Catenary method of helicopter live-line work in transmission line

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Abstract. The load of wire in helicopter live-line work is analysed, and the calculation method for cable lifting of helicopter is proposed based on catenary theory of suspension cable. The nonlinear equation set is established to calculate the lifting force of the helicopter. The tangent stiffness matrix of the iteration method is expressed in explicit formulation and a numerical study is performed for two cases in practical engineering of helicopter live-line overhaul. The results show the method is a high speed, convenient and accurate numerical method which can be used in analysis of suspension bridges, cargo ropeways and other various types of cable structures for the designer's reference.

Keywords: helicopter; transmission line; suspension cable; catenary method; Newton iteration method.

1 Introduction

Helicopter live-line work method is commonly used in developed countries [1], which is of the feature of high efficiency. With the expansion of 500 kV grid and the construction of 1000 kV lines in China, the introduction of advanced maintenance method is of significance. The mechanical analysis of overhead line in helicopter live-line overhaul is important for broad applications with efficiency, safety, economy and applicability. Its conclusion is worth using for reference in developing helicopter live-line work in China.

Figure 1. Photo of helicopter live-line work

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In helicopter suspension method a platform or cage is suspended below the helicopter and the workers can operate overhaul through the insulating rope or insulating rod on platform, shown in Figure 1. In order to ensure the platform be in relatively stable situation, platform connects the live-line with a wire hook, so the helicopter will bear the part weight of the line during the operation [1].

When the line is lifted up at some position by helicopter, the force analysis of line is necessary for helicopter to estimate the load which is important for the safety of work method.

2 Initial line shape before helicopter lifting

The over line is the ideal suspension cable structure which can be analyzed by the catenary theory. The cable section is shown in Figure 2 which only bears dead weight q evenly distributed along arc. Where, V_A , V_B are cable vertical component, θ_A , θ_B are angle at end point A and B respectively, H is horizontal component of tensile force, L and h are horizontal distance and height difference between terminal ends.

Figure 2. Force analysis of suspension cable

The equation for suspension cable [2] is as follows:

$$y = \frac{H}{q} \cosh(a) - \frac{H}{q} \cosh(a - \frac{q}{H}x) \quad (1)$$

$$s = \frac{H}{q} \sinh(a) - \frac{H}{q} \sinh(a - \frac{q}{H}x) \quad (2)$$

Because $\left. \frac{dy}{dx} \right|_{x=0} = \sinh(a) = \tan \theta_A = \frac{V_A}{H}$, there is $a = \sinh^{-1}(\frac{V_A}{H})$.

When slope of the end A is $\tan \theta_A$ and the position of end point A and B are given, the approximate sag f can be calculated by parabola formula, and then initial cable length

$S_0 = L(1 + \frac{8f^2}{3L^2})$ and horizontal component force $H_0 = \frac{qL^2}{8f}$ are obtained.

Using the H_0 and $a = \sinh^{-1}(\tan \theta_A)$ as the iterative initial value of Newton iteration method [3], horizontal component force H can be solved and the arc length S_{AB} can be obtained from Eq. (2).

3 Line shape after helicopter lifting

When helicopter lifts the cable (wire) on point C_0 , it is reasonable to assume that the cable length S_{AC_0} and S_{C_0B} are unchangeable during lifting, i.e. S_{AC_0} is equal to S_{AC} and S_{C_0B} is equal to S_{CB} . The S_{AC} and S_{CB} can be obtained from Eq. (2).

To balance the horizontal force, the horizontal location of C is different with C_0 when the C_0 rise h_c to point C , shown as Figure 3.

Figure 3. Sketch map of helicopter lifting

Assuming the horizontal distance between A and C is L_1 , between C and B is L_2 . The force analysis of suspension cable sections AC and CB is shown in Figure 4.

Figure 4. Force analysis of suspension cable section

There is the same horizontal force H in AC and CB [4] and the lifting force V_C is equal to $V_{C_1} + V_{C_2}$. According that the resultant of all external forces is zero in vertical direction, there is $q(S_{AC} + S_{CB}) - (V_A + V_B + V_C) = 0$.

