

# Optimized Design of Crimping Tubes Matching with 1000mm<sup>2</sup> Conductor

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**Abstract**—The large cross-section conductors with 1000mm<sup>2</sup> sectional area are widely applied in South Hami - Zhengzhou ± 800kV UHVDC power transmission project. The Al wires withstand relatively high tension for the large ratio of Al to steel, so the grip strength of crimping tube designed according to traditional experiences cannot meet the requirements of standard. Optimized design of crimping tube is necessary to minimize the strength loss of Al wires caused by crimping and improve grip strength. Orthogonal test schemes basing on combinations of different inner diameters and taper lengths of tube are designed after analyzing the factors which influence the grip strength. The influencing effects on grip strength of inner diameters and taper lengths are discovered by normal statistical analysis on test results of different tubes and the same conductor. The guaranteed value of grip strength residual ratio for optimal tube is gained. Optimal sizes of hydraulic tube are recommended to manufacturer, and sampling test results indicate that optimized fittings achieve the expected results.

**Keywords**- transmission line; conductor; strain clamp; splicing sleeve; crimping; grip strength

## I. INTRODUCTION

UHVDC (ultra-high voltage direct current) power transmission employs multi-bundle conductor with large-section to increase transmission capacity, reduce line loss, save engineering investment and overall life cycle cost [1][2]. For ±800kV power transmission project from South Hami to Zhengzhou, rated transmission capacity is 8000 MW, its rated current is 5000A, conductor for common line is hexagon-bundled and that for 10mm and below ice region line is JL/G3A-1000/45-72/7 type ACSR (aluminium stranded conductor steel-reinforced). 1000mm<sup>2</sup> conductor is in four-layer aluminium stranded structure with large section, so crimping of conductor and matched fitting is an important item in manufacture and field construction of fitting, which concerns safe operation of line [3]. Therefore, optimized design of strain clamp and splicing sleeve is necessary for the aim of enhancing grip strength of fitting for conductor and providing basis for optimized design of fitting as well as strength matching between conductor and fitting [4].

## II. CHARACTERISTICS OF LARGE-SECTION CONDUCTOR

### A. Structure and Parameters

Aluminium strand of JL/G3A-1000/45-72/7 ACSR has four layers, as can be seen in Fig. 1 and of which main technical parameters are as shown in Table I.

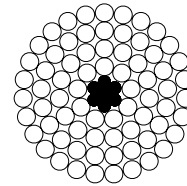


Figure 1. Construction of JL/G3A-1000/45-72/7 conductor.

TABLE I. MAIN TECHNICAL PARAMETERS OF JL/G3A-1000/45-72/7 TYPE CONDUCTOR

| Parameters                  | Values         |
|-----------------------------|----------------|
| Construction                | 72/4.21+7/2.80 |
| Outer diameter (mm)         | 42.08          |
| 20°C DC resistance (Ω/km)   | 0.02862        |
| Mass per unit length (kg/m) | 3.1000         |
| Rated tensile strength (kN) | 221.14         |

### B. Rated Breaking Force of Conductor

Rated tensile strength (RTS) is an important technical parameter of ACSR, and which is calculated as in (1).

$$T = A_a \cdot \sigma_a + A_s \cdot \sigma_{1\%} \quad (1)$$

Where,  $A_a$ -aluminium nominal area, (mm<sup>2</sup>)

$A_s$ - steel nominal area (mm<sup>2</sup>)

$\sigma_a$ - tensile strength required of single aluminium wire before stranded (MPa)

$\sigma_{1\%}$ - stress required of galvanized steel wire with 1% elongation (MPa)

In ASTM B232, calculation of conductor RTS takes into account strength reduction coefficient of aluminium strand and steel core respectively, which is related to conductor construction, and rated tensile strength is calculated as in (2).

$$T = f_a \cdot A_a \cdot \sigma_a + f_s \cdot A_s \cdot \sigma_{1\%} \quad (2)$$

Where,  $f_a$ - aluminium strength reduction coefficient, relevant to construction of single aluminium wire and varying within 0.90~0.96

$f_s$ - steel strength reduction coefficient, relevant to construction of galvanized steel wire with 0.96 for seven-strand steel wire and 0.93 for nineteen-strand steel wire

By comparison between (1) and (2), as strength loss caused by stranding is considered and thus two coefficients less than 1 are introduced in the latter, the calculated result is smaller than that of the former, as shown in table II.

