

Finite Element Simulations and Experimental Research of Grip Clamps of Expanded Diameter Half-Hard Aluminum Conductors Composite Core Reinforced

Jiancheng Wan, Yaao Zhou, Min Wang, Ming Jiang, and Yong Ma

Abstract—The cross-sectional area and outer diameter of the wire that have been put into use in the project are similar to those of the newly designed JLZX1K/F2A-530(630)/55 sparse-twisted carbon fiber expanded wire. The finite element analysis and the compatibility test of the stranded carbon fiber expanded diameter wire were carried out, and the combination of test and simulation was used to judge the radial pressure resistance of the composite mandrel and the force of the aluminum strand of the profile. It is concluded that the newly designed JLZX1K/F2A-530(630)/55 sparse-twisted carbon fiber expanded conductor can be used with the SKLT-60 grip clamps; the aluminum strand stress concentrates from the inner layer to the outer when the wire clamp clamps the wire.

Index Terms—Grip clamps, expanded diameter half-hard aluminum conductors composite core reinforced, force transfer finite element, test.

I. INTRODUCTION

Carbon fiber composite conductor has been widely used in transmission line engineering due to its advantages of high strength, large capacity, high temperature resistance, light weight, low linear expansion coefficient, low sag, non-magnetic, high temperature resistance and corrosion resistance [1], [2]. With the promotion of the theme of energy conservation and environmental protection, a new type of sparsely twisted carbon fiber diameter enlargement (reducing the material cost but ensuring the cross-sectional area of the conductor) conductor JLZX1K/F2A-530(630)/55 (below "530k630 carbon fiber diameter enlargement conductor") was born [3]. During the construction of all kinds of temporary anchor and tight wire for erecting wires, the force transmission between the wire and the anchor force system should be completed through the clamping of the clamping device.

Compatibility finite element analysis is carried out on 530k630 expanded diameter half-hard aluminum conductors

composite core reinforced with grip clamps of three conductors with equal outer diameter that has been put into use in the project in this paper, and according to the results are related with test and analysis, finally got 530k630 expanded diameter half-hard aluminum conductors composite core reinforced can be used with SKLT-60 type grip clamps.

II. ANALYSIS OF FORCE PRINCIPLE OF CARD WIRE DEVICE

The parallel movable grip clamps is A four-link structure, as shown in Fig. 1. The pull plate and the press-plate are hinged at point A, and the press-plate and the upper press-plate are hinged at point C. The distance between hinge point A and the far end point B of the slideway is the length of the drawplate LAB, and the distance between hinge point A and O is the length of the clamping plate LOA. The pull ring of the cable clamping device can be opened by parallel movement to the left. The wire is put in from the side, and the upper and lower clamping nozzles hold the wire after tightening the pull ring. TAB under transverse tensile F_0 , the tension through four bar linkage pass and translated into positive pressure toward a wire clip mouth F_N , pulling through the TAB to the grip clamps of the fuselage.

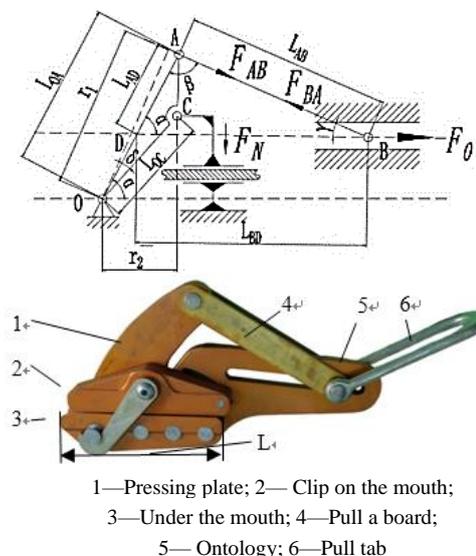


Fig. 1. Clamping force and structure diagram of clamping device.

