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Simulation of Continuous Tension Stringing Process of Conductor with Bending Stiffness Model

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***Abstract*—At present, there is no research on the calculation of tension variation of the conductor with bending stiffness model between the continuous span during tension stringing construction. Aiming at the typical terrain with large elevation difference in UHV project, a vector finite element method for calculating the tension of the conductor with bending stiffness model passes through the pulley in the process of tension stringing is proposed. The process of the wire rope under the action of the tractor pulling the conductor passes through the pulley continuously is realized. The variations of tension of tensioner and tractor, reaction force of pulley and envelope angle of the conductor passes through the pulley are obtained by simulation of tension stringing conditions such as 1 pulls 1, 1 pulls 2, etc, which provides reference for equipment selection for the tension stringing construction of mountain terrain with large elevation difference.**

Keywords*—transmission line, bending stiffness, conductor, tension stringing, vector finite element method, numerical simulation

I. Introduction

In the tension stringing process of UHV transmission line engineering, it is often faced with severe topographical conditions such as large elevation difference and large span, etc. During the construction, the tension is large and needs high control accuracy. Meanwhile, the working condition of conductor passes through the pulley is more complicated. At present, there is no relevant research on the tension variation of the conductor with bending stiffness model between the continuous span in the process of tension stringing [1-5]. Therefore, it is necessary to carry out numerical simulation on the continuous tension stringing process of conductor with bending stiffness model.

In this paper, the vector finite element method is used to calculate the tension variation of conductor under typical terrain with large elevation difference in UHV engineering [6], which provides technical support for tension stringing in terrain with large elevation difference.

II. Simulation of Equivalent Bending Stiffness of Conductor

The type of conductor is 8×JL1/G2A-1250/100 aluminium cable steel reinforced, the cylindrical structure is used as the equivalent structure of the conductor with bending stiffness model. According to the simulation results of equivalent bending stiffness of 1250mm^2 large section conductor [7], equivalent bending stiffness EI=113.678N·m^2 and tensile stiffness EA=25090010N. Establish a simplified equivalent cylinder model, according to the formula:

$$EI_{\text{cylinder}} = E \cdot \frac{\pi}{64} D^4 \tag{1}$$

$$EA_{\text{cylinder}} = E \cdot \frac{\pi}{4} D^2 \tag{2}$$

In the formula:

EI is equivalent bending stiffness of conductor, N·m^2;

EA is tensile stiffness of conductor, N;

E is modulus of elasticity, GPa;

D is the diameter of the simplified equivalent cylinder, m;

A is the cross section area of the simplified equivalent cylinder, m^2;

Thus:

$$D = 4\sqrt{\frac{I}{A}} \tag{3}$$

$$A = \frac{\pi D^2}{4} \tag{4}$$

The equivalent structural parameters of the conductor are shown in the table I.

TABLE I. Equivalent Structural Parameters of the Conductor

Modulus of elasticity (GPa)	Mass per unit length (kg/m)	Diameter (m)	Cross section area (m^2)
440	4.252	8.514×10^{-3}	5.691×10^{-5}

III. Vector Finite Element Simulation of Continuous Tension Stringing Process of Conductor

In the past, the force on the conductor passing through the suspension point was calculated directly in the tension stringing construction process, without considering the tension change of the process of wire rope pulls conductor [8]. In order to better conform to the actual condition of tension stringing construction, the calculation model of wire rope pulls conductor is adopted. According to the vector finite element method proposed in references [6], the continuous tension stringing process of conductor is simulated.

(1) Selection of tension stringing section

According to the tower location details of an UHV transmission line project, the conductor length *L*=6300m is set for tension stringing, and the location of the tower pulley (span, elevation difference) are selected as shown in table II.

