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Study on sag characteristics calculation of CFCC Composite Core Wire

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Abstract. With the rapid growth of the domestic economy, especially the development of urbanization, the demand for transmission capacity has also increased. The existing transmission lines can no longer meet the requirements, so the development of the capacity-enhanced wires is particularly important. Stranded carbon fiber composite core wire is a new type of capacitance-enhanced wire, as a second generation carbon fiber wire, it has excellent mechanical and electrical properties. In this paper, based on the existing research results, the temperature-sag performance is calculated and analyzed, and its superior sag characteristics in the operation of the hanging net are demonstrated.

1. Preface

With the continuous development of the national economy and the ever-increasing scale of urbanization, the requirements for transmission capacity have also been rising. Today's existing transmission lines are no longer able to meet the increasing demand, so increasing transmission capacity is imminent. And in a variety of compatibilization programs, it is also the most advantageous to develop the capacity-enhanced wires. The program does not need to add new transmission lines, and does not need to transform or add poles. It only needs to use the original lines to achieve the effect of increasing capacity or even double the capacity, which can effectively solve the constraints of transmission capacity on power development.

The study of the capacity-enhanced wires was first started in the middle of the last century. Its main principle is to increase its long-term operating temperature by changing the material or structure of the wire to achieve the effect of compatibilization. Initially, people used heat-resistant aluminum alloys, high-strength steels, and invar alloys to increase wire operating temperatures. At the end of the 20th century, with the advancement of materials technology, a number of new composite materials, such as aluminum-based ceramics and carbon fiber, were applied to wire development. These new types of wires can not only achieve the compatibilization of wires, but also weigh less than normal wires. With better low sag characteristics, it can make more perfect use of the existing towers to achieve wire-line work and improve the safety and reliability of wire operation.

2. Overview of CFCC composite core wire performance

There are two kinds of common carbon fiber composite core wires, which are rod-shaped carbon fiber wires (ACCC wires) and stranded carbon fiber wires. Both of them use carbon fiber materials to form the core wire. Therefore, they have the characteristics of small density, high strength, and strong corrosion resistance while improving the wire carrying capacity. However, because the carbon fiber material is a brittle material, its flexibility and resistance to lateral pressure are poor. Therefore, the ACCC wire cannot be bent at a large angle during the installation process, and the brittle fracture easily occurs during the crimping process of the gold fitting.

The CFCC composite core wire is a new type of capacitance-enhanced wire. It adopts a novel structure based on the ACCC wire. As shown in Figure 1, it consists of an inner carbon fiber core and an outer soft aluminum stranded. The core wire is made by sizing a bundle of 12,000 carbon fibers having a diameter of 7 μm into a bundle, infiltrating a thermosetting resin (modifying epoxy resin or double brim resin), and wrapping the organic fibers around the bundle to form strands. After a certain number of strands are twisted together and then thermoset by resin, a stranded carbon fiber composite core is formed [1]. The conductor part of the outer layer is the same as the ACCC wire, and annealed 63%IACS heat-resistant soft-aluminum wire (T-type or SZ-type) is used.

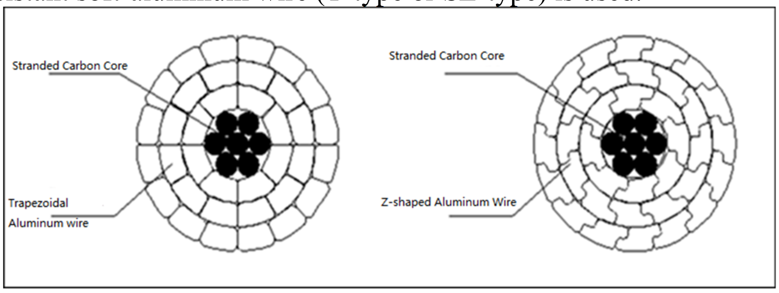

Fig. 1. Stranded carbon fiber composite core wire section

Due to the twisted structure of the CFCC composite core wire, its flexibility is greatly improved. Similar to conventional wires, the maximum bending radius of the core can reach 40D (D is the diameter of the composite core). Its lateral pressure resistance is also greatly enhanced, and it can be crimped using conventional fittings, which greatly simplifies the construction process and improves economic efficiency.

