

Calculation method of multi-span tension stringing in transmission line

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Abstract. The process of multi-span tension stringing in transmission line is analysed based on elastic catenary equation. From the tower condition of transmission line, the conservation equations of span spacing and elevation difference are built for conductor, and the tension balance equations of conductor between different spans are got considering the rolling friction of the pulley. Added the external tension condition, the overall nonlinear equations of multi-span tension stringing are set up which can be solved by Newton iteration method. The iterative process is listed for the calculation of the conductor tension and sags in engineering problems. Compared the results with the numerical example, this method are proved the reliability. The calculation amount, efficiency and accuracy of this method can meet the needs of the practical engineering.

1. Preface

With the development of the Ultra-high voltage transmission line in China, the tension stringing technology has been widely accepted and adopted in the industry. During the whole stringing process of UHV, conductor tension must be kept large enough to raise the conductors off the ground, cross obstacles and facilities. This can avoid conductor damage, ensure the quality of the transmission lines, and minimize the influence for environment. Therefore, the construction technology of tension stringing must be applied in string operation. The selection of construction machinery and equipment is based on the conductor tension and traction, so the tension calculation method for conductor is important for engineering safe [1].

Nowadays, the major way of string construction calculation is the parabolic method [2], but this method has poor precision compared with actual measurement. Other method such as catenary method [3, 4] is more accurate, but the calculation is relatively complex. Therefore, the accurate calculation method of the tension and traction is proposed.

2. Condition of multi-span tension stringing

There are many important conditions for the process of tension stringing construction, such as the span spacing and elevation difference between towers in transmission line, and the material parameters of conductor.

2.1. Main parameter of transmission line

There are n continuous spans in the transmission line, and the span spacing is L_{si} , elevation difference is h_{si} ($i=1, \dots, n$), shown as figure 1. The unit gravity of conductor is q , the product of cross-sectional area and elasticity modulus is EA_0 .



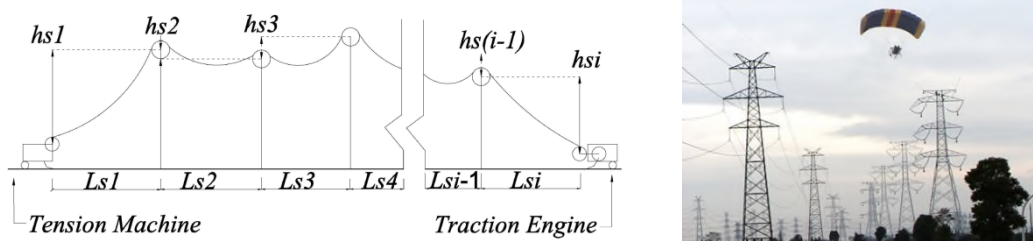


Figure 1. Schematic diagram of the multi-span tension stringing.

The total length s_0 of the conductor can be obtained by measurement before the engineering construction.

Assuming that initial conductor length of each span is s_i , horizontal tension is H_i , vertical tension on point A is $V_{Ai}(i=1, \dots, n)$, so the vertical tension on point B can be expressed as

$$V_{Bi} = V_{Ai} + qs_i \quad (i=1, \dots, n). \quad (1)$$

The calculation formula of span spacing and elevation difference of conductor is [5]:

$$L_i = \frac{H_i}{q} \left[\frac{qs_i}{EA_0} + \operatorname{asinh} \frac{V_{Bi}}{H_i} - \operatorname{asinh} \frac{V_{Ai}}{H_i} \right] \quad (i=1, \dots, n). \quad (2)$$

$$h_i = \frac{V_{Bi}^2 - V_{Ai}^2}{2qEA_0} + \frac{H_i}{q} \left(\sqrt{1 + \frac{V_{Bi}^2}{H_i^2}} - \sqrt{1 + \frac{V_{Ai}^2}{H_i^2}} \right)$$