TABLE II. THE LOCATION OF THE TOWER PULLEY

Tower number	Span (m)	Elevation difference (m)
N4890	50643	750.1
N4891	51288	959.4
N4892	51797	1087.7
N4893	52488	1343.3
N4894	53003	1273.5
N4895	53897	1075.3
N4896	54732	955.7
N4897	55183	939.8
N4898	56175	1022.4
N4899	56542	1046.6

(2) Analysis of simulation results

The traction mode is set as 1 pulls 1 (A wire rope pulls a conductor), 1 pulls 2 and 1 pulls 4. The traction speed is set as *v*=1.39m/s and *v*=0.695m/s.

Through simulation, the configuration of wire rope pulls conductor is obtained as shown in figure 1, curves of tension of tensioner (point A) and tractor (point B) versus time are shown in figure 2, curves of horizontal and vertical reaction force of pulley (point O) versus time are shown in figure 3, curves of envelope angle of the conductor passes through the pulley versus time are shown in figure 4.

1) 1 pulls 1, *v*=1.39m/s

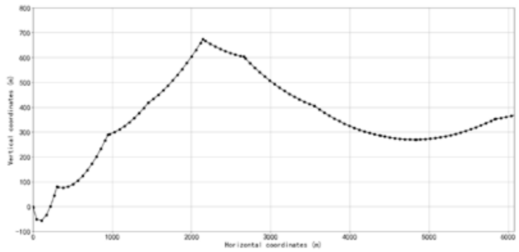

Fig. 1. Configuration of wire rope pulls conductor (traction speed v = 1.39m/s, traction mode: 1 pulls 1)

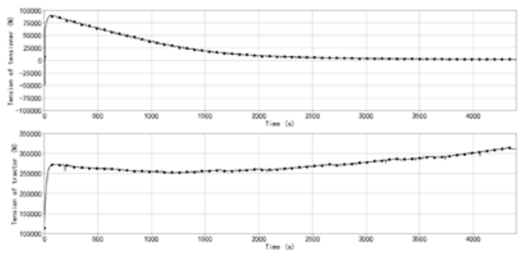

Fig. 2. Curves of tension of tensioner (point A) and tractor (point B) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 1)

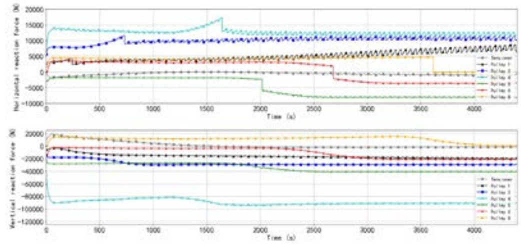

Fig. 3. Curves of horizontal and vertical reaction force of pulley (point O) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 1)

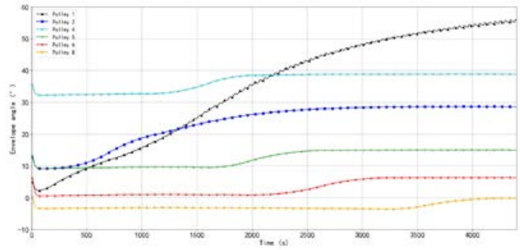

Fig. 4. Curves of envelope angle of the conductor passes through the pulley versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 1)

2) 1 pulls 2, *v*=1.39m/s

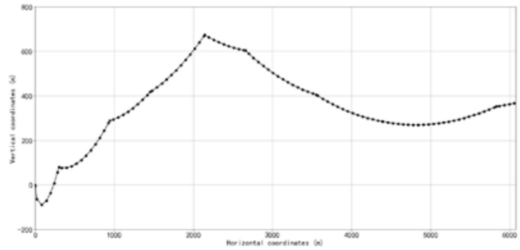

Fig. 5. Configuration of wire rope pulls conductor (traction speed v = 1.39m/s, traction mode: 1 pulls 2)

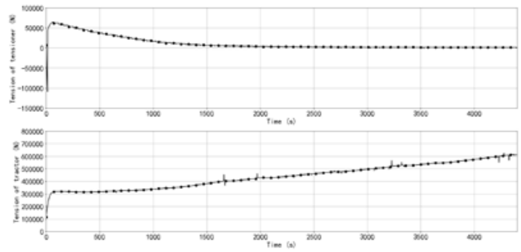

Fig. 6. Curves of tension of tensioner (point A) and tractor (point B) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 2)

