Development of mid-span tension joint and tension clamp for large section energy-saving conductor in 1100kV UHV DC transmission

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Abstract. For the large cross-section energy-saving conductor JL1/LHA1-935/415-63/28 used in ±1100kV UHV DC project, the matching tension clamp and mid-span tension joint were designed. Based on the statistical analysis of the grip strength test results, the optimized design of the tension clamp and mid-span tension joint were completed. The grip strength after optimization is more than 95% RTS, which meets the requirements of standard. The results show that the developed tension clamps and mid-span tension joints have excellent performance and could be used in actual engineering.

Keywords: UHV DC engineering, large cross-section energy-saving conductor, tension clamp, mid-span tension joint, grip strength test.

1. Introduction
Because of long length and large transmission capacity for the UHV DC transmission line, the application of large cross-section energy-saving conductor can reduce the transmission loss, lower carbon dioxide emissions and decrease the cost, which has good social benefits [1-3]. Due to the large cross-section and complex structure, the material and structure of large cross-section energy-saving conductor have their particularity, which will inevitably lead to large damage in crimping and difficulty in keeping the grip strength [4, 5]. The crimping of large cross-section energy-saving conductor has become a major technical problem in the engineering application [6]. Therefore, it is necessary to study on material selection, structural design and manufacturing process of tension clamp and mid-span tension joint. And a large number of experiments should be carried out for the optimization of the design. In this paper, the tension clamp and mid-span tension joint, for conductor JL1/LHA1-935/415-63/28 used in ±1100kV UHV DC project, were designed, and the results of grip strength test were analyzed based on statistics. The design of the tension clamp and mid-span tension joint were optimized. The grip strength of optimized fittings is greater than 95% rated tensile strength of the conductor, which means the developed tension clamp and mid-span tension joint for large cross-section energy-saving conductor have excellent performance, and can be applied in actual engineering.
2. Development of tension clamp and mid-span tension joint

2.1. Material selection

Conductor JL1/LHA1-935/415-63/28 is aluminium conductor aluminium alloy reinforced, and the parameters are shown in Table 1. According to the previous research, aluminium alloy wires cannot be crimped directly through steel tube, because hardness of steel is higher than that of aluminium alloy, which leads to a large crimping damage [4]. Then the aluminium alloy wires cannot make the whole contribution to conductor tension, which means the value of grip strength will be lower than the required value. Therefore, based on the structural characteristics of conductor [7], crimping material for aluminium alloy wires is selected to be aluminium alloy with the grade of 6063 [8, 9], and the tensile strength is required to be not less than 160MPa and elongation not less than 12%, which ensure the strength and compressibility. The stranded conductor should be cramped by aluminium tube, whose material is selected as deformed aluminium 1050A [10, 11].

| Item                | Unit        | Value       |
|---------------------|-------------|-------------|
| Type                | /           | JL1/LHA1-935/415-63/28 |
| Aluminium wires     |             |             |
| Outer layer         | Number/Diameter(mm) | 30/4.35    |
| Inner layer         | Number/Diameter(mm) | 24/4.35    |
| Aluminium alloy wires |             |             |
| Outer layer         | Number/Diameter(mm) | 9/4.35+9/4.35 (Half are aluminium wires and Half are aluminium alloy wires) |
| Adjacent outer layer| Number/Diameter(mm) | 12/4.35    |
| Adjacent inner layer| Number/Diameter(mm) | 6/4.35     |
| Inner layer         | Number/Diameter(mm) | 1/4.35     |
| Area                |             |             |
| Total               | mm²         | 1352.41     |
| Aluminium wires     | mm²         | 936.29      |
| Aluminium alloy wires | mm²      | 416.13      |
| Diameter            | mm          | 47.85       |
| Linear density      | kg/km       | 3739.87     |
| DC resistance at 20 °C | Ω/km    | ≤0.02221    |
| Rated tensile strength (RTS) | kN | 274.33 |

2.2. Design of mid-span tension joint

2.2.1. Inner diameter of aluminium alloy tube. The aluminium alloy wires are 19 strand structures, and the butt joint is selected as the connecting type. Considering the tolerance and operability, the inner diameter of aluminium alloy tube is determined to be 1.07 times of the aluminium alloy wires diameter, and the value is 32 mm after rounding.