2.2. Tension of conductor

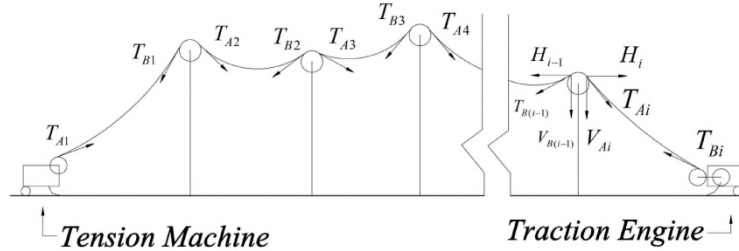


Figure 2. The force diagram of multi-span tension stringing.

One end of the conductor is pulled by traction engine and the other end by the tension machine, shown as figure 2. The tangential tension on the starting point A and end point B of each span are as follow:

$$T_{Ai} = \sqrt{H_i^2 + V_{Ai}^2} \quad (i=1, \dots, n). \quad (3)$$

$$T_{Bi} = \sqrt{H_i^2 + V_{Bi}^2}$$

3. Analysis of multi-span tension stringing

The structural characteristics and the force balance of the conductor in the process of multi-span tension stringing are the key points of structural analysis.

3.1. Constant of spacing and elevation difference of each span

The spacing and elevation difference of each span is constant no matter how the length of conductor changes, so the equations about the spacing and elevation difference of conductor can be obtained.

$$\begin{aligned} \frac{H_i}{q} \left[\frac{qs_i}{EA_0} + \operatorname{asinh} \frac{V_{Bi}}{H_i} - \operatorname{asinh} \frac{V_{Ai}}{H_i} \right] - L_{si} &= 0 \\ \frac{V_{Bi}^2 - V_{Ai}^2}{2qEA_0} + \frac{H_i}{q} \left(\sqrt{1 + \frac{V_{Bi}^2}{H_i^2}} - \sqrt{1 + \frac{V_{Ai}^2}{H_i^2}} \right) - h_{si} &= 0 \end{aligned} \quad (i=1, \dots, n) \quad (4)$$

Therefore, there are $2n$ equations of conductor for spacing and elevation difference of all spans.

3.2. Conductor tension balance besides stringing blocks

The conductor will be influenced by frictional force in tension stringing. The friction is equal to the difference of the tangential tensions of conductor on both sides of the pulley. The tangential tensions of conductor besides of the i^{th} pulley is shown in figure 3.

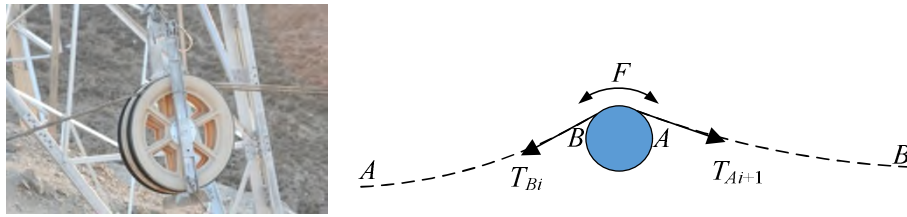


Figure 3. The conductor and pulley and the rolling friction.

The friction is associated with the frictional parameter μ , the envelope angle θ and the conductor tensions on both sides of pulley:

$$F_i = F(\mu, \theta, T_{Ai+1}, T_{Bi}) \quad (5)$$

3.2.1. *The envelope angle.* Envelope angle is the angle of contact arc of conductor, shown as figure 4.

$$\theta = \tan^{-1} \left(\frac{V_{Bi}}{H_i} \right) - \tan^{-1} \left(\frac{V_{Ai+1}}{H_{i+1}} \right) \quad (6)$$

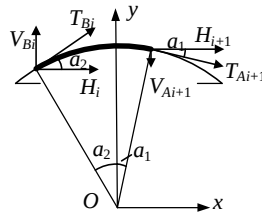


Figure 4. Contact arc of conductor and pulley.