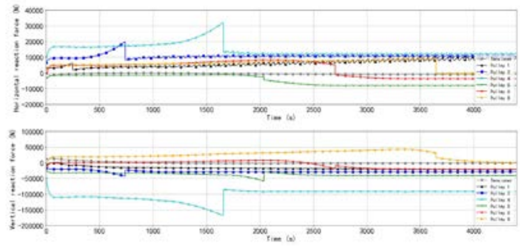

Fig. 7. Curves of horizontal and vertical reaction force of pulley (point O) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 2)

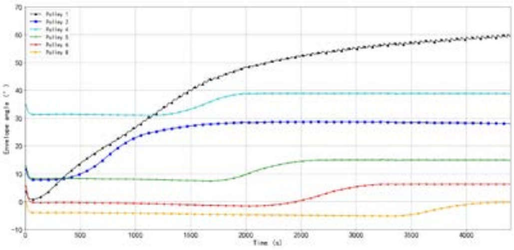

Fig. 8. Curves of envelope angle of the conductor passes through the pulley versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 2)

3) 1 pulls 4, v=1.39m/s

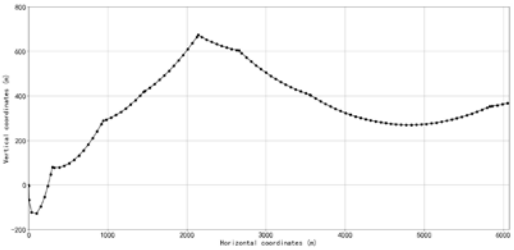

Fig. 9. Configuration of wire rope pulls conductor (traction speed v = 1.39m/s, traction mode: 1 pulls 4)

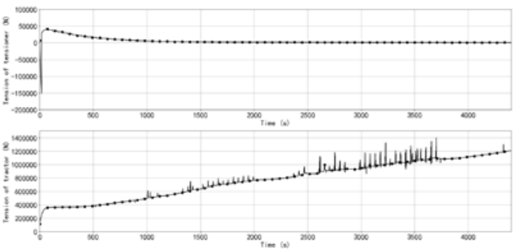

Fig. 10. Curves of tension of tensioner (point A) and tractor (point B) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 4)

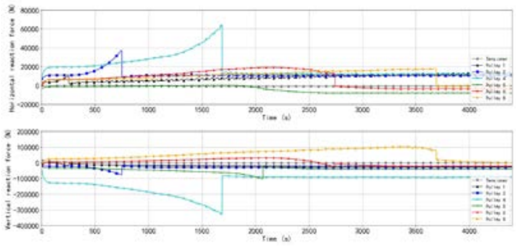

Fig. 11. Curves of horizontal and vertical reaction force of pulley (point O) versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 4)

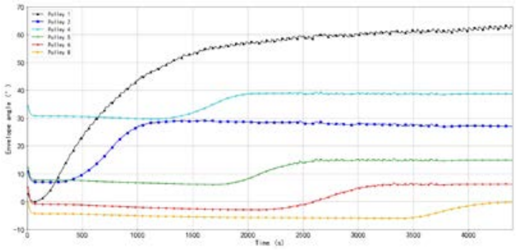

Fig. 12. Curves of envelope angle of the conductor passes through the pulley versus time (traction speed v = 1.39m/s, traction mode: 1 pulls 4)

The maximum value of tension of tensioner (point A) and tractor (point B) are shown in table III, the maximum value of horizontal and vertical reaction force of pulley (point O) and envelope angle of the conductor passes through the pulley are shown in table IV. The tension of the tensioner (point A) decreases gradually with the increase of time after reaching the peak at the initial moment, and the final value tends to zero. The tension of the tractor (point B) increases gradually with the increase of time. When the traction speed *v*=1.39m/s, the more conductors pulled by wire rope, the smaller the peak tension of tensioner (point A), the larger the variation range of the tension of the tractor (point B), and the final tension value of the tractor (point B) increases linearly with the number of conductor pulled by wire rope. When the traction speed *v*=0.695m/s, the tension of the tensioner (point A) and tractor (point B) decreases with time.

