Study on the Effect of Different Starting Conditions on the Load of Freight Ropeway Working-rope

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Abstract. In order to study the structural performance of freight ropeway under the influence of dynamic factors, a method for dynamic analysis and calculation of freight ropeway is proposed. Based on the theory of finite particle method, this method gives the expressions of the interaction force between the carrying rope and running trolley, and the haulage rope and running trolley. The motion equations of the particle of the carrying rope, traction rope and running trolley are established respectively, and the coupling force calculation of the carrying rope and traction rope is realized. The influence of load quality, starting speed and starting position on the tension of working-rope of freight ropeway is analysed with the proposed calculation method, which can provide more scientific and reasonable reference for the design of freight ropeway.

1. Introduction

With the advantages of low erection difficulty, strong terrain adaptation, less environmental damage and small investment, the freight ropeway of transmission line is widely used in the construction of mountainous area in overhead transmission line \cite{1-2}.

The core of the design for freight ropeway is the calculation of working-rope (carrying rope and haulage rope), which directly affects the economic and safety performance of the ropeway. At present, the freight ropeway of transmission line engineering mainly uses catenary, parabola and other analytical methods to calculate the strength of carrying rope \cite{3-6}, while the traction rope is selected according to experience, without considering the response such as the interaction of working-rope, starting speed and position, which results in the safety of design to ropeway cannot meet technical requirements.

In recent years, the finite particle method \cite{7} has achieved good results in dealing with large deformation of structures such as cable structures \cite{8}. Based on the finite particle method, this paper puts forward the dynamic calculation method of freight ropeway, and applies the calculation method to the analysis of the influence of load weight, starting speed and starting position on the structure of freight ropeway, so as to provide safer and effective calculation results for the design of freight ropeway.

2. Description of Ropeway Structure

Freight ropeway mainly includes structural components such as carrying rope, haulage rope, trestle, running car, etc. the span of ropeway is $L$, and the height difference is $H$, as shown in Figure 1.
3. Finite Particle Method for Dynamic Calculation of Ropeway

The finite particle method is used to discretize the carrying rope and haulage rope into a series of nodes, as shown in Figure 1. The mass of rope is shared by the nodes, which are connected by elements. The motion of the nodes follows Newton's second law.

3.1. Calculation of Rope Node Force

3.1.1. Internal force of rope element. The rope only bears the axial tension, does not bear the pressure and bending moment, and is always in linear elastic state, and the cross-section area remains unchanged.

\[ f_{i-1}^{in} = EA \frac{l_{i-1} - l_{i-1}^0}{l_{i-1}^0} \]  \hspace{1cm} (1)

In the formula, \( l_{i-1} \) is the length of the node \( i-1 \) to node \( i \) in working-rope; \( l_{i-1}^0 \) is the initial unstressed length of rope element \( i-1 \), as shown in Figure 2. When there is no load in the rope element, the internal force of the element is

When the rope element has a load node \( P \), as shown in Figure 2, the internal force of the element is

\[ f_i^{in} = EA \frac{l_i + l_{i+1} - l_i^0}{l_i^0} \]  \hspace{1cm} (2)

In the formula, \( l_i^0 \) is the original length of element \( i \); \( l_i \) is the length from node \( i \) to contact node \( P \) at current time; \( l_{i+1} = |x_{i+1} - x_P| \) is the length from contact node \( P \) to node \( i + 1 \) at current time.

The resultant force \( F_i \) of node \( i \) is

\[ F_i = M_i G + f_i^e \]  \hspace{1cm} (3)

In the formula, \( f_i^e \) is the resultant force of adjacent rope element to node \( i \), and \( M_i G \) is the gravity of node \( i \), \( M_i \) is the mass of node \( i \) and \( G \) is the acceleration vector of gravity.

Taking Figure 2 as an example, \( f_i^e \) is

\[ f_i^e = f_{i+1}^{in} (-e_{i+1}) + f_{i}^{in} e_{i,P} \]  \hspace{1cm} (4)
In the formula, \( f_{ini-1} \) is the force exerted by the element on the left side of node \( i \); \( e_{i-1} \) is the unit vector of element on the left side of node \( i \); \( f_{ini} e_{i, P} \) is the force of the element on the right side of node \( i \); \( e_{i, P} \) is the unit vector of node \( i \) to the contact node \( P \).

### 3.1.2. Interaction force between carrying rope and haulage rope

When the running car is rolling in contact with the element \((i)\) (nodes \( i \) and \( i+1 \)), as shown in Figure 3, the force acting on the running car by the carrying rope (as shown in Figure 4) is:

\[
N^p = f^p_i e_{P,i} + f^p_{i+1} e_{P,i+1}
\]

In the formula, \( f^p_i \) is internal force of the carrying rope element \( i \); \( e_{P,i} \) and \( e_{P,i+1} \) are unit vectors of elements on both sides of contact node \( P \).

The force acting on the running car by haulage rope (as shown in Figure 4) is:

\[
N^T_j = f^T_{j-1} e_{j-1} + f^T_j e_j
\]

In the formula, \( f^T_{j-1} \) and \( f^T_j \) are internal forces of haulage rope elements connected to the running car; \( e_{j-1} \) and \( e_j \) are unit vectors of elements on both sides of haulage rope node \( j \).

![Figure 3. Travelling trolley and working cables](image)

![Figure 4. Acting force on travelling trolley](image)

### 3.2. Equation of Node Motion

The equations of motion for carrying rope and haulage rope can be expressed as follows

\[
M \ddot{x} = F
\]

In the formula, \( M \) is the mass of node; \( \ddot{x} \) is the acceleration vector of node; \( F \) is the resultant force of node.