At the same time, the sag characteristic is also very good as a capacity-enhanced wire, under the same conditions far beyond the traditional steel-cored aluminum-stranded wire, and even better than the general capacity-enhanced wire.

3. CFCC composite core wire sag calculation

The sag calculation method of the CFCC composite core wire is different from the traditional steel-cored aluminum stranded wire, and the concept of " inflection point temperature " needs to be introduced. The inflection point temperature is a critical temperature: Due to the difference in the material of the wire core bearing portion and the outer current carrying portion, the linear expansion coefficients of the two are also different. Under normal circumstances, when the wire is wired or operated at normal temperature, we often use the linear expansion coefficients of the two to be equivalent, and the linear expansion coefficient of the wire is the default linear expansion coefficient at this time. Generally speaking, the inner core wire generally has a smaller coefficient of linear expansion, so as the temperature increases, when it exceeds a certain temperature value, the load of the outer current-carrying part is zero. At this time, the entire wire load is borne by the internal core wire. This temperature value is called the “inflection point temperature” [2].

The conventional ACSR also has inflection point temperature, but its long-term operating temperature is far lower than its inflection point temperature, so it is usually not considered. Since the operating temperature of the capacity-enhanced wires is generally higher than the inflection point temperature, the calculation of the inflection point temperature must be performed first. When the temperature is lower than the inflection point temperature, its calculation method is equivalent to the conventional wire; and when the temperature is higher than the inflection point temperature, the linear expansion coefficient and the elastic modulus of the wire are approximately the same as the core wire.

In the calculation of transmission line conductors, the effect of twisting on the entire conductor is generally ignored. Therefore, we usually think that after the wire is stretched, the outer aluminum wire and the inner wire have the same elongation, that is:

$$\Delta \boldsymbol{L_a} = \Delta \boldsymbol{L_x} \qquad (1)$$

ΔL_a—The change in elongation of the aluminum wire;

ΔL_x—The change in elongation of the core.

The change in elongation is equal to the sum of its elastic elongation and thermal expansion.

$$\Delta \boldsymbol{L_a} = \frac{\boldsymbol{T_a}}{\boldsymbol{E_a A_a}} \boldsymbol{l_0} + \boldsymbol{\alpha_a}(\boldsymbol{t} - \boldsymbol{t_0})\boldsymbol{l_0} + \frac{\boldsymbol{T_a}}{\boldsymbol{E_a A_a}} \boldsymbol{l_0} \boldsymbol{\alpha_a}(\boldsymbol{t} - \boldsymbol{t_0}) \qquad (2)$$

$$\Delta L_x = \frac{T_x}{E_x A_x} l_0 + \alpha_x (t - t_0) l_0 + \frac{T_x}{E_x A_x} l_0 \alpha_x (t - t_0) \qquad (3)$$

$T_a \backslash T_x$—The respective tension of aluminum wire and core wire;

$E_a \backslash E_X$—The respective elasticity coefficient of aluminum wire and core wire;

$A_a \backslash A_X$—The respective calculated cross-sectional area of aluminum wire and core wire;

$\alpha_a \backslash \alpha_X$—The respective linear expansion coefficient of aluminum wire and core wire;

l_0—The initial length of the wire;

t_0—The initial temperature of the wire;

t—The operating temperature of the wire.

According to (1)(2)(3), we have:

$$\frac{T_a}{E_a A_a} l_0 + \alpha_a (t - t_0) l_0 \left(1 + \frac{T_a}{E_a A_a}\right) = \frac{T_x}{E_x A_x} l_0 + \alpha_x (t - t_0) l_0 \left(1 + \frac{T_x}{E_x A_x}\right) \qquad (4)$$

Ignore the small amount and simplify:

$$\frac{T_a}{E_a A_a} + \alpha_a (t - t_0) = \frac{T_x}{E_x A_x} + \alpha_x (t - t_0) \qquad (5)$$

At the inflection point temperature (t_c), the tension of the aluminum wire (T_a)=0 , at this time, the tension of the wire (T) is equal to the tension of the core wire (T_x), and the inflection point temperature of the wire is:

$$t_c = \frac{T_c}{E_x A_x (\alpha_a - \alpha_x)} + t_0 = \frac{T_c}{EA(\alpha_a - \alpha)} + t_0 \qquad (6)$$

T_c—The tension of the wire at the inflection point temperature (t_c).