TABLE III. MAXIMUM VALUE OF TENSION OF TENSIONER (POINT A) AND TRACTOR (POINT B)

	1 pulls 1 v=1.39m/s	**1 pulls 2 v=1.39m/s**	**1 pulls 4 v=1.39m/s**	**1 pulls 1 v=0.695m/s**
Tension of tensioner (point A) $F_{A\ tension}$(N)	90691.49	64389.36	40997.26	65131.51
Tension of tractor (point B) $F_{B\ tension}$(N)	310968.44	611827.90	1206901.62	176785.94

TABLE IV. MAXIMUM VALUE OF HORIZONTAL AND VERTICAL REACTION FORCE OF PULLEY (POINT O) AND ENVELOPE ANGLE OF THE CONDUCTOR PASSES THROUGH THE PULLEY

		Pulley 1	Pulley 2	Pulley 4	Pulley 5	Pulley 6	Pulley 8
Horizontal reaction force of pulley F_x(N)	1 pulls 1 v=1.39m/s	8631.73	11561.88	17232.57	-8206.93	3535.74	4720.45
	1 pulls 2 v=1.39m/s	10705.42	19643.03	31994.93	-8229.71	8379.37	8828.05
	1 pulls 4 v=1.39m/s	13876.92	36832.60	63648.19	-8416.7	19080.54	17634.88
	1 pulls 1 v=0.695m/s	4394.04	10832.98	14846.27	-8056.05	1334.98	3029.11
Vertical reaction force of pulley F_y(N)	1 pulls 1 v=1.39m/s	-20622.61	-30165.54	-94733.45	-41403.13	-21277.19	15403.15
	1 pulls 2 v=1.39m/s	-22505.60	-42871.19	-167504.87	-57308.01	-21486.48	43154.59
	1 pulls 4 v=1.39m/s	-25341.20	-76231.59	-326379.38	-102523.41	-24444.20	101659.37
	1 pulls 1 v=0.695m/s	-17111.50	-28800.87	-78026.18	-37698.67	-27121.94	3722.73
Envelope angle of the conductor passes through the pulley α(°)	1 pulls 1 v=1.39m/s	55.91	28.69	38.88	15.02	6.36	0.41
	1 pulls 2 v=1.39m/s	60.01	28.78	39.03	15.16	6.39	0.091
	1 pulls 4 v=1.39m/s	63.34	29.29	39.37	15.41	6.74	0.0
	1 pulls 1 v=0.695m/s	41.67	34.54	43.76	20.57	13.33	4.91

When the conductor passes through the pulley, the horizontal reaction force and the vertical reaction force of the pulley are instantaneously increased to the peak and then decreased, and oscillate smoothly with the increase of time. When the traction speed v=1.39m/s, the more conductors pulled by wire rope, the greater the horizontal reaction force and vertical reaction force of the pulley. When the traction speed v=0.695m/s, the horizontal reaction force and vertical reaction force of the pulley decrease, which shows that the force on the pulley can be reduced by reducing the traction speed.

As the conductor passes through the pulley, the envelope angle reaches its peak value and then tends to be stable. The tower position of pulley 4 has a large relative span and elevation difference with the adjacent tower positions, when the conductor passes through the pulley, the pulley receives the maximum horizontal reaction force and vertical reaction force.

IV. CONCLUSION

In this paper, the vector finite element method is used to study the variations of tension of tensioner and tractor, horizontal and vertical reaction force of pulley and envelope angle of the conductor passes through the pulley in the continuous tension stringing process of conductor with bending stiffness, which provides a reference basis for equipment selection for the tension stringing construction of mountain terrain with large elevation difference.

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