### 3.3. Solution of Motion Equation

The center difference method is used to solve the motion equation of nodes. Time increment step size is \( h \), node movement time \( t = t_n = nh \), \( n \geq 0 \); \( x^{n+1}, x^n \) and \( x^{n-1} \) are respectively the node position vectors at \( n-1, n \) and \( n+1 \) time steps. Considering the influence of structural damping, the damping coefficient \( \zeta \) is introduced. According to the central difference formula, the following results are obtained:

\[
x^{n+1} = (2x^n - x^{n-1}) + \frac{h^2}{M} F^n / c_1
\]

In the formula, \( c_1 = 1 + \frac{\zeta h}{2} \), \( c_2 = 1 - \frac{\zeta h}{2} \).

### 4. Dynamic Impact Analysis of Ropeway Starting Process

During the start-up operation of the ropeway, the tension of the haulage rope will change dramatically due to the sudden acceleration of the haulage rope, and it also has certain influence on the carrying rope. In this paper, the tension of the ropeway starting state and the tension of the stable state are compared according to several conditions.

Taking single-cable ropeway as an example, the basic parameters of the ropeway are: The span is 350m, height difference is 130m; diameter of carrying rope is 30mm, mass per unit length is 4.57kg/m, medium deflection coefficient is 0.03; diameter of haulage rope is 26mm, mass per unit length is 3.4kg/m; elastic modulus of working-rope is 110GPa.
4.1. Calculation Conditions
Considering the influence of load weight, starting position and starting speed on the structure of ropeway, the maximum tension of carrying rope and haulage rope is calculated. The working conditions are shown in Table 1.

| Category | Load (t) | starting speed (m/min) | starting position (m) |
|----------|---------|------------------------|-----------------------|
| 1        | 2, 3, 4 | 30                     | 190                   |
| 2        | 2       | 15, 30, 60             | 190                   |
| 3        | 2       | 30                     | 75, 190, 300          |

4.2. Effect of Load on Tension of Working-rope
Figure 5-7 shows the tension curves of the carrying rope and haulage rope at load 2t, 3t and 4t when the ropeway is started. When the load is 2t, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 2.29%, and that of the haulage rope is 125.18%; when the load is 3t, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 3.14%, and that of the haulage rope is 94.24%; when the load is 4t, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 3.45%, and that of the haulage rope is 69.77%. It can be seen that the starting state has little influence on the carrying rope, but has a greater influence on the tension of the haulage rope; at the same time, the smaller the load weight is, the greater the dynamic fluctuation of the haulage rope tension is.

![Figure 5](image1)

(a) the carrying rope  
(b) the haulage rope

**Figure 5.** Curve of tension during ropeway starting under 2t load

![Figure 6](image2)

(a) the carrying rope  
(b) the haulage rope

**Figure 6.** Curve of tension during ropeway starting under 3t load
4.3. Effect of Starting Speed on Tension of Working-rope

Figure 5, figure 8 and Figure 9 show the tension curves of the carrying rope and haulage rope starts at the speed of 15m / min, 30m / min and 60m / min, respectively. When the ropeway is started at 15m/min, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 0.78% and that of the haulage rope is 56.19%. When the ropeway is started at 30m/min, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 2.29%, and that of the haulage rope is 125.18%. When the ropeway is started at 60m/min, the maximum deviation of tension for the carrying rope between the starting state and the stable state is 3.81% and that of the haulage rope is 149.41%. It can be seen that the starting speed has little influence on the carrying rope, but has a great influence on the tension of haulage rope. The greater the starting speed, the greater the tension fluctuation of the haulage rope. Therefore, the running speed of the ropeway haulage device should be reduced when the ropeway is started.
4.4. Effect of Starting Position on Tension of Working-rope

Figure 5, Figure 10 and Figure 11 show the tension variation curves of the carrying rope cable and the haulage rope when the cableway starts at the front (75m), middle (190m) and rear (300m) positions respectively. The maximum deviation of tension for the carrying rope between the starting state and the stable state is -2.14% and that of the haulage rope is 92.35% when starting at the front (75m); The maximum deviation of tension for the carrying rope between the starting state and the stable state is 2.29% and that of the haulage rope is 125.18% when starting at the middle position (190m); The maximum deviation of tension for the carrying rope between the starting state and the stable state is 3.13% and that of the haulage rope is 164.28% when starting at the rear (300m) position. It can be seen that starting position has a great influence on the tension of haulage rope. The closer the load is to the end support at start-up, the greater the fluctuation on the tension of haulage rope.

Figure 9. Tension change curve at starting speed of 60m/min

Figure 10. Tension change curve at the front position (75m)

Figure 11. Tension change curve at the rear position (300m)
5. Summary
In this paper, a dynamic calculation method of freight ropeway based on the theory of finite particle method is proposed. The method can realize the structural force calculation of freight ropeway under dynamic influencing factors and obtain the structure performance of freight ropeway more accurately. By analyzing the tension changes of the ropeway carrying rope and haulage rope under different loads, starting speed and starting position when the ropeway is started, it is concluded that the starting process has a great influence on the maximum tension fluctuation of the haulage rope, especially the starting speed and starting position have the greatest influence on the tension of the traction cable. The running speed of the haulage device for the ropeway should be reduced when the ropeway is started.

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