Research on Contact Simulation of Strands in Large Cross-Section ACSR

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***Abstract*—In the process of tension stringing, conductor withstands the action of axial tension and torsion. In order to study the contact force between strands of cross-section ACSR after loading, the equivalent stress and contact results of 1250 mm^2 ACSR under different loads combined by axial tension and tension-torsion are analyzed by finite element method. The results show that the steel core of the conductor bears the main stress, and the stress distribution of the same layer strand is basically the same; the maximum contact force between the strands of each layer appears near the middle section of conductor, and the maximum contact force occurs between steel strand and steel strand.**

Keywords—large cross-section, ACSR, strand, contact analysis, finite element analysis

I. Introduction

Large cross-section ACSR has many advantages, such as low line loss, high energy transmission efficiency, saving investment and operation cost. It has remarkable economic and social benefits. It has been widely used in UHVDC transmission lines in recent years [1]. The Changji-Guquan (+1100kV) UHVDC transmission line project adopts 1250mm^2 large section conductor [2], which is composed of middle steel strand and four layers of aluminium strand. In the process of tension stringing construction, the stress of conductor is complex, and there are few studies on the contact state and law of each layer in conductor strands. The change of contact state for strands and the cause of defects such as loose strands and jump strands are not clear.

In this paper, 1250mm^2 large cross-section ACSR commonly used in UHVDC project is taken as the research object. According to the stress condition of the conductor in the actual process of tension stringing, the contact force results of each layer in the conductor are obtained by finite element analysis, which provides support for further research on the contact deformation of the layered conductor strands.

II. Force analysis of conductors

In the tension stringing process, the conductor not only bears the axial tension, but also bears the torsional load. According to the analysis of literature [3], there exists an angle between the rotation direction of the outer line strand and the tangent direction of the pulley edge when the conductor passes through the release pulley, which causes the conductor to be subjected to the action of torque. As shown in Fig. 1, F is the axial tension of the conductor, q is the unit line-loaded of the pulley to the strand, α is the envelope angle, R is the radius of the pulley.

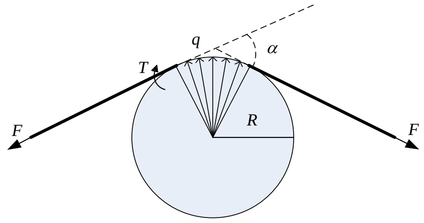


Fig. 1. Force analysis of conductor passing through pulley

The torsion of the conductor is

$$T = \mu F\alpha \bullet d/2 \quad (1)$$

In the equation, d -strand diameter, mm; μ-friction coefficient.

III. Finite element method analysis

A. Conductor Modeling

The conductor type is JL1/G3A-1250/70-76/7, which consists of steel core (1+6) and four layers of aluminum strand (10+16+22+28). The detailed structure parameters of the conductor are shown in Table I.

TABLE I. Structural parameters of JL1/G3A-1250/70-76/7

Layer	Quantity	Diameter(mm)	Lay ratio		Material
			Specified value	*Current value*	
mid	1	3.57	/	/	steel
1	6	3.57	16-22	21	steel
2	10	4.58	13-16	14	aluminum
3	16	4.58	12-15	13	aluminum
4	22	4.58	11-14	12	aluminum
5	28	4.58	10-12	11	aluminum

According to the geometric parameters of the conductor in Table 1, the helix of each layer of the conductor is established, and then the circle of the section of the line is generated by the vertical helix. Then the solid model of the line can be generated by scanning the section along the helix. Finally, the solid model of the finite element analysis can be obtained by rotating the array of the layers along the central axis of the line, as shown in Fig. 2. In order to reduce the computational workload of finite element analysis, the modeling length of conductor is 100mm.

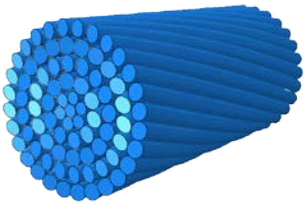


Fig. 2. Conductor Modeling

B. Material properties

The material and properties of the conductor are shown in Table II. The material is isotropic.