The main force type of connecting rod is axial tension or pressure. When the clamping device clamps the wire, it shall ensure that the wire is stable and not loose when it is clamped [5]:

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$$F_N \mu = F_f \geq F_0 \quad (1)$$

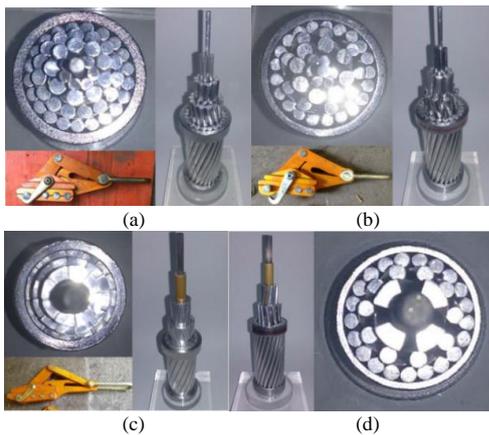
Formula: F_0 —TAB tension, N ;

F_N —Positive pressure on the wire, N ;

μ —Coefficient of friction between the connector and the conductor;

F_f — F_N produces the friction force of the clamp against the wire, N .

Has been put into use in the project of JL/G1A-630/55 type steel reinforced aluminium conductor (hereinafter referred to as the "630 conductor"), JLK/G1A-530 (630)/stranded type 45 hole diameter in thin steel core aluminum stranded wire (hereinafter referred to as the "530k630 steel core al stranding wire") and JLRX1/F1A-710/70 type carbon fiber wire (hereinafter referred to as the "710 carbon fiber wire"), with 530k630 carbon fiber wire diameter hole diameter wire almost consistent, and were verified by engineering supporting card line, as shown in Fig. 2(b), (c), (d) and shown in Table I. The length of the clamping nozzle determines whether the wire part held by the clamping device is damaged or damaged [4]. In the engineering site often appear equal outside diameter wire clamping device to replace the use of the phenomenon, which will bring some safety hazards to the construction of the project.



(a) 630 steel-cored aluminium strand
 (b) 530k630 steel-cored aluminium strand
 (c) 710 carbon fiber conductor
 (d) 530k630 carbon fiber expanded conductor
 Fig. 2. wire and matching grip clamps.

TABLE I: TYPES OF FOUR TYPES OF CONDUCTORS AND MATCHING GRIP CLAMPS

Wire type	diameter (mm)	grip clamps	The jaw length (mm)	Weight (kg)
(a)	34.30	SKLQ-65	219	12.5
(b)	33.75	SKLK-45	273	14
(c)	32.80	SKLT-60	335	14
(d)	33.80	/	/	/

III. STUDY ON THE CRITERION OF SIMULATION ANALYSIS

In order to study the status of the mandrel and aluminum strand when the 530k630 carbon fiber reamed wire is clamped by the clamping device, the radial pressure test and simulation stress analysis data of the mandrel and the plastic zone range of the 530k630 steel core aluminum strand

which has been applied in the project and is clamped by the SKLK-45 clamping device can be taken as the analytical criterion [6].

A. Pressure Criterion of Composite Mandrel

In order to evaluate whether the mandrel is damaged when the conductor is clamped, radial mandrel pressure test and simulation [5] in the figure below are used as damage criteria. As shown in Fig. 3:

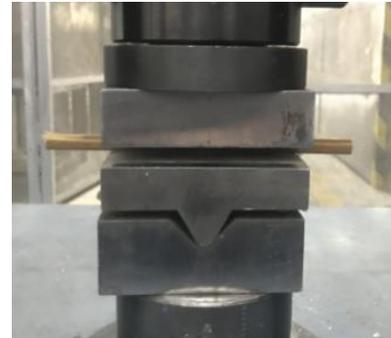


Fig. 3. Radial pressure test of mandrel.

The upper pressing block extruded the mandrel at a speed of 1mm/min until the failure of the mandrel stopped the test. Five 160mm composite mandrel mandrel were selected in the test. The length of the pressing block was 100mm.