TABLE II. COMPARISON ON CONDUCTOR RTS RESULTS CALCULATED ACCORDING TO TWO STANDARDS

| Conductor Specification | Rated Tensile Strength (kN) |              | Ratio |
|-------------------------|-----------------------------|--------------|-------|
|                         | GB/T 1179-2008              | ASTM B232-11 |       |
| 1000/45                 | 221.14                      | 203          | 91.8% |

It shows that RTS of ACSR with same specification varies when calculated according to national standard and ASTM standard as strength loss as a result of stranding is taken into account in ASTM while not in national standard. Actually, during manufacture of conductor, strength loss of single wire as a result of stranding exists, and not all aluminium single wireS or galvanized steel wireS reach maximum tensile strength simultaneously. Therefore, conductor tensile strength, in national standard, is calculated on the basis of such a hypothesis that both single aluminium wire and galvanized steel wire have certain strength margin. In case only single wire meets minimum value required before stranding, tensile strength of conductor after stranding will never reach rated value.

### III. DESIGN AND TEST OF FITTING MATCHING WITH LARGE-SECTION CONDUCTOR

#### A. Structural Type of Splicing Sleeve

Splicing sleeve matching with ACSR consists of two parts, namely steel tube and aluminium tube, where steel tube is used to crimp steel core and aluminium tube to crimp conductor aluminium strand [5]. Splicing sleeve matching with 1000/45 conductor is as shown in Fig. 3.

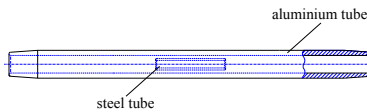


Figure 2. Construction diagrammatic sketch of JYD-1000/45 splicing sleeve

#### B. Structural Type of Strain Clamp

Strain clamp has such structural types as hydraulic, bolted, pre-stranded, and so forth, but only hydraulic type can be used because tensile strength of large-section conductor is relatively large [5]. Strain clamp consists of three parts, namely steel anchor, jumper clamp and aluminium tube on which drainage plate connecting to jumper clamp in double-side contact manner is welded. Strain clamp for 1000/45 ACSR is as shown in Fig. 2.

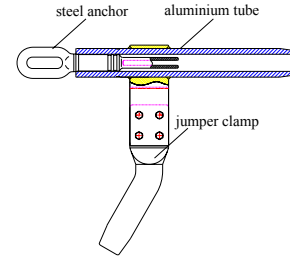


Figure 3. Construction diagrammatic sketch of NY-1000/45 strain clamp

#### C. Design of Crimping Tube

According to experiences in design and service of crimping tube, that for ACSR normally adopts deforming aluminium with commonly used brand number of 1050A. Design of crimping tube mainly includes aluminium tube inner diameter, outer diameter, taper length, crimping length, and so forth, where according to traditional experiences, its inner diameter is taken as 1.04 times of conductor diameter, its outer diameter shall make sure strength of aluminium tube is not lower than that of aluminium strand, and taper length equals to outer diameter of conductor [6]. Electric power fitting standard requires grip strength of hydraulic strain clamp and splicing sleeve for conductor shall not be lower than 95% of RTS of conductor, i.e.  $221.14 \times 95\% = 210.1 \text{ kN}$ , otherwise, test is unqualified.

#### D. Grip Strength Test

Certain strength loss of fitting will emerge after hydraulic connection with conductor. To facilitate analysis of relationship between grip strength of fitting and conductor strength accumulated tensile strength of conductor and survival rate of fitting grip strength are defined as following [7]:

Accumulated tensile strength = actually measured average strength of aluminium wires  $\times$  nominal section area of aluminium wires + actually measured 1% elongation stress of steel wires  $\times$  nominal section area of steel wires

Survival rate of fitting grip strength = test value of fitting grip strength  $\div$  accumulated tensile strength.

After trial-manufactured strain clamp and splicing sleeve are crimped with conductor, test grip strength according to standard specified methods. Average tensile strength of single aluminium wire after conductor stranding is 179MPa and average survival rate of grip strength for six testing samples is 84.6%, which shows grip strength loss of fitting after crimping is relatively large and fitting requires further optimization.

### IV. OPTIMIZATION OF CRIMPING TUBE

#### A. Break-down of Crimping Tube Inside

It can be drawn out from component breakdown photo after crimping tube is crimped with conductor, conductor steel core with steel anchor, as well as aluminium wire with aluminium tube and steel anchor are all tightly crimped. Conductor damage manifests as rupture of aluminium strand

at taper area near tube orifice. In view of strength of the entire component, orifice of aluminium tube features relatively weak strength due to crimping. Therefore, selection of proper inner diameter and taper angle is a main consideration during design of strain clamp and splicing sleeve so as to lower strength loss of aluminium wire at aluminium tube orifice.