TABLE II. CONDUCTOR MATERIAL PROPERTIES

Material	Density(t/mm^3)	Modulus of elasticity(MPa)	Poisson ratio
steel	7.8×10^{-9}	1.96×10^{5}	0.28
aluminum	2.7×10^{-9}	5.9×10^{4}	0.33

C. Element Mesh

C3D8R hexahedron element is used in finite element analysis. The global size of mesh is controlled to 3 (12 along the circumference direction) and the number of elements is 51316. The model after meshing is shown in Fig. 3.

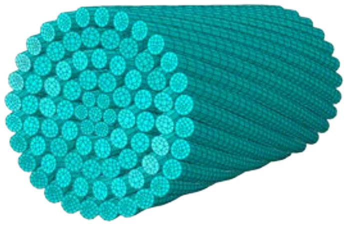


Fig. 3. Meshing Model

D. Contact, boundary conditions and loading methods

The strands of each layer in the conductor are set as general contact. The tangential and normal behavior of contact is defined by penalty function method. The friction coefficient is 0.15. In order to study the influence of conductor force on the contact condition of strand, the boundary conditions and loading modes are analyzed by finite element method under two working cases of axial tension and tension-torsion combined load.

1) Axial tension working-case

One end of the conductor is fully constrained, the other end is coupled to the reference point RP1 at the center of the section, and the tension F is applied to the reference point RP1, as shown in Fig. 4.

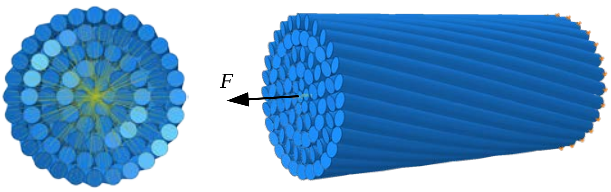


Fig. 4. boundary conditions of model

2) tension-torsion working-case

The calculation model is the same as the working-case *1)*. The torque T is increased at the loading point RP1, as shown in Fig. 5. Torque T can be determined by (1).

Fig. 5. Boundary conditions of tension and torsion combined

IV. CONTACT ANALYSIS RESULTS

A. Analysis of the results under axial tension

In practice, the axial tension *F* does not exceed 30% RTS and working tension does not exceed 25% RTS [4]. Therefore, 25% RTS and 30% RTS are taken as the axial tension conditions for finite element analysis.

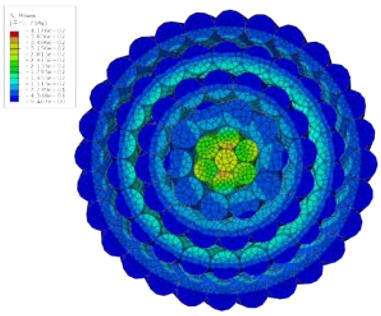
The rated tensile strength (RTS) of JL1/G3A-1250/70-76/7 ACSR is greater than 294.23kN, 95% of which is taken as the calculated breaking force [5], namely 279.5kN. The axial tensile load F is as shown in Table III.

TABLE III. AXIAL TENSILE LOAD CONDITIONS

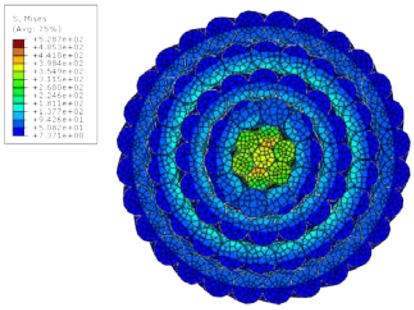
No.	Working-cases	Axial tension *F*(kN)
1	25%RTS	69.875
2	30%RTS	83.850

The stress results of conductor under 25% RTS and 30% RTS axial tension *F* are obtained by calculation. In order to avoid the effect of end restraint on stress results, the equivalent stress of the middle cross-section in conductor is selected as shown in Fig. 6.