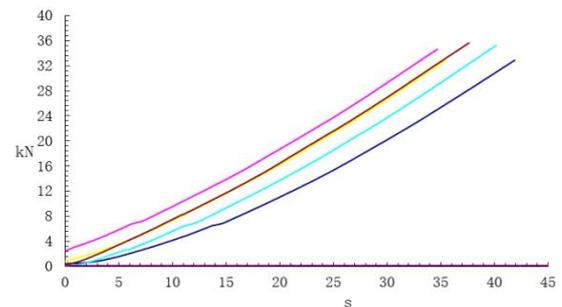


Fig. 4. Force - time curve of composite mandrel.

TABLE II: MATERIAL PARAMETERS OF MANDREL

material	diameter (mm)	elasticity modulus (GPa)	Poisson's ratio	density (kg/m ³)
glass fibre	0.425 (thickness)	Axial	50	2600
		radial	12	
carbon fiber	7.65	Axial	158	1620
		radial	15	

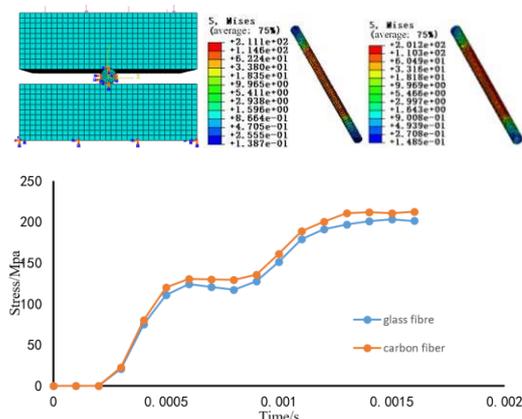


Fig. 5. Simulation stress of radial compression of carbon and glass fiber.

Glass fiber and carbon fiber are anisotropic materials, and

the parameters are shown in Table II. The upper and lower pressing dies are set as rigid, and the lower pressing dies are completely restrained, and the upper pressing dies are pressed to perform dynamic simulation [7]. According to the simulation stress cloud diagram 6, the maximum simulation stress of the compressive stress of carbon fiber and glass fiber layer is 211.1Mpa and 201.2Mpa. The stabilized stress values of 211Mpa and 201MPa are taken as the criterion for the compressive failure stress of carbon fiber and glass fiber.

B. Criterion for Semi-duralumin Damage

The plastic range of the aluminum strand when the 530k630 steel-core aluminum strand is clamped by the clamp can be used as the criterion for damage of the aluminum strand. The model parameters of 530k630 steel-core aluminum strand are shown in Table III Based on the calculation of the transmission mechanism and the technical parameters of 530k630 steel-core aluminum strand, the model of the card connector is simplified into two upper and lower platens. The model construction and simplification are shown in Fig. 6:

TABLE III: TECHNICAL PARAMETERS OF 530K630 STEEL-CORED ALUMINUM STRAND WIRE

Number of Layers (inside out)	Material	Diameter (mm)	The number of wires	Section ratio
1	Steel wire	2.8	1	--
2	Steel wire	2.8	6	18
3	aluminium stranded wire	4.23	8	15
4	aluminium stranded wire	4.23	9	13
5	aluminium stranded wire	4.20	21	11



Fig. 6. Criterion model of wire and card holder.

The simplified clamping device and wire model were imported into software, in which the elastic modulus of steel core and upper and lower pressing blocks was 206Gpa, the elastic modulus of aluminum stock was 69Gpa, and the poisson's ratio was 0.3. Normal behavior was selected as the default, and tan-gential behavior was set as penalty function. The frictional coefficient between steel strand lines, steel strand lines and aluminum strand lines of general wire was greater than 0.1, and the frictional coefficient was 0.1[8], so the results were conservative.

The aluminum strand of 530k630 steel core aluminum strand is made of hard aluminum. In the load test, 30% of the calculated breaking force in the engineering is taken as the standard, that is, the rated load =RTS*0.3= 40.3kn (take 41kN). Combined with the formula (6) of the compressive stress on the wire, the pressure on the upper jaw is 23.81mpa and the yield strength is 120MPa. Simulation analysis results are shown in Fig. 7.

