plate and generated stress extremum.



a) Path one



b) Path two

Figure 6. Two paths distribution diagram

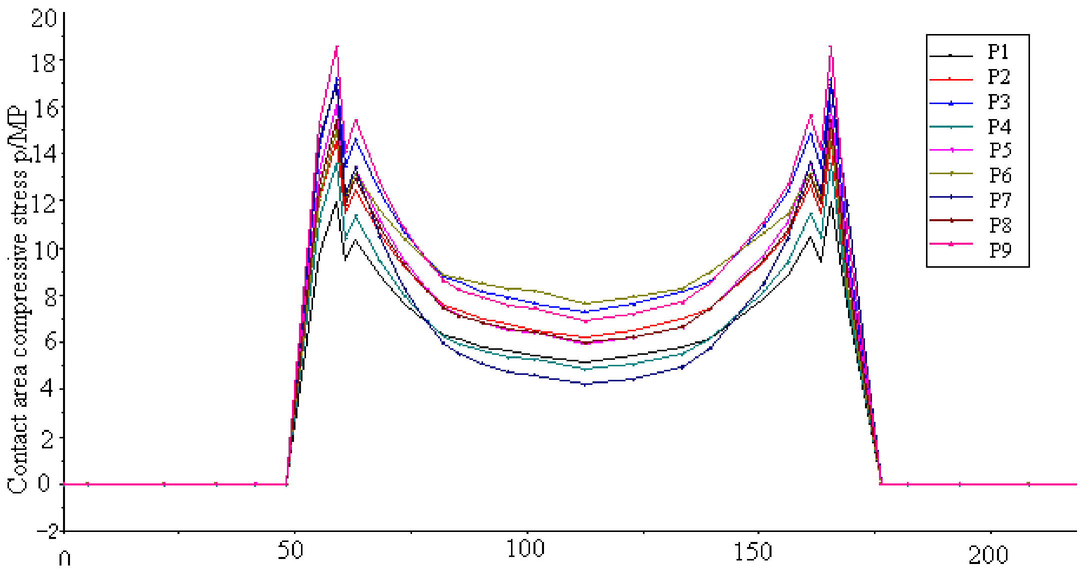


Figure 7. Distribution of contact stress along the path 1

In Figure 7, under the conditions of the No.1,No.2 and No.3 test schemes, when the wires dangle angle was constant, the clamping force was gradually increased from 1562.5N to 2187.5N and the cross-section tension gradually was increased from 5411 N to 10822 N, the minimum compressive stress in the middle of the contact area was increased from 5.2 MPa to 7.2 MPa, the stress of the contacting edge was increased from 12 MPa to 17 Mpa and the press plate edge stress value was increased from 10 MPa to 14 Mpa. It was demonstrated that the stress of the overall contact area was increased with the clamping force and sectional tension increased, while the change trends were same .

Under the No.1, No.4, No.7 test schemes, when the clamping force was constant, the wires drape angle was increased from 8.08° to 9.05° and the sectional tension was increased from 5411 N to 10822 N, the minimum compressive stress of contact area in centre was decreased from 5.2 MPa to 4.2 MPa, the stress on the edge of the contact area was increased from 12MPa to 17MPa, and the stress on the edge of the press plate was increased from 10 Mpa to 13.4 MPa. The central stress value was decreased, two stress extreme values both were increased. That was because the increasing wire drape angle leaded to the degree of bending of the wire increased in the holder section, resulting in the decreasing of the pressure of the wire to the central of clamp. At both ends near the contact edges, wire bending had less effecte. When the section tension and drape angle of the wire increased, the contact pressure in the part of the region would increase, leading to the stress extremum increased.

Under the No.3, No.5, No.7 test schemes, when the section tension was constant, the wires drape angle was increased from 8.08° to 9.05° and the holding force was increased from 1562.5 N to 2187.5 N, the minimum stress in middle of the contact area was decreased from 7.3MPa to 4.2Mpa, the the stress of contact edge was maintained at about 17MPa, and the stress of the press plate at the edge was reduced from 14.6MPa to 13.4Mpa. It is shown that the stress value variation in the middle of clamping area was large, and the changes in stress on both sides were small. It was indicated that the stress value in the middle of the clamping segment would be affected mainly by the changes of the dangle angle and clamping force of the wires.

The stress distributions of the contact area along the path 2 under 9 test schemes are shown in Figure 8. As seen in Figure 8, under the 9 test schemes, the pressure stress in contact area along the section direction in wire clamp all had the same trend, and the contact stress in LPC was distributed symmetrily along contact center. The stress distribution in this path could be divided into three regions: stress-free contact area, which was located in the upper half of the clamp, and it was in the minimal stress part of contact area with the conductor; contact transition area, which was located in the lower part of the clamp that was a small range area, and the stress in this area had an obvious increasing turning point suddenly; extremum stress contact area, which was located at the bottom of the clamp, approach to line contact. Due to the stress concentrated in a small area, the contact type of the exit section of the clamps was complex, the contact body could not be simplified into a half-space, and its distribution form could not be explained by the classical theory of general shape objects contact which was corresponded that Hertz theory was inapplicability in this case.

