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Influence of elastic modulus of steel rope on longitudinal vibration of high speed elevator hoisting system

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Abstract—In order to study the influence mechanism of the elastic modulus of steel wire rope on the high-speed elevator hoisting system of comfort, with high speed elevator vertical vibration as the research object, the establishment of high-speed elevator hoisting system of longitudinal vibration of discrete distributed parameter model. The five polynomial is used to fit the ideal operation curve of the high speed elevator's ascending process, and it is used as the parameter input. The model is simulated by Matlab software. The results show that the elastic modulus of the steel wire rope is inversely related to the displacement of the longitudinal vibration of the elevator, and is positively related to the magnitude of the longitudinal vibration acceleration of the elevator.

Keywords— high speed elevator; steel wire rope; the elastic modulus; longitudinal vibration

I. INTRODUCTION

With the rapid development of urbanization, high-rise buildings and super high-rise buildings are surging. As the vertical transportation tools of high-rise buildings, elevators are also developing towards large travel and high speed. The increase of elevator speed and travel making the elevator hoisting system inevitably lead to various vibration phenomena in the process of operation, the elevator hoisting system is mainly composed of wire rope and connected at both ends of the heavy blocks, and the performance of the steel wire rope is directly related to the safety and comfort of the elevator.

The elastic modulus of steel wire rope, as the main performance parameter of wire rope, is an important parameter to be considered in the design of equipment and facilities for wire rope, and the elastic elongation is inevitable when the wire rope is loaded. Therefore, whether the selection of elastic modulus is appropriate or not will directly affect the comfort of the elevator, but the mechanism of the influence of the elastic modulus of the wire rope on the comfort of the elevator has not been studied yet. Moreover, in the hoisting system, when the initial conditions are the same, the effect of longitudinal vibration on the system is much greater than that of the transverse vibration [1]. Therefore, taking the longitudinal vibration of the elevator as the research object, it is of great theoretical and practical significance to explore the influence mechanism of the elastic modulus of the wire rope on the elevator vibration.

The establishment of dynamic model of wire rope for hoisting system of high speed elevator is the basis of the research on the influence of elastic modulus of wire rope. At present, a lot of research work has been done on the discrete model of steel wire rope based on distributed parameter at home and abroad [2-6], but this kind of model is a multi-body dynamics model, which cannot show the continuous characteristics of the wire rope. Therefore, the distribution parameters which can well describe the flexibility characteristics of the wire rope are gradually being applied. Bao [7] establishes the control equation of flexible lifting wire rope by Hamilton principle, studies the nonlinear vibration of flexible hoisting wire rope with time varying length, and verifies the theoretical model by experiment. Zhang et al. [8] based on the Hamilton principle, the motion differential equations and energy equations for the longitudinal vibration of a flexible lifting system with arbitrary variable length are established, and the correctness of the modeling and energy method of the continuous system is verified. However, the above literatures were studied and analyzed for the influence of the elastic modulus of steel wire rope on elevator vibration.

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II. Establishment of Dynamic Model of High Speed Elevator Hoisting System

Aiming at the above problems, by using the energy method and the Hamilton principle to establish high-speed elevator hoisting system time-varying dynamics model, using the ideal operation curve of five polynomial fitting on the process of elevator uplink and downlink and as input parameters, using Matlab to simulate the dynamic model, analyzes the influence of elastic modulus of wire rope for elevator longitudinal vibration.

As shown in Fig. 1, the time varying model of longitudinal vibration of high speed elevator hoisting system is presented. The linear density of the traction rope is ρ , the cross sectional area is A, the elastic modulus is E, the tangent point of the traction wheel and the hoist rope is the coordinate origin, and the vertical downward direction is the positive direction of the shaft. The length of the traction rope at the distance between the top and the bottom of the car is $l(t)$, the vibration displacement at the string $x(t)$ is $y(x(t),t)$, and $v(t)$ is the running speed of the high-speed traction elevator.