According to the results of the analysis of cloud picture shows the maximum stress section aluminum into the plastic range area grid of aluminum shares section at 14.47% to the total number of grid, within the scope of the outer aluminum

stocks into the plastic mesh of the outer aluminum section to 11.90% total grid, in the same proportion of the outer is 11.11%, the inner aluminium stocks the proportion is 25.00%, as carbon fiber wire hole diameter aluminium wire damage criterion.

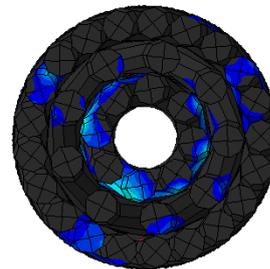


Fig. 7. Plasticity zone of aluminum strand in 530k630 steel core aluminum strand.

IV. SIMULATION STUDY ON EQUAL OUTER DIAMETER WIRE CARD HOLDER

In this chapter, 530k630 carbon fiber reinforced steel conductors is modeled, and three kinds of equal section and equal outer diameter steel wire clamps are simplified. The model of wire clamp device was assembled in Analysis software, and finite element simulation analysis was carried out according to rated working conditions. The co-operation of 530k630 carbon fiber expansion conductors and three clamping devices was studied.

A. Finite Element Modeling based on Analysis Software

1) 3D model building and mesh generation

According to the calculation of the force transfer mechanism of the SKLT-60 parallel mobile cable clamp model, the model is simplified into two clamping plates. According to the technical parameters of 530k630 carbon fiber diameter expanding conductors, as shown in Table IV, the 3D modeling software Solidworks is used for modeling.

TABLE IV: TECHNICAL PARAMETERS OF CARBON FIBER EXPANDING WIRE

Layers (inside out)	Material	Diameter (mm)	The wire number	Section ratio
1	Carbon fiber core	8.5	1	--
2	glass fibre	0.425	--	--
3	Trapezoidal aluminium stranded	5.55	4	14
4	Circular aluminium stranded	4.22	10	13
5	Circular aluminium stranded	4.22	21	12



Fig. 8. Simplified overall matching model.

In order to ensure the accuracy of grid division, the upper

and lower clamping nozzles of the simplified clamping device are not rounded, as shown in Fig. 8.

2) *The material properties*

The established wire model conversion format was imported into Analysis software, and the boundary condition setting and mesh division contact during the analysis were consistent with the analysis of 530k630 steel-core aluminum strand in the aluminum strand damage criterion. The material properties of upper and lower platen and composite mandril are consistent with the above criteria[9]. The elastic modulus, poisson's ratio and density of semi-duralumin are: 69GPa, 0.3, 2700kg/m³.

3) *The loading of three kinds of cable clamp*

Carbon fiber wire hole diameter model JLZX1K/F2A-530(630)/55, load test in engineering calculation is 30% of the tensile force, namely the rated load = RTS×0.3 = 191.61×0.3 kN = 57.48 kN (60 kN), by the structure and the experience to the force coefficient is 4.825, the wire clamp on the pressure formula of model applied

load, hydrophobic ground type carbon fiber conductors hole diameter with three kinds of card wire clamp on the applied load in the following Table V:

TABLE V: LOAD APPLIED ON THE SURFACE OF THE UPPER PLATEN IS AS FOLLOWS

Card wire type number	SKLQ-65	SKLK-45	SKLT-60
Rated load(kN)	60		
Upper platen pressure (MPa)	30.53	24.04	20.51

4) *To solve the calculation*

The remaining calculation Settings are consistent with the simulation method of 2.2 damage criterion research.

B. *Finite Element Analysis Results*

The carbon and glass fiber equivalent stresses of the three kinds of clamping simulators and the deformation of aluminum strands of the three kinds of clamping simulators were statistically analyzed, as shown in Table VI:

TABLE VI: SIMULATION RESULTS OF MAXIMUM STRESS STATE

Criterion	Number of plasticity of aluminum strands in each layer (unit)			Plasticity ratio of aluminum strands (%)				Carbon fiber stress criterion(MPa)	Glass fiber stress criterion(MPa)
	Inner	In the outer	Outer	Inner	In the outer	Outer	entirety		
SKLQ-65	8	4	10	25.00%	11.11%	11.90%	14.47%	211.0	201.0
SKLK-45	16	32	39	26.67%	20.00%	11.61%	15.11%	326.3	240.7
SKLT-60	13	21	31	21.67%	13.13%	9.26%	12.05%	225.6	209.3
SKLT-60	11	14	18	18.33%	8.75%	5.36%	7.73%	186.8	147.9