### B. Factors Influencing Grip Strength

Grip strength of fitting is directly related to conductor tensile strength, compression ratio of aluminium tube reflects compressed degree of conductor and taper length of aluminium tube affects stress concentration level near its section. With outer diameters of aluminium tube and conductor fixed, inner diameter of aluminium tube decides compression ratio, namely the larger the inner diameter, the smaller the compression ratio. In sum, parameters influences grip strength of fitting for conductor consist of conductor tensile strength, inner diameter of aluminium tube and taper length.

1) *Conductor tensile strength*: As average strength of single aluminium wire in the conductor exerts a direct influence over grip strength of fitting, and for 1000/45 conductor, single aluminium wire accounts for a major proportion in conductor tensile strength, to make sure fitting boasts sufficient grip strength for the conductor, there must be a requirement for strength of single aluminium wire in the conductor. In addition, as strength of single aluminium wire, related to raw material and manufacture process, affects also conductivity, there shall be a reasonable scope for strength of single aluminium wire.

2) *Inner Diameter of Aluminium tube*. Transmission of force between two elements at crimping positions is actually dependent on friction between tube and single wire after deformation, i.e. friction between aluminium tube and aluminium stranded wire and between steel tube and steel core [8]. Section of aluminium tube before compression is a circular ring, then after compression, its outside becomes a regular hexagon inscribed in circle, and inner diameter at its inside decreases accordingly. Compression of steel tube resembles that of aluminium tube. For aluminium tube, its outer diameter equals to compression mould and its inner diameter directly decides compression ratio, where over-large compression ratio will engender strength loss of aluminium wire in the conductor while over-small compression ratio will lead to loose crimping, which causes displacement between fitting and conductor as a result of insufficient friction. Definition of a reasonable inner diameter of aluminium tube can obtain desired compression ratio, which not only realizes force transmission between fitting and conductor but also reduces compression caused strength loss.

3) *Taper Length of Aluminium Tube*. Numerous tests of fitting grip strength shows that rupture happens to the aluminium wire at taper position of aluminium tube due to

sudden change in strength at this part, where strength of crimped part between conductor and aluminium tube is higher than that of conductor, therefore aluminium tube is not fractured, but aluminium wire deforms when squeezed, its effective stress section at taper position experiences sudden change and ruptures under the effect of tension force. In sum, squeezed degree of conductor and taper length exert direct influence over grip strength. Generally, aluminium tube is designed with a certain length of taper at its tube orifice position to alleviate stress concentration at outlet of aluminium tube after crimping, namely the longer the taper, the smoother the section transition. For conductors with three or less layers of aluminium strands, taper length of aluminium tube is normally not less than conductor diameter and proper increase in taper length contributes to alleviation of section sudden change and decrease in strength loss of compressed aluminium wire.

According to above analysis, with conductor parameters decided, grip strength of fitting for conductor can be enhanced and optimized design of fitting realized with reasonable inner diameter of aluminium tube and taper length.

### C. Orthogonal Test Schemes

Accumulated tension of specific 1000/45 conductor employed in crimping test is 250.2kN calculated on the basis of actually measured strength parameter of single wire. Three groups of specimens for aluminium tube inner diameter (44.2mm, 44.6mm and 45.0mm respectively) and two groups of specimens for taper length (120mm and 150mm respectively) are selected for orthogonal test with two factors combined.

### D. Analysis of Test Results

Carry out test of fitting grip strength according to orthogonal test plan as well as list and compare average, maximum and minimum values of grip strength, as shown in table III.

TABLE III. TEST RESULT OF FITTING GRIP STRENGTH FOR ALUMINIUM TUBES WITH THREE INNER DIAMETERS

| Inner Diameter of Aluminium Tube (mm) | Statistical Value (kN) |               |               |            |
|---------------------------------------|------------------------|---------------|---------------|------------|
|                                       | Maximum Value          | Minimum Value | Average Value | Dispersity |
| 44.2                                  | 221.6                  | 217.6         | 219.0         | 4.0        |
| 44.6                                  | 223.8                  | 217.4         | 220.3         | 6.4        |
| 45.0                                  | 225.0                  | 217.6         | 222.0         | 7.4        |

It can be drawn out from table III that results of grip strength test feature certain dispersity, minimum value of fitting grip strength for aluminium tubes with threes inner diameters are basically the same, but maximum value and average value increase along with increase in aluminium tube diameter. Comparatively, aluminium tube with inner diameter of 45.0mm is relatively good.

On the basis that inner diameters of aluminium tubes are all 45.0mm, crimping test for aluminium tubes with two

taper lengths is performed, of which results are as shown in table IV.