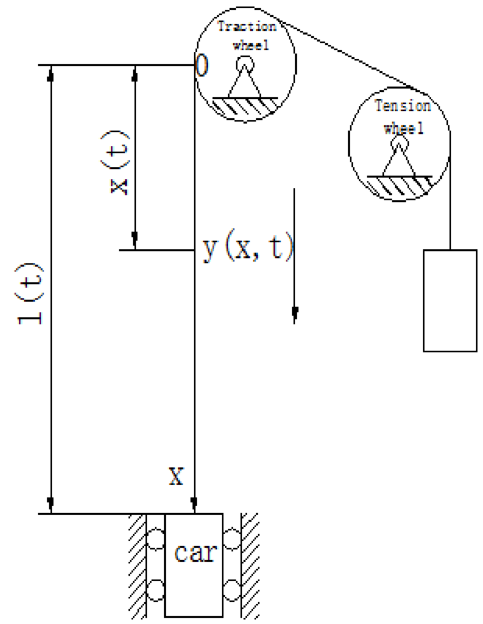


Fig. 1. Time varying model of high speed elevator hoisting system

Using the finite deformation theory of continuous medium, the displacement vector and velocity vector of $x(t)$ in the x axis are as follows

$$r=\left[x(t)+y(x(t),t)\right]j \tag{1}$$

$$V=\left[v(t)+y_t(x(t),t)\right]j \tag{2}$$

The j is the unit vector along the x axis, and $y_t(x(t),t)$ is the partial conductance of $y(x(t),t)$ to t . The following are used for y, y_t for $y(x(t),t)$, $y_t(x(t),t)$ respectively.

Similarly, it can be seen that the displacement vector and velocity vector of the car in the x axis are as follows

$$r_c=[l(t)+y]j \tag{3}$$

$$V_c=[v(t)+y_t]j \tag{4}$$

The kinetic energy of the system can be expressed as:

$$E_k=\frac{1}{2}mV^2\Big|_{x=l(t)}+\frac{1}{2}\rho_1\int_0^{l(t)}V^2ds \tag{5}$$

System elastic potential energy can be expressed:

$$E_s=\int_0^{l(t)}(Py_x+\frac{1}{2}EAy_x^{\ 2})ds \tag{6}$$

$y_x(x(t),t)$ is a partial derivative of x , which is expressed as $y_x(x(t),t)$ by y_x .

P is the straining force of the hoist rope in the static equilibrium state, and the hoist rope is affected by the gravity and the gravity of the car:

$$P=[\mathrm{m}+\rho(l(t)-x)]g \tag{7}$$

The expression of gravitational potential energy of the system is:

$$E_g=-\int_0^{l(t)}\rho_1 gdt-mgy\Big|_{x=l(t)} \tag{8}$$

According to Hamilton principle:

$$I=\int_{t_1}^{t_2}[\delta E_k-\delta E_s-\delta E_g]dt=0 \tag{9}$$

The time boundary conditions and geometric boundary conditions are also used:

$$\delta y(0,t)=\delta y(x,t_1)=\delta y(x,t_2)=0 \tag{10}$$

The longitudinal vibration dynamic equation of hoisting system of high speed traction elevator is obtained:

$$\rho(y_{tt}+a)-P_x-\rho g-EAy_{xx}=0, 0<x<l(t) \tag{11}$$

$$m(a+y_{tt})+\rho v(v+y_t)+EAy_x+P-mg=0,\ \ x=l(t) \quad (12)$$

Type (12) is the boundary condition of chord at $x=l(t)$.

III. Galerkin Discretization of Time Varying Partial Differential Equations for Longitudinal Vibration of Lifting System

For the partial differential control equations with infinite degrees of freedom (11), the partial differential equations are discretized by the Galerkin method. The dimensionless parameter ξ is introduced to normalize the original variables, that is $\xi = x/l(t)$, The time domain of x becomes the fixed domain [0,1] of ξ. It is assumed that the infinite degree of freedom distribution function $y(x,t)$ can be used to represent the solution of (11):

$$y(x,t)=\sum_{i=1}^{n}\varphi_i(\xi)q_i(t)=\sum_{i=1}^{n}\varphi_i(\frac{x}{l(t)})q_i(t) \quad (13)$$

Among them, $\phi_i(\xi)$ is a trial function,

$$\varphi_i(\xi)=\sqrt{2}\sin(\frac{2i-1}{2}\pi\xi)(i=1,2,\cdots,n) \quad (14)$$

Then there are:

$$y_x=\frac{1}{l(t)}\sum_{i=1}^{n}\varphi_i'(\xi)q_i(t) \quad (15)$$

$$y_{xx}=\frac{1}{l(t)}\sum_{i=1}^{n}\varphi_i''(\xi)q_i(t) \quad (16)$$

$$y_t=\sum_{i=1}^{n}\varphi_i(\xi)\dot{q}_i(t)-\frac{\xi v}{l(t)}\sum_{i=1}^{n}\varphi_i'(\xi)q_i(t) \quad (17)$$

$$y_{tt}=\sum_{i=1}^{n}\varphi_i(\xi)\ddot{q}_i(t)-\frac{2\xi v}{l(t)}\sum_{i=1}^{n}\varphi_i'(\xi)\dot{q}_i(t)+\frac{2\xi v^2}{l^2(t)}\sum_{i=1}^{n}\varphi_i'(\xi)q_i(t)-\frac{a\xi}{l(t)}\sum_{i=1}^{n}\varphi_i'(\xi)q_i(t)+\frac{\xi^2v^2}{l^2(t)}\sum_{i=1}^{n}\varphi_i''(\xi)q_i(t) \quad (18)$$