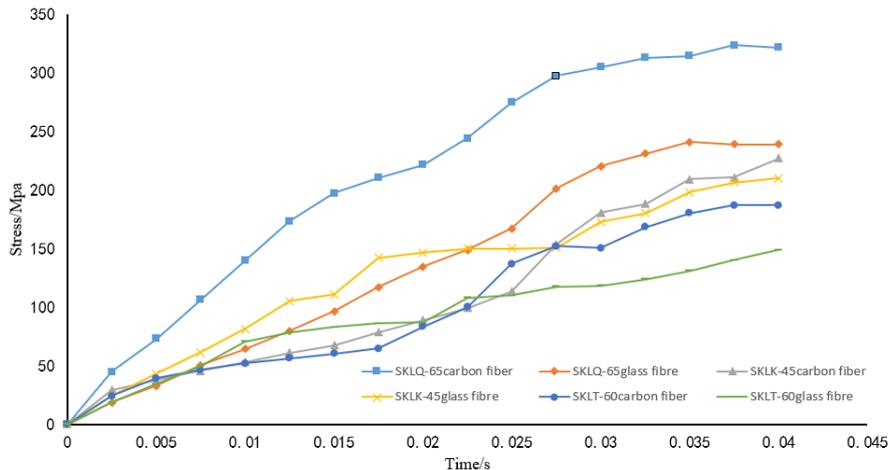


Fig. 9. Equivalent stress time history curve of carbon fiber glass fiber.

1) *Equivalent stresses of carbon and glass fiber are clamped by cable clamp*

The carbon fiber core stress of 530k630 carbon fiber reamed conductors was simulated and analyzed with SKLQ-65, SKLK-45 and SKLT-60 type clamping device, As shown in Fig. 9, The maximum stresses on carbon fiber and glass fiber under three loading conditions are as follows: 326.3Mpa, 225.6Mpa and 186.8Mpa. At 240.7Mpa, 209.3Mpa, and 147.9Mpa (the maximum stress is near the clamp mouth), it is obvious that the analysis results of SKLQ-65 and SKLK-45 type clamp coordination exceed the criterion, and the mandrel fails.

2) *Three kinds of clamps are used to simulate the deformation of aluminum strand*

Cloud picture of aluminum strand entering plastic

deformation area under the clamp of three kinds of card line simulator (SKLQ-65, SKLK-45, SKLT-60) (highlighted part) As shown in Fig. 10.

Based on the finite element analysis results of aluminum strand damage criteria, the damage status of aluminum strand under various pressures is summarized as shown in Tab.7: the plastic ratio of trapezoidal aluminum strand in the inner layer of the conductor with SKLQ-65 clamp is 26.67%, and the plastic ratio of round aluminum strand adjacent to the outer layer is greater than the criterion, so the selection of the clamp is unreasonable. After matching with SKLK-45 connector, the plastic ratios of inner layer, adjacent layer and outer layer aluminum strand are: 21.67% (close to the criterion), 13.13% (beyond the criterion), and 9.26% (close to the criterion), so the connector selection is unreasonable. After the combination analysis with sklt-60

connector, both the composite core rod and the plasticity ratio of aluminum strands in each layer are within the criterion, so the JLZX1K/f2a-530(630)/55 spare-twisted carbon fiber diameter expanding conductors can achieve compatibility and cooperation with SKLT-60 connector.