TABLE IV. TEST RESULT OF FITTING GRIP STRENGTH FOR ALUMINIUM TUBES WITH TWO TAPER LENGTHS

| Taper Length of Aluminium Tube (mm) | Statistical Value of Grip Strength (kN) |               |               |            |
|-------------------------------------|---|---------------|---------------|------------|
|                                     | Maximum Value                           | Minimum Value | Average Value | Dispersity |
| 120                                 | 226.6                                   | 217.6         | 222.4         | 9.0        |
| 150                                 | 224.6                                   | 219.8         | 223.0         | 4.8        |

It can be drawn out from table IV that maximum grip strength of fitting for aluminium tube with 150mm taper length is slightly lower than that of aluminium tube with 120mm taper length, but both minimum value and average value are larger than the latter, and its dispersity manifests obvious reduction, which reflects proper extension of taper length is conducive to increase of grip strength and decrease of dispersity of grip strength. Therefore selection of 150mm long taper is appropriate.

After comparatively good inner diameter of aluminium tube and taper length are determined, re-machine fitting as per optimized drawing and carry out numerous grip strength tests to verify effect of fitting grip strength after optimization. To facilitate analysis, statistical analysis of test results is performed. Refer to table V for statistical values of grip strength and Fig. 4 for distribution curve of grip strength test results.

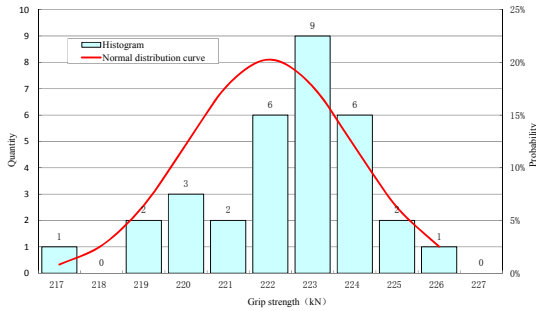


Figure 4. Distribution curve of test results on grip strength

TABLE V. STATISTICAL VALUES OF TEST RESULTS FOR GRIP STRENGTH OF 1000/45 CONDUCTOR FITTING AFTER OPTIMIZED

| Quantity of Specimen | Statistical Value (kN) |               |                     |            |                             |
|----------------------|------------------------|---------------|---------------------|------------|-----------------------------|
|                      | Maximum Value          | Minimum Value | Average Value $\mu$ | Dispersity | Standard Deviation $\sigma$ |
| 32                   | 226.6                  | 217.6         | 222.6               | 9.0        | 1.97                        |

It can be drawn out from Fig. 4 that test results of grip strength is basically in normal distribution, which is mainly caused by dispersity of crimping itself with same conductor and fitting. According to characteristics of normal distribution, confidence coefficient of grip strength value not lower than  $\mu - 2\sigma = 218.6\text{kN}$  is 97.8%, thus 218.6kN can be used as guarantee value of grip strength and survival rate of fitting grip strength is  $218.6/250.2 = 87.4\%$ , on which strength loss as a result of crimping is analyzed.

To ensure grip strength meets requirement of 95% RTS, average tensile strength of single aluminium wire after stranded is preferably no less than 180MPa.

## V. ENGINEERING APPLICATION OF OPTIMIZED FITTING

Optimized design achievement of strain clamp and splicing sleeve matching with 1000/45 conductor is applied to unitary design of line fitting for  $\pm 800\text{kV}$  UHVDC power transmission line project from South Hami to Zhengzhou. Before line construction, the construction affiliation organized training on crimping for participating building units, who crimped 23 groups of test specimens after training, wherein 10 of them were not applied further after grip strength reached 95% RTS and the rest 13 specimens were loaded until they broken, of which average effective value is 222.7kN, exceeding 100% RTS and corresponding to survival rate of 88.3%, which reflects optimized fittings achieve the expected results..

## VI. CONCLUSIONS

1) Grip strength of fitting for conductor is related to conductor strength, inner diameter of aluminium tube and taper length at end of aluminium tube. The larger the conductor strength, the larger the grip strength of fitting; proper increase in aluminium tube inner diameter and taper length within certain range contributes to reduction of strength loss caused by crimping and increase in grip strength of fitting for conductor;

2) Through analysis of grip strength test results, optimum key dimensions of fitting matching with 1000/45 conductor are obtained; outer dimension of aluminium tube is 72mm, inner diameter 45mm, and taper length 150mm. On the basis of normal statistical analysis of grip strength of fitting after optimized, survival rate of 87.4% with certain confidence for grip strength of optimized fitting is achieved.

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