Experimental Study on Friction Coefficient of Strands for Large Cross-Section ACSR in Transmission Lines

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Abstract. According to the structural characteristics of aluminum conductor steel reinforced (ACSR), an experimental system is developed for the contact friction between steel and aluminum strands. The test parameters such as contact force and cross angle between strands are determined by the ACSR structure of JL1/G3A-1250/70-76/7. The curves of frictional force are obtained from the contact friction tests between steel core and aluminum strand, aluminum strand and aluminum strand under different conditions. The friction coefficient of strands under different contact conditions is obtained by statistical analysis, which provides support for further research on contact deformation analysis of strands in ACSR.

1. Introduction
Bare stranded wire is used for conductors in overhead transmission lines. One or more layers of strands are spirally twisted around a central straight core, and adjacent layers are twisted in opposite directions to offset the unidirectional twisting effect of the strands caused by winding in the same direction. Among them, ACSR is the most widely used in China because of high cost performance [1]. In the process of tension stringing construction, the strands of each layer in conductor are repeatedly squeezed and contacted during the movement, which is easy to cause strand wear. At present, scholars have derived the calculation method of extrusion force of strands based on the conductor structure [2-4], studied on the influence of contact friction and slip between layers on bending stiffness of conductor [5-6]. The finite element method is used to analyze the delamination stress and the contact wear of strands [7-9]. However, the law of contact friction between strands is still unclear.

In this paper the test system for contact friction is designed according to the structural characteristics of ACSR, and the contact friction coefficient is obtained by statistical analysis, which provides support for the further study of contact deformation between strands.

2. Characteristics of Contact Friction Between Strands
The ACSR in overhead transmission line is shown in figure 1. Friction between strands occurs when the conductor is subjected to an external load as shown in figure 2.
It is generally believed that the contact friction of strands follows the classical friction law, i.e.

\[ F = \mu N \]  

(1)

In the formula, \( F \) is the friction force; \( \mu \) is the coefficient of sliding friction; \( N \) is the normal contact force.

In fact, the friction coefficient is related to many factors such as material properties, contact force, surface film, sliding speed, temperature and so on. In engineering, the coefficient of friction for metal surface is less than that of pure metal due to the existence of surface film such as oxide film, which is about 0.1 or even smaller.

3. Friction Experiment on Strand

3.1. Design of Experimental Device

A friction experimental measurement system is designed, which can adjust the number of contact pairs, contact force and cross angle, as shown in figure 3. The system control module is equipped with touch screen, which can complete the functions of test project establishment, test operation control, data measurement and recording.

The friction experiment module of strand can measure the friction force of different numbers of strands under different contact forces and cross angles by adjusting the number of weights, the number of installed strands and the cross angle of upper and lower mounting plates, as shown in figure 4.

3.2. Sample Preparation

The JL1/G3A-1250/70-76/7 ACSR commonly used in UHV engineering lines is taken as experimental subject. In order to obtain smooth friction data during measurement, the sample length is taken as 300mm, as shown in figure 5 and figure 6.
During the experiment, the strand sample is pre-straightened, and the two ends are fixed on the upper and lower mounting plates by pressing sheets.

![Figure 5. Aluminum strand sample](image1.png)

![Figure 6. Steel strand sample](image2.png)

3.3. Experimental Conditions
The contact force in this experiment refers to the contact force between steel strand and aluminum strand or aluminum strand and aluminum strand, its value is quoted in reference [10]. The cross angle of the strands is calculated from the helical angle of the strands of the conductor. The specific experimental conditions are shown in table 1.

| Conductor          | Strand material       | Number of contact pairs | Contact force (N) | Cross angle       |
|--------------------|-----------------------|-------------------------|-------------------|-------------------|
| JL1/G3A-1250/70-76/7 | Steel - Aluminum      | 1-1                     | 100, 140          |                   |
|                    |                       | 1-2                     | 160, 200, 240     | 18°               |
|                    |                       | 1-4                     | 320, 400, 480     |                   |
| JL1/G3A-1250/70-76/7 | Aluminum - Aluminum  | 1-1                     | 40, 80, 120       | 18°, 24°, 30°     |
|                    |                       | 1-2                     | 80, 120, 160      |                   |
|                    |                       | 1-3                     | 60, 120, 180      |                   |
|                    |                       | 1-4                     | 80, 180, 240      |                   |

In the experiment the influence of temperature is ignored, and the relative sliding speed of conductor is small during construction, so the sliding speed is set at 30mm/min.

4. Data Analysis of Strand Friction
According to the experiment conditions listed in table 1, the friction between JL1/G3A-1250/70-76/7 strands under different conditions is measured and the friction coefficient is calculated. By using the statistical method to process the friction coefficient experiment data, the reasonable value of friction coefficient is obtained.