As seen from Fig. 6, the equivalent stress of conductor under 25% RTS axial tension is basically the same as that under 30% RTS axial tension. The equivalent stress of steel cores is greater than that of aluminum strands and bears the main stress. The equivalent stress of aluminum strands decreases gradually from the inner layer to the outer layer. The equivalent stress of each strand in the same layer distributes annularly along the center of conductor section.



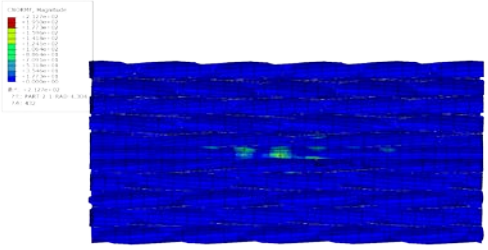
(a) middle cross-section under 25% RTS



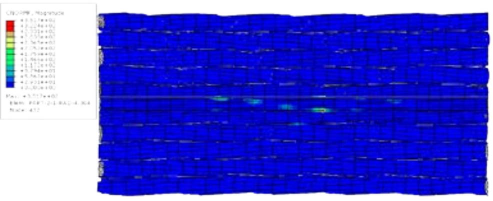
(b) middle cross-section under 30% RTS

Fig. 6. The equivalent stress

The contact force of each layer in the conductor is obtained by calculation. The maximum contact force of strands in each layer appears near the middle cross-section of conductor as shown in Fig.7, and the specific results are shown in Fig. 8.



(a)25%RTS



(b)30%RTS

Fig. 7. Contact force distribution of conductor

B. Analysis of the results under tension-torsion

The torque values of JL1/G3A-1250/70-76/7 ACSR under different tension loads are obtained through (1), as shown in Table IV. They are used in working-cases. According to the loading mode of section III, the finite element analysis are carried out.

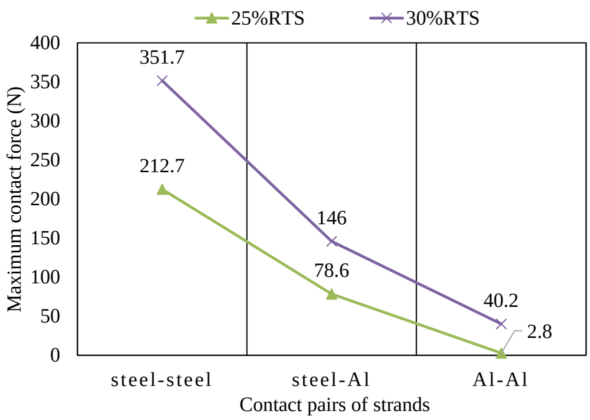
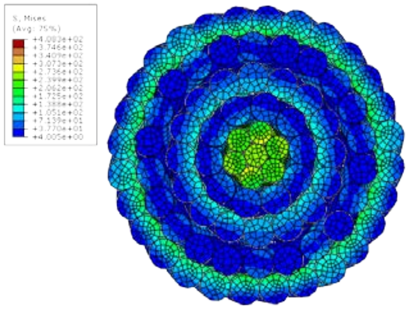


Fig. 8. Maximum contact force of strand in each layer of conductor

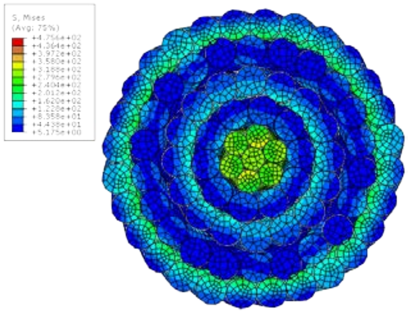
TABLE IV. TENSION-TORSION WORKING-CASE

No.	Axial tension *F*(N)		Torque *T*(N.mm)
1	25%RTS	69875	259855
2	30%RTS	83850	311826

The stress results of the conductor under different tension-torsion working-cases are obtained by calculation. Similarly, the middle cross-section of conductor is selected as shown in Fig. 9.