In addition, the wire length can be approximated as:

$$L = \mathrm{s} \times \left[1 + \frac{s^2}{24}\left(\frac{W}{T}\right)^2\right] \qquad (7)$$

s—Span

W—Vertical load

From (2)(3)(7) we can see that when the tension is maximum:

$$\mathrm{s} \times \left[1 + \frac{s^2}{24}\left(\frac{W_m}{T_m}\right)^2\right] = l_0 \left(1 + \frac{T_m}{EA}\right) [1 + \alpha(t_m - t_0)] \qquad (8)$$

At the inflection point temperature:

$$\mathrm{s} \times \left[1 + \frac{s^2}{24}\left(\frac{W_c}{T_c}\right)^2\right] = l_0 \left(1 + \frac{T_c}{EA}\right) [1 + \alpha(t_c - t_0)] \qquad (9)$$

T_m—Maximum tension

W_m—Total load at maximum tension;

W_c—Total load at the inflection point temperature;

t_m—Temperature at maximum tension.

Add (8)(9) two formulas together and eliminate a small quantity to get a unitary cubic equation:

$${T_c}^3 + \left[\frac{{W_m}^2 s^2 EA}{24{T_m}^2} - T_m + \alpha(t_c - t_m)EA\right]{T_c}^2 = \frac{{W_c}^2 s^2 EA}{24} \qquad (10)$$

The inflection point temperature and its corresponding tension can be found immediately after the (6) (10) two-step linkage.

After finding the inflection point temperature, we will make a judgment. When the temperature is below the inflection point temperature, E, A and α are substituted into equation (10) for iteration; when the temperature is higher than the inflection point temperature, E_x, A_x and α_x are used to calculate the tension of the wire at any temperature. Then, the arc (d) at this temperature is determined by (11).

$$d=\frac{Ws^2}{8T} \qquad (11)$$

4. Calculation examples

The following is a research project through a 220KV expansion capacity transformation line project. The sag characteristics of a certain CFCC composite core wire type JLRX1/JFB-300/40 were calculated and analyzed. Some technical parameters of this wire are shown in Table 1.

Table 1. Technical parameters of CFCC composite core wire JLRX1/JFB-300/40

project		parameter
Structure (n/mm)	Aluminum wire	16/4.98
	Core wire	7/2.6
Area (mm^2)	Aluminum wire	311.3
	Core wire	37.17
	total	348.47
Wire outer diameter (mm)		21.49
Calculate breaking force (kN)		95.931
Elastic modulus (GPa)	Below the Inflection point temperature	65.13
	Above the inflection point temperature	150
Linear expansion coefficient (10^{-6}/°C)	Below the Inflection point temperature	15.1
	Above the inflection point temperature	1.0
Annual average tension (N)		21902.3
Vertical load (N/m)		9.05
Annual average temperature (°C)		20

Substituting the parameters and calculation results in the table into equation (6)(10)

$$T_c{}^3+\left[\frac{W^2s^2EA}{24T_0{}^2}-T_0\right]\frac{(\alpha_a-\alpha)}{\alpha_a}T_c{}^2=\frac{W^2s^2EA}{24}\frac{(\alpha_a-\alpha)}{\alpha_a}$$

$$T_c{}^3+\left[\frac{9.05^2\times50^2\times348.47\times65130}{24\times21902.3^2}-21902.3\right]\frac{(23-15.1)}{23}T_c{}^2=\frac{9.05^2\times50^2\times348.47\times65130\times(23-15.1)}{24\times23}$$

The tension at the inflection point temperature is T_c=8428.16N.

$$t_c=\frac{T_c}{EA(\alpha_a-\alpha)}+t_0=\frac{8428.16}{348.47\times65.13\times10^{-3}\times(23-15.1)\times10^6}+20$$

The inflection point temperature t_c=66.29°C.