2.2.2. Outer diameter of aluminium alloy tube. The strength of aluminium alloy tube shall not be lower than that of aluminium alloy wires. Then the outer diameter of aluminium alloy tube could be calculated according to the following formula.

\[
\sigma = \frac{\pi d^2}{4} k_2 - \frac{\pi}{4} (0.87d)^2 = \sigma_s \frac{\pi}{4} (0.87d)^2
\]
Where: $\sigma$ is the strength of aluminium alloy tube; $\sigma_m$ is the tensile strength of aluminium alloy wires; $k_2$ is the percentage coefficient of inscribed circle; $d$ is the aluminium alloy wires diameter.

According to the formula, the outer diameter of aluminium alloy tube shall be 1.64 times of the aluminium alloy wires diameter. That is, the outer diameter should be greater than 49.5 mm. Considering the inner diameter, the value of outer diameter is determined to be 50 mm.

2.2.3. Crimping length and taping length of aluminium alloy tube. Based on previous cramping experience, the length of single side crimping is taken as 6 times of the conductor diameter. Then, the crimping length of aluminium alloy pipe is 12 times of the conductor diameter, the value is 380 mm after rounding. And the taping length for both ends is 50 mm.

2.2.4. Inner diameter of aluminium tube. The inner diameter of aluminium tube is determined to be 1.07 times the conductor diameter, and the value is 51.5 mm.

2.2.5. Outer diameter of aluminium tube. Considering the match of the tension clamp mid-span tension joint, and the safety factor, the outer diameter of the aluminium tube is determined to be 80.0 mm.

2.2.6. Crimping length and taping length of aluminium tube. The crimping length of aluminium tube is determined to be 5.5 times of the conductor diameter, and the value is 270 mm. The taping length is 150 mm.

2.2.7. Naming of mid-span tension joint. Based on the naming method of power fittings product, the mid-span tension joint for conductor JL1/LHA1-935/415-63/28 is named as JY-935/415, where J stands for the mid-span tension joint and Y stands for hydraulic type. The design drawing of mid-span tension joint is shown in Figure 1.

![Figure 1. Design drawing of mid-span tension joint JY-935/415](image)

2.3. Design of tension clamp

2.3.1. Structure of steel anchor. The steel anchor of tension clamp is a composite structure, which is composed of steel and small aluminum alloy tube. Aluminum alloy tube should be both crimped with steel anchor and aluminum alloy wires.

2.3.2. Dimensions of tension clamp. The inner diameter, outer diameter and single side crimping length of the aluminum alloy tube of tension clamp are consistent with those of mid-span tension joint. The inner diameter is 32 mm, the outer diameter is 50 mm, and the crimping length is 190 mm. According to the selection results of fittings string, the type of U-ring connecting the conductor is U-32S. Therefore, the strength of the steel anchor ring should meet the requirements of 320 kN according to the fitting’s standards.

The dimensions of aluminum tube of tension clamp are also consistent with that of mid-span tension joint. Therefore, the inner diameter is 51.5 mm, the outer diameter is 80 mm, the crimping length is 270 mm, and the taping length is 150mm.