The (15-18) is brought into the kinetic (12), and the two sides are multiplied by $\varphi_i(\xi)$, and their ξ are integrated in the range of $[0,1]$. The original partial differential equations are discretized into

$$M\ddot{q}_j+C\dot{q}_j+Kq_j=F \quad (19)$$

In the formula, $q_j=[q_1(t),q_2(t),\cdots,q_n(t)]$ is the generalized coordinate vector.

$$M=\rho\delta_{ij}+\frac{m}{l}\varphi_i(1)\varphi_j(1)$$

$$C=-\frac{2\rho v}{l}\int_0^1\xi\varphi_i'\varphi_j d\xi+\frac{\rho v}{l}\varphi_i(1)\varphi_j(1)$$

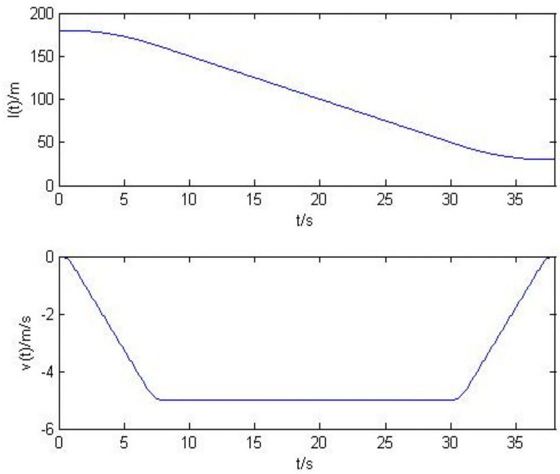
$$K=\frac{mv^2}{l^3}\varphi_i''(1)\varphi_j(1)-\frac{\rho a}{l}\int_0^1\xi\varphi_i'\varphi_j d\xi-\frac{\rho v^2}{l^2}\int_0^1\xi^2\varphi_i'\varphi_j' d\xi-\frac{EA}{l^2}\int_0^1\varphi_i''\varphi_j d\xi$$

$$F=-\rho a\int_0^1\varphi_j d\xi-\frac{ma}{l}\varphi_j(1)-\frac{\rho v^2}{l}\varphi_j(1)$$

IV. Case Analysis

A high-speed elevator, Shandong Fushi Yuzhi Elevator Co. Ltd developed as the analysis object, the traction rope line density is $\rho=0.87kg/m$, the sectional area is $A=89.344mm^2$, the hoisting quality of the single traction rope is $m=400kg$ (Car, car frame and specified load), The maximum speed of elevator is $5m/s$, the maximum acceleration is $0.75m/s^2$, lifting height is $150m$. As shown in Fig. 2, the running state curve of uplink of the high speed elevator is obtained by five-degree polynomial fitting.

"Mine hoisting equipment", edited by China University of Mining and Technology, gives the elastic modulus of wire rope $7.35\sim14.7\times10^{10}N/m^2$. Therefore, the influence of elastic modulus on longitudinal vibration of high speed elevator is analyzed when elastic modulus $E=9\times10^{10}$、11×10^{10}、$13\times10^{10}N/m^2$ are taken respectively.



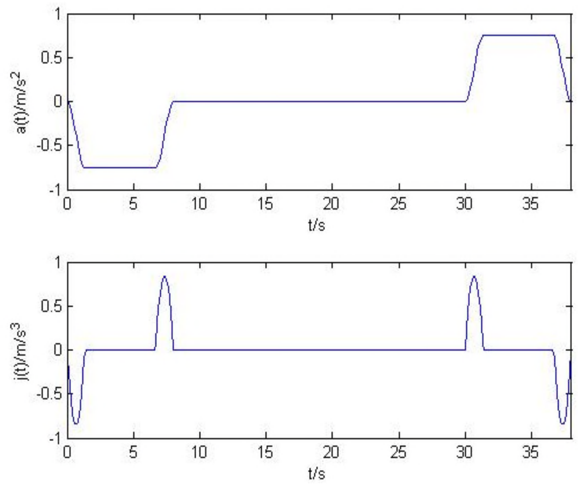


Fig. 2. Upward running state curve of high speed elevator