3.2.2. *The force of conductor acting on the pulley.* Due to small contact part of the arc, the force N_p acting on pulley can be considered as the sum of both sides vertical force, as shown in figure 4.

$$N_p = V_{Ai+1} - V_{Bi} \quad (7)$$

3.2.3. *Direction of rolling friction.* When $T_{Bi} - T_{Ai+1} > 0$, the direction of the rolling friction is along x axis, otherwise the opposite. Therefore, the rolling friction can be expressed as:

$$F_i = \operatorname{sign}(T_{Bi} - T_{Ai+1}) \mu F(\theta, N_p) \quad (8)$$

Establish the equilibrium equations of the conductor tangential tensions:

$$T_{Bi} - T_{Ai+1} = F_i = \operatorname{sign}(T_{Bi} - T_{Ai+1}) \mu F(\theta, N_p) \quad (i=1, \dots, n-1) \quad (9)$$

3.2.4. *The condition of traction tension.* The end tension of conductor is the traction tension T_c :

$$T_c = T_0 \quad (10)$$

4. Nonlinear equations

Taking the span spacing s_i , horizontal tension H_i , vertical tension V_{Ai} of conductor as the unknown quantities, the nonlinear equations of the conductor for the multi-span tension stringing can be expressed as

$$F(X) = 0 \quad (11)$$

Here $X = [s_1, s_2, \dots, s_n, H_1, H_2, \dots, H_n, V_1, \dots, V_n]^T$.

This nonlinear equations can be solved by Newton iteration method [6].

5. Calculation process

The process of the method for the multi-span tension stringing is shown in figure 5.

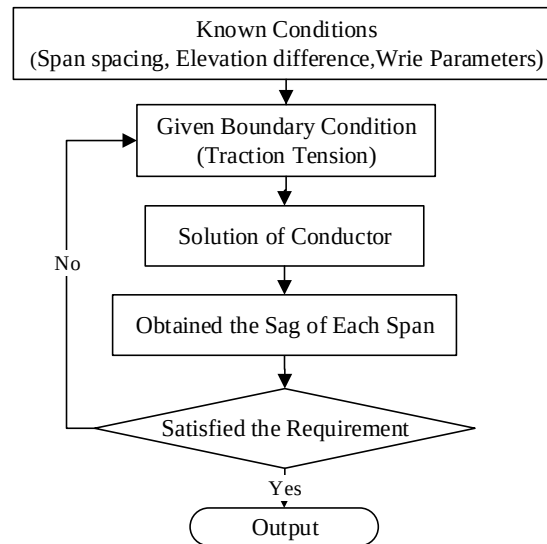


Figure 5. Calculation process.

6. Calculation cases

Taking the $\pm 500\text{kV}$ Caopu-Changkou tension stringing construction project in references [7] as example. The traction tension is 14kN . Conductor parameters and the span information are shown in table 1 and table 2.

Table 1. Conductor parameters.

Type of conductor	LGJ-400/50	Unit weight (kg/m)	1.511
Cross-sectional area (m ²)	20	Gravitational acceleration (kg/N)	10
Elasticity modulus (Pa)	15	Coefficient of tidity	0.012

Table 2. Information of span.

Tower number		Span spacing(m)	Elevation difference(m)	Tower number		Span spacing(m)	Elevation difference(m)
N0	N1	114	-16.4	N10	N11	289	31.6
N1	N2	298	32.2	N11	N12	724	87
N2	N3	380	6.5	N12	N13	286	46.7
N3	N4	1035	-162.1	N13	N14	476	73.2
N4	N5	810	149.7	N14	N15	610	127.2
N5	N6	171	21.4	N15	N16	694	56

N6	N7	270	-5.3	N16	N17	520	-37.5
N7	N8	824	-7.6	N17	N18	375	-2.4
N8	N9	522	3.5	N18	N19	206	-5.6
N9	N10	486	39.4	N19	N20	608	-19.7

According to the known condition, the calculated results of the conductor shape and tension are shown in figure 6.