Another type of CFRC composite core wire JLRX1/JF1B-400/35, calculate the tension and sag characteristics at different temperatures, as shown in Figure 2, Figure 3.

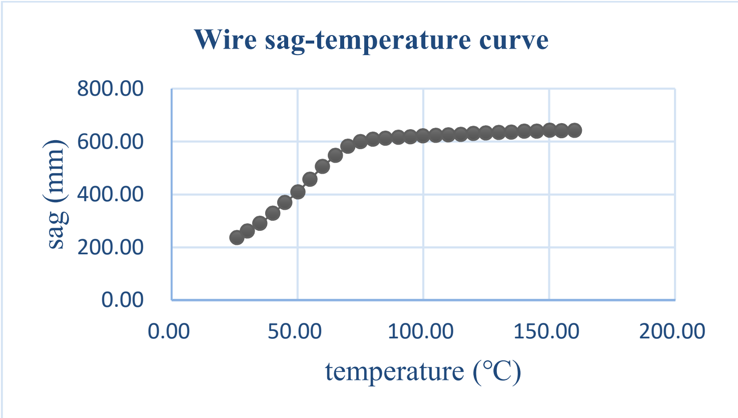

Fig. 2. The sag-temperature curve of CFCC composite core wire JLRX1/JF1B-400/35

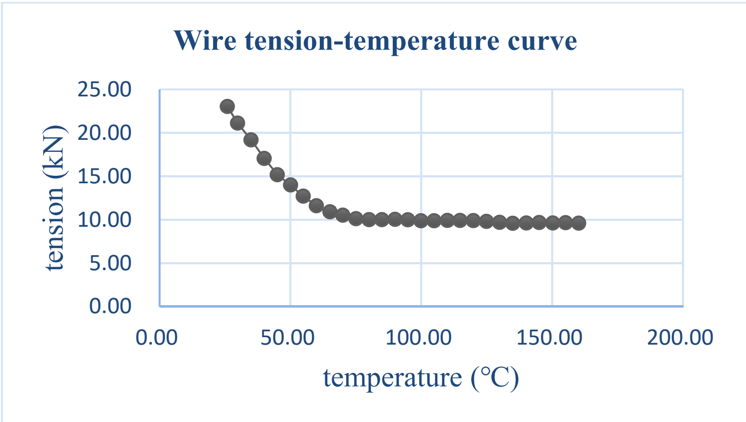

Fig. 3. The tension-temperature curve of CFCC composite core wire JLRX1/JF1B-400/35

From the above two figures, it is easy to see that the sag characteristics of the CFCC composite core wire are affected by the inflection point temperature, and its sag characteristics are excellent. When the temperature is higher than the inflection point temperature, the increase in sag and tension is small. Because at this time the entire wire tension is borne by the stranded carbon core, and the linear expansion coefficient of the carbon core is much smaller than that of the entire wire, it exhibits excellent low sag characteristics.

5. Conclusion

Through the above analysis we can see:

(1), CFCC composite core wire arc changes with the inflection point changing. The inflection point temperature is affected by the range, tension and other conditions, and also the wind pressure, ice and other conditions are considered in the actual calculation.

(2), CFCC composite core wire has a good sag characteristics. When the temperature is higher than the inflection point temperature, the sag is hardly changed, so that the original transmission line can be fully utilized and the cost can be greatly reduced. At the same time, it is simple and easy to install and has a good prospect for development.

References

[1] Fang Jianyin, Zhou Zhengmin, et al. New Design of Stranded Carbon Fiber Composite Core Conductor and Its Application in Overhead Lines [C].Proceedings of the 3rd National Technical Conference on Overhead Transmission Lines. 2012:156-164.

[2] Zhao Xinyuan, Zhang Xinlin.Characteristics and theoretical sag calculation of heat-resisting wire of Yingang[C]. National Technical Conference on Overhead Transmission Lines, 2009.

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[3] Yingying Zhang.Analysis and calculation of tension sag characteristics of double capacity wire [J]. Electric Power Construction, 2006,27 (9): 7.