4.1. Analysis of Friction Experiment Data Between Steel and Aluminum Strands
For the friction experiments of strand between steel and aluminum, the friction experimental data with contact pairs of 1-1, 1-2 and 1-4 are analyzed by statistical method. Taking the friction experimental data with contact pairs of 1-2 strands as an example, ANOVA is performed on the experimental data under 160N and 200N contact forces. The results are shown in table 2. It is concluded that
$P=0.135>0.05$, the contact force has no significant influence on the friction coefficient measured by the experiment. The mean value of friction coefficient of steel strand and aluminum strand with contact pairs of 1-2 is 0.120, 95% confidence interval of mean value [0.100, 0.140].

| Source          | DOF | Adj SS  | Adj MS  | F value | P value |
|-----------------|-----|---------|---------|---------|---------|
| Contact force   | 1   | 0.00059 | 0.00059 | 4.12    | 0.135   |
| Error           | 3   | 0.000429| 0.000143|         |         |
| Total           | 4   | 0.001019|         |         |         |

When the contact force is 200N, the uneven surface of strand leads to incomplete contact between the strand of the upper plate and the two strands of the lower plate, which results in greater friction and wear of some strands during the experiment measurement, as shown in figure 7. At this time, the friction coefficient is larger than that of uniform contact, and the mean value of friction coefficient between strands is 0.21.

![Figure 7. Strand wear.](image)

By analyzing all friction experimental data of steel and aluminum strand, it is concluded that the friction coefficient between steel and aluminum strand is 0.12 when contact force $F\leq140$N and 0.21 when contact force $F>140$N.

4.2. Analysis of Friction Experiment Data Between Aluminum Strands
For the friction experiments between aluminum strands, the friction experimental data with contact pairs of 1-1, 1-2, 1-3 and 1-4 are analyzed by statistical method. Taking the friction experimental data with contact pairs of 1-4 strands as an example, the results are shown in table 3 by ANOVA of the experimental data.

| Source          | DOF | Adj SS  | Adj MS  | F value | P value |
|-----------------|-----|---------|---------|---------|---------|
| Contact force   | 2   | 0.000328| 0.000164| 1.59    | 0.311   |
| Cross angle     | 2   | 0.00022 | 0.00011 | 1.06    | 0.427   |
| Error           | 4   | 0.000414| 0.000103|         |         |
| Total           | 8   | 0.000962|         |         |         |

The ANOVA shows that the contact force $P=0.311>0.05$ and the cross angle $P=0.427>0.05$. Therefore, the influence of contact force and cross angle on the friction coefficient is not significant in the experiment. The data of friction coefficient experiment for aluminum strands with contact pairs of
1-4 obey normal distribution, with the mean value of 0.075, 95% confidence interval of mean value [0.066, 0.083], as shown in figure 8.

![Histogram of friction coefficient distribution](image)

**Figure 8.** Histogram of friction coefficient distribution

The uneven surface of strand leads to incomplete contact between the strand of the upper plate and the four strands of the lower plate, which results in greater friction and wear of some strands during the test measurement, as shown in figure 9.

![Strand wear](image)

**Figure 9.** Strand wear

The friction coefficient between strands under the contact force of 180N is larger than that under uniform contact. One-way ANOVA analysis shows that at the significance level of 0.05, the influence of the crossover angle on the coefficient of friction is not significant, then the mean value of the coefficient of friction is 0.145, and the confidence interval of the mean value is [0.107, 0.182].

By analyzing all friction experimental data of aluminum strands, it is concluded that the friction coefficient between aluminum strands is 0.07 when contact force $F \leq 120$N and 0.15 when contact force $F > 120$N.

5. **Conclusion**

In order to measure the contact friction between the strands of ACSR, an experiment device is developed. Considering the strand material, number of contact pairs, contact force and cross angle of the strands in contact friction of JL1/G3A-1250/70-76/7, the experimental conditions are designed. The friction coefficient of different strands measured by the experiment shows that:

(1) When the contact force of strands is small, the surface wear between strands is slight and the friction coefficient is relatively small.
(2) When the contact force is large, the material matrix participates in friction after the surface film of strands is worn and the friction coefficient between strands increases.

(3) When the contact force $F \leq 140$N, the friction coefficient between steel strands and aluminum strands is 0.12; when the contact force $F > 140$N, the friction coefficient is 0.21.

(4) When contact force $F \leq 120$N, the friction coefficient between aluminum strands is 0.07; when contact force $F > 120$N, the friction coefficient is 0.15.

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