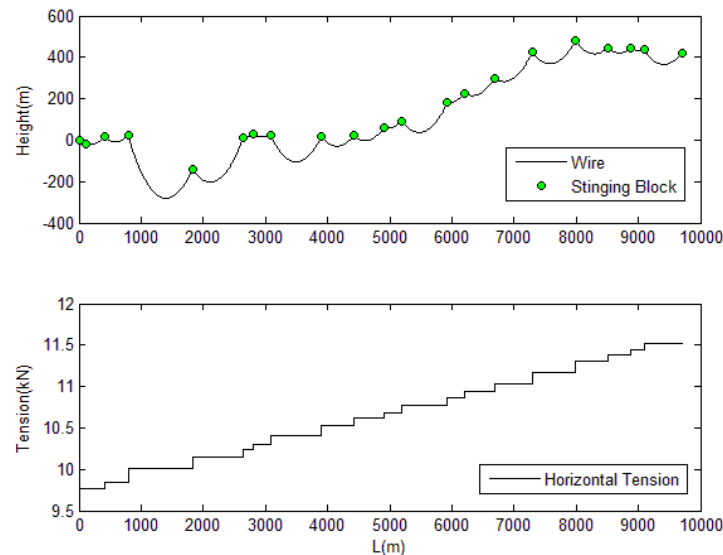


Figure 6. Calculated shape and horizontal tension of conductor.

The comparison of conductor sag and length of each span are shown in table 3 between the results calculated by this method and data in the literature [7].

Table 3. Comparison of conductor sag and length of each span.

Conductor sag of each span			Conductor length of each span		
Calculate result from literature(m)	Calculate result from this method(m)	Error(%)	Calculate result from literature(m)	Calculate result from this method(m)	Error(%)
2.2744	2.407	5.8301	115.2	114	-1.0530
15.5408	17.308	11.3714	300.3	298	-0.7720
25.27	27.9317	10.5330	381.2	380	-0.3160
187.4644	208.8044	11.3835	1070	1035	-3.3820
114.8176	124.587	8.5086	834.4	810	-3.0120
5.1172	5.4627	6.7517	172.4	171	-0.8190
12.7576	13.3717	4.8136	270.5	270	-0.1850
118.8208	126.8477	6.7555	835.5	824	-1.3960
47.6848	49.4378	3.6762	524.9	522	-0.5560
41.3344	42.4979	2.8148	489.9	486	-0.8020
14.6162	14.8857	1.8438	291.2	289	-0.7610
91.7308	93.6205	2.0600	736.9	724	-1.7820
14.3144	14.3106	-0.0270	290.3	286	-1.5030
39.6508	39.3831	-0.6750	483.8	476	-1.6390
65.1176	63.9066	-1.8600	627.7	610	-2.9020
84.2864	82.918	-1.6240	703.1	694	-1.3110
47.32	45.2745	-4.3230	524.2	520	-0.8080
24.6094	23.4323	-4.7830	376.1	375	-0.2930

7.4264	6.9839	-5.9580	206.3	206	-0.1460
64.6912	61.2765	-5.2780	612.9	608	-0.8060

The comparison shows that the results by this method agrees well with the data from literature [7], the maximum error of conductor sag of each span is 11.38%, the maximum error of conductor length of each span is 3.38%. That means the method is valid in calculation of multi-span tension stringing.

7. Summary

The nonlinear equations of multi-span tension stringing are present which include the conservation equations of span spacing and elevation difference and the tension balance equations of conductor. From the method, the traction, length and sag of conductor of each span in transmission line can be calculated to use in the selection of the traction machine.

The proposed method has good convergence and high calculation speed, which can fully meet the needs of engineering.

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