According to Eq. (1) and Eq. (2), the nonlinear equations of lifted cable sections AC and CB for unknown a_1 , a_2 , t and g are established [5]. The y_c can be obtained from Eq. (1).

$$\begin{aligned} t[\cosh(a_1) - \cosh(a_1 - g)] &= y_c \\ t[\sinh(a_1) - \sinh(a_1 - g)] &= S_{AC} \\ t[\cosh(a_2) - \cosh(a_2 + g - L/t)] &= -(y_c + h) \\ t[\sinh(a_2) - \sinh(a_2 + g - L/t)] &= S_{CB} \end{aligned} \quad (3)$$

in which $a_1 = \sinh^{-1}(V_A/H)$, $a_2 = \sinh^{-1}(V_{C_2}/H)$, $t = H/q$ and $g = L_1/t$.

The non-linear equation group can be expressed as:

$$F(X) = 0 \quad (4)$$

Here $X = (a_1, a_2, t, g)$.

Newton iteration method is used to solve this non-linear equation group which is simple and clear in this issue, so its Jacobi matrix can be directly listed as following:

$$F'(X) = \begin{pmatrix} M_1 & M_3 \\ M_2 & M_4 \end{pmatrix} \quad (5)$$

$$\text{Here } M_1 = \begin{pmatrix} t[\text{sh}(a_1) - \text{sh}(a_1 - g)] & 0 \\ t[\text{ch}(a_1) - \text{ch}(a_1 - g)] & 0 \end{pmatrix}, \quad M_2 = \begin{pmatrix} 0 & t[\text{sh}(a_2) - \text{sh}(a_2 + g - L/t)] \\ 0 & t[\text{ch}(a_2) - \text{ch}(a_2 + g - L/t)] \end{pmatrix},$$

$$M_3 = \begin{pmatrix} \text{ch}(a_1) - \text{ch}(a_1 - g) & t \text{sh}(a_1 - g) \\ \text{sh}(a_1) - \text{sh}(a_1 - g) & t \text{ch}(a_1 - g) \end{pmatrix}, \quad M_4 = \begin{pmatrix} \text{ch}(a_2) - \text{ch}(a_2 + g - L/t) & -t \text{sh}(a_2 + g - L/t) \\ -L/t \text{sh}(a_2 + g - L/t) & \text{sh}(a_2) - \text{sh}(a_2 + g - L/t) \\ \text{sh}(a_2) - \text{sh}(a_2 + g - L/t) & -t \text{ch}(a_2 + g - L/t) \\ -L/t \text{ch}(a_2 + g - L/t) & \text{ch}(a_2) - \text{ch}(a_2 + g - L/t) \end{pmatrix}.$$

Firstly obtain initial iteration value X_0 according to the initial cable result, and then carry out iteration according to following formula [6]:

$$X_{n+1} = X_n + [F'(X_n)]^{-1} \cdot F(X_n) \quad (n=0, 1, 2, \dots) \quad (6)$$

4 Example

For a 500kV AC single circuit transmission line, the span L of overhead power line is 500m and the height difference h is zero. The JL/G1A-630/45-45/7 ACSR (aluminium cable steel reinforced) is used with $q=30.38\text{N/m}$. According to the tension resistance, the sag of line f is 15.78m and the horizontal force H is 60.2kN.

The case 1: The horizontal location of C_0 is 150m and the h_c is 3m.

The shapes of cable are shown in Figure 5. The relationship curves between the lifting force V_C , horizontal force H and the horizontal location L_1 of C with lifting height h_c are shown in Figure 6.

Figure 5. The initial cable and lifted cable of case 1

Figure 6. Results of case 1

The case 2: The horizontal location of C_0 is 200m and the h_c is 3m.

The shapes of cable are shown in Figure 7. The relationship curves between the lifting force V_C , horizontal force H and the horizontal location L_1 of C with lifting height h_c are shown in Figure 8.

Figure 7. The initial cable and lifted cable of case 2

Figure 8. Results of case 2

5 Conclusions

The lifting force of helicopter in live-line work method is very important for the safety of worker and construction operation. The type choice of helicopter and the design of suspend platform are closely related with the result of lifting force for different transmission lines.

The calculation method based on catenary theory is suitable for the special issue which can obtain quickly and easily the lifting force V_C , horizontal force H and the horizontal location L_1 of C with lifting height h_c .

The numerical results of two cases are quite consistent with measurement in construction work and verify the reliability of this method. The method can be popularized in transmission line.

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