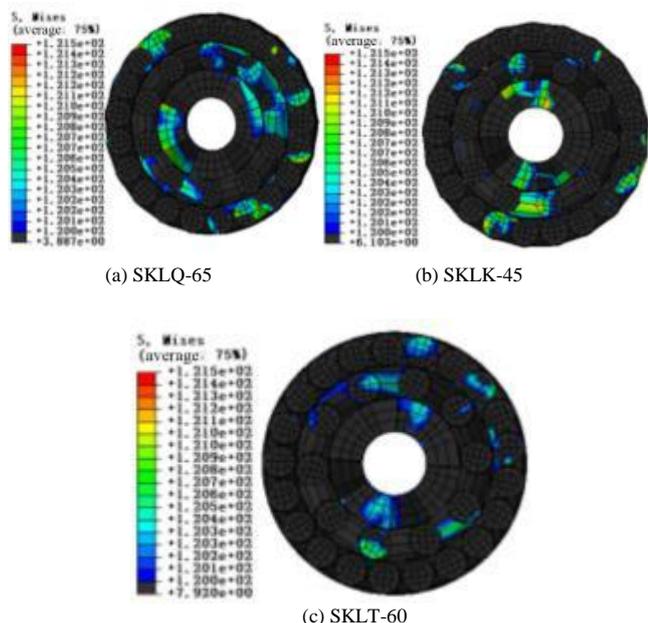


Fig. 11. Cloud picture of plastic deformation of aluminum strand.

V. VERIFICATION TEST OF SKLT-60 GRIP CLAMPS

According to the basic requirements of transmission line construction equipment design and test [10], Rated load tests were carried out on 530k630 carbon fiber diameter expanding conductors and SKLT-60 type wire clamp. (note: forehead load = $RTS \times 0.3 = 194.53 \times 0.3 \text{ kN} = 58.36 \text{ kN}$ (take 60kN)). Clamping the wire within the nominal section scope with the clamping mouth of the clamping device, one end of the wire is fixed, the other end of the clamping device (pull ring or pull plate) is connected with the wire rope, the other end of the wire and the wire rope are respectively fixed in the horizontal tension machine clamp.

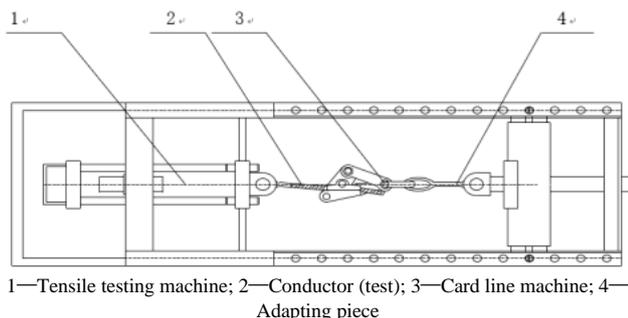


Fig. 11. Schematic diagram of test layout.

1, 1.5 times rated load after the completion of the test in sequence, the slip relative to the wire is less than 5mm, no shrinkage core, no obvious indentation on the conductors surface, after unloading the wire clamp should be installed and removed freely, no damage phenomenon. In addition, the average diameter of carbon fiber wire is not less than 97% before clamping, there is no obvious scratch damage on the surface of the conductors, and the damage of the inner

layer of the thin twisted aluminum strand is more obvious than that of the outer layer. SKLT-60 type clamping device and 530k630 carbon fiber diameter expanding conductors match to meet the technical requirements.

VI. CONCLUSION

- 1) The results of the finite element analysis and the compatibility verification experiment of the SKLT-60 card connector 530k630 carbon fiber expanding conductors have proved that the two are compatible and can meet the technical requirements;
- 2) In the process of clamping this kind of carbon fiber reinforced thin twisted wire with clamping device, the plastic ratio of wire aluminum strands decreases from the inner layer to the outer layer layer by layer;
- 3) Aluminum conductor with the same sectional area and similar external diameter may cause damage to aluminum strand and mandrel when it is mixed with matching clamps;
- 4) The clamping area between the clamping device and the conductor, especially the area near the clamping mouth of the clamping device, is the stress concentration area of the conductor. The construction damage problem of the conductor is most likely to occur at this position, so it can be inspected and repaired at these positions.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Wan jiancheng, Jiang ming concuted the research; Zhou yao, Zhao shijie, Ma yong analyzed the data; Zhou yao, Zhao shijie, Ma yong wrote the paper; all authors had approved the final version.

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