According to the method for nomenclature of power fittings, the tension clamp for conductor JL1/LHA1-935/415-63/28 is named as NY-935/415, where N stands for the tension clamp and Y stands for hydraulic type. The design drawing of tension clamp is shown in Figure 2.
3. Grip strength test

3.1. Test methods
According to the requirements of standards for electric power fittings [12], the grip strength of the compressed fittings (tension clamp and mid-span tension joint) should not be less than 95% of conductor rated tensile strength (RTS), and the specific values are shown in Table 2. The grip strength tests were carried out by a 1000KN electro-hydraulic horizontal tension machine based on the standard of electrical fittings mechanical test. The test sample is the conductor with tension clamps at both ends and mid-span tension joint in the middle, as shown in Figure 3.

| Type of fittings | Type of conductor | RTS (kN) | Requirement value of grip strength (kN) |
|------------------|------------------|----------|---------------------------------------|
| NY-935/415       | JY-935/415       | 274.33   | ≥260.6                                |
|                  | JL1/LHA1-935/415 |          |                                       |

3.2. Test samples
(1) Test conductor
Conductors from the same batch produced by the same manufacturer are selected as the test conductors to eliminate unnecessary influence for the analysis of test results.
Before crimping, the tensile strength of single wire was tested, and the results are shown in Table 3.
Table 3. Tensile strength of single wire

| Type of conductor | Average tensile strength of aluminium wires (MPa) | Average tensile strength of aluminium alloy wires (MPa) |
|-------------------|-----------------------------------------------|-----------------------------------------------------|
| JL1/LHA1-935/415-63/28 (63/4.35+28/4.35) | 189 | 323 |

(2) Tension clamp and mid-span tension joint

The tension clamp and mid-span tension joint for the test are produced by the same manufacturer, and the sample is shown in Figure 4.

![Mid-span tension joint JY-935/415](image1.png)  ![Tension clamp NY-935/415](image2.png)

(a) Mid-span tension joint JY-935/415  (b) Tension clamp NY-935/415

Figure 4. Test samples

3.3. Test results and analysis

The grip strength tests of tension clamp and mid-span tension joint were carried out, and the statistical values of test results are shown in Table 4.

Table 4. Statistical values of grip strength test results

| Number of test samples | Statistical values (kN) |
|------------------------|-------------------------|
|                        | Maximum | Minimum | Average | Dispersivity |
| 6                      | 281.2   | 272.4   | 273.8   | 8.8          |

For the sake of reliability, the retention rate of grip strength was calculated by taking the minimum value as the actual grip strength of the fittings. The tension of the test conductor is 304.6 kN, and then the retention rate of grip strength is 272.4/304.6 = 89.4%.

Assuming that the average tensile strength of aluminum wires is 181 MPa, and the average tensile strength of aluminum alloy wires is 309 MPa, then the tension of the test conductor is 291.6 kN, and the grip strength of the fittings is 291.6×89.4%=260.7, which is larger than 260.6 kN, the require value. That is, the grip strength of the fittings meets the requirements.

If 95% times 95% of RTS is required, then the required grip strength is 247.48 kN. Based on the calculation results, assuming that the average tensile strength of aluminum wires is 170 MPa, and the average tensile strength of aluminum alloy wires is 305 MPa, then the tension of the test conductor is 273.8 kN, and the grip strength of the fittings is 273.8×89.4% = 251.5 kN, which is larger than 247.48 kN, the require value. That is, the grip strength of the fittings meets the requirements.

4. Requirements of technical parameters

According to the analysis, in order to ensure that the grip strength of fittings meets the requirements of standards, the tensile strength of single wires should meet the requirements. The tensile strength requirements of single wire are shown in Table 5. If the grip strength of fittings needs to be checked, the tensile strength of single wires shall increase accordingly.
Table 5. Tensile strength requirements of single wires

| Item                                  | Unit | Standard of fitting test (No less than 95% RTS) | No less than 95%×95% RTS | Required value of standard |
|---------------------------------------|------|------------------------------------------------|--------------------------|----------------------------|
| **Aluminum wires**                    |      |                                                 |                          |                            |
| Minimum before stranded               | MPa  | ≥176                                            | ≥165                     | ≥152                       |
| Average before stranded               |      | /                                               | /                        | ≥165                       |
| Minimum after stranded                |      | ≥181                                            | ≥170                     | ≥157                       |
| Average after stranded                |      | /                                               | /                        | ≥152                       |
| Uniformity                            |      | ≤25                                             | ≤25                      | ≤25                        |
| **Aluminum alloy wires**              |      |                                                 |                          |                            |
| Minimum before stranded               | MPa  | /                                               | /                        | ≥325                       |
| Minimum after stranded                |      | ≥309                                            | ≥305                     | ≥309                       |
| Uniformity                            |      | ≤25                                             | ≤25                      | ≤25                        |