From Figure 8, the results of No.1, No.7, No.9 test programs had obvious characteristics. The stress extremum in program 1 is minimum, the stress of the transition region in program 7 was maximum, and the stress extremum of the contact in program 9 was maximum. Under the No.1 and No.7 test programs, when the clamping force was constant, the dangle angle was increased from 8.08° to 9.05° and of the sectional tension was increased from 5411N to 10822N, the maximum stress was increased from 12.2MPa to 17.3MPa, and the break point value of stress rise and decline stage was increased from 5.6MPa to 9.2Mpa. The whole stress value was increased because the increasing of the dangle angle and tension of the wire makes the pressure increased in the edge of contact area. Compared No.7 programs with No.9 programs, when the dangle angle of the conductor was constant, the clamping force was increased from 1562.5N to 2187.5N and the sectional tension was decreased from 10822N to 8116.5N, the maximum stress was increased from 17.3MPa to 19Mpa, and the break point value of stress rise and decline stage was increased from 7.2MPa to 9.2Mpa. It indicated that the increasing of the clamping force makes the stress extremum of the contact area increased, and the decreasing of the sectional tension makes the pressure of contact area reduced which leads the contact area decreased, while the stress concentration area was also decreased.

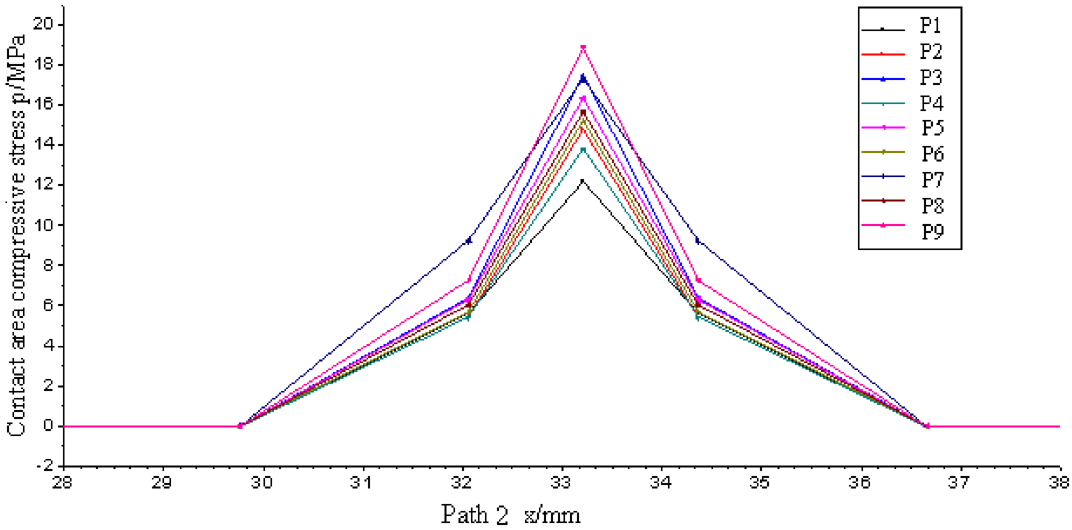


Figure 8. Distribution of contact stress along path 2

According to the results analyed above, it was shown that the dangle angle, clamping force and sectional tensile of the wires had large effects on the stress of the contact area. For the clamping area, the greatest impact factor was dangle angle, the holding force was followed, and the minimal impact factor was sectional tension. For the clamp exit section, the greatest impact factor was sectional tension, the dangle angle was followed and the clamping force had minimal impact. In order to reduce wear and extend clamp life, these factors should be taken into consideration comprehensively when designing the clamp.

6. Conclusion

In this paper, the influences of the dangle angle, clamping force and sectional tension of wire impacting on the contact characteristics were analyzed by finite element methods, and we got the following conclusions:

(1) The pressure stress distribution of the contact area in the clamp along the axial direction is symmetric. The stress has a maximum value on the edge of the contact area (LPC), and has a smaller value in the sandwiched middle. There is a stress extremum appeared in the edge of the holding portion which is located in the clamp corresponding to the edge of the press plate.

(2) When the dangle angle is constant and the clamping force and sectional tension are increased, the overall contact stress along the axial direction of the clamp is increased and the graphical trend remains unchanged. When the clamping force is constant and the dangle angle and sectional tension are increased, the stress in the middle of the clamping area is decreased, and the stress extremum are increased in two parts. When the sectional tension is constant and the drape angle and clamping force are increased, the stress value in the middle of the clamping area is changed greatly, while the stress on both sides of the clamping has small changes.

(3) When the clamping force is constant and the wires dangle angle and section tension are increased, the overall stress values along the radial direction on the edge of the clamp contact area is increased. When the dangle angle is constant, the clamping force is increased and the section tension is decreased, the stress extremum in contact area is increased, and the area of stress concentration is reduced.

(4) The dangle angle, clamping force and section tension have great influences on the stress stress of the contact area. In the clamping area, the greatest impact factor is dangle angle, the holding force is followed, and the minimal impact factor is section tension. In the

clamp exit section, the greatest impact factor is section tension, the dangle angle is followed and the minimal impact factor is the clamping force.

Aknowlegement

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