(a) tension-torsion under 25%RTS

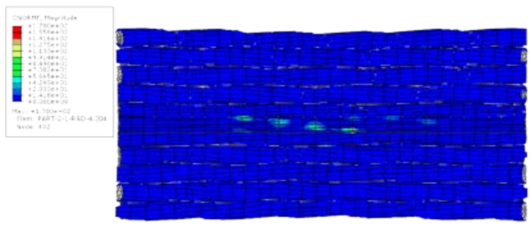


(b) tension-torsion under 30%RTS

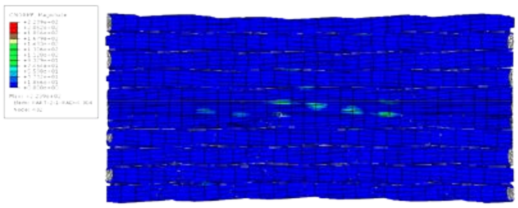
Fig. 9. The equivalent stress of middle cross-section

As seen from Fig. 9, the equivalent stress of each strand in the same layer distributes annularly along the center of conductor section. The steel core still bears the main stress. Unlike conductors only subjected to axial tension, the equivalent forces of the outermost aluminum strands and the third layer aluminum strands are higher than those of the subouter aluminum strand and the inner aluminum strand. This is because the outermost aluminum strand and the third aluminum strand are right-handed and the other two aluminum strands are left-handed. When the conductor is subjected to right-handed torsion, the right-handed aluminum strand is tightened and the stress is increased. The stress decreases with the relaxation of the left-handed aluminum strand.

The contact force of each layer in the conductor is obtained by calculation. The maximum contact force of strands in each layer appears near the middle cross-section of conductor as shown in Fig. 10, and the specific results are shown in Fig. 11.



(a) tension-torsion under 25%RTS



(b) tension-torsion under 30%RTS

Fig. 10. Contact force distribution of conductor

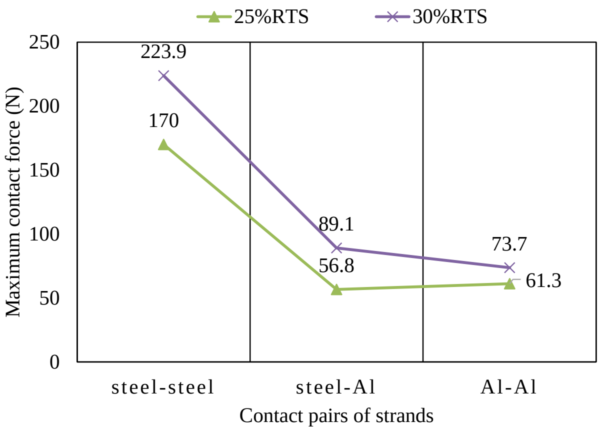


Fig. 11. Maximum contact force of strand in each layer of conductor

V. CONCLSION

In this paper, the stress and contact force results of a 1250 mm2 large cross-section ACSR under the action of axial tension and tension-torsion are obtained by finite element analysis, which can provide reference and support for the study of the layered stress and contact deformation of the conductor.

(1) Under the action of axial tension, the steel core of the conductor bears the main stress and decreases gradually outwards. The contact force between the middle steel cores is the largest, and the contact force between the outer layers decreases gradually. This is consistent with the inward extrusion of the strand after deformation.

(2) Under the combined action of tension and torsion, the stress of each layer changes due to the influence of the direction of torsional load and the rotation of the strand. When the direction of strands is the same as that of torsional load, the stress of the strands increases, otherwise the stress of the strands decreases. When the direction of torsional load is the same as that of stranding of outermost strand, the maximum contact force between steel core-aluminum strand and aluminum strand-aluminum strand is close to each other. The maximum contact force between steel core and steel core is about three times that of the other two.

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