5. Dimensions of optimized fittings
Dimensions of tensile clamp and mid-span tension joint are shown in Table 6. The appearance, dimension and tolerance of tension clamp and mid-span tension joint shall not only meet the requirements of technical drawings, but also meet the requirements of standards. The ultimate tolerances are shown in Table 7.

Table 6. Dimensions of tensile clamp and mid-span tension joint  Unit: mm

| Type       | Steel anchor | Aluminium tube |
|------------|--------------|----------------|
|            | Inner diameter | Outer diameter | Crimping length | Inner diameter | Outer diameter | Taping length | Crimping length | Aluminium tube length |
| NY-935/415 | 32           | 50             | 190             | 51.5           | 80             | 150           | 270           | 900                |
| JYD-935/415| 32           | 50             | 380             | 51.5           | 80             | 150           | 270           | 1370               |

Table 7. Ultimate tolerances of tensile clamp and mid-span tension joint  Unit: mm

| Outer diameter $D$ | Inner diameter $d$ |
|-------------------|-------------------|
| Dimension         | Ultimate tolerance | Dimension         | Ultimate tolerance |
| Steel anchor      | 14≤$D$≤22         | -0.2~+0.3         | /                  | /                |
|                   | 22≤$D$≤34         | -0.2~+0.4         | 9≤$d$≤16           | ±0.2             |
| Aluminum tube     | 32≤$D$≤50        | +0.6              | 22≤$d$≤36          | -0.4             |
|                   | 50≤$D$≤80        | +1.0              | 36≤$d$≤55          | -0.4             |

6. Conclusion
For the large cross-section energy-saving conductor JL1/LHA1-935/415-63/28 used in ±1100kV UHV DC project, the matching tension clamp and mid-span tension joint were designed. Then, based on the statistical analysis of the grip strength test results, the design of the tension clamp and mid-span tension joint were optimized. The values of grip strength after optimization are more than 95% RTS, which meets the requirements of standard. The results show that the developed tension clamps and mid-span tension joints have excellent performance and could be used in actual engineering.
(1) Crimping material for aluminium alloy wires is selected to be aluminium alloy with the grade of 6063, and crimping material for aluminium tube is selected as deformed aluminium 1050A.

(2) For the tension clamp, the inner and outer diameter of aluminium alloy tube are 32 mm and 50 mm respectively. And the crimping length of aluminium alloy tube is 205 mm. The inner and outer diameter of aluminium tube are 51.5 mm and 80 mm respectively. And the crimping length and taping length of aluminium tube is 270 mm and 150 mm respectively. The length of aluminium tube is 900 mm.

(3) For the mid-span tension joint, the inner and outer diameter of aluminium alloy tube are 32 mm and 50 mm respectively. And the crimping length of aluminium alloy tube is 410 mm. The inner and outer diameter of aluminium tube are 51.5 mm and 80 mm respectively. And the crimping length and taping length of aluminium tube is 270 mm and 150 mm respectively. The length of aluminium tube is 1500 mm.

(4) If the required value of grip strength is 95% of RTS, then after stranded, the minimum tensile strength of aluminum wires shall exceed 176 MPa, the average tensile strength of aluminum wires shall exceed 181 MPa and the minimum tensile strength of aluminum alloy wires shall exceed 309 MPa. If the required value of grip strength is 95% times 95% of RTS, then after stranded, the minimum tensile strength of aluminum wires shall exceed 165 MPa, the average tensile strength of aluminum wires shall exceed 170 MPa, and the minimum tensile strength of aluminum alloy wires shall exceed 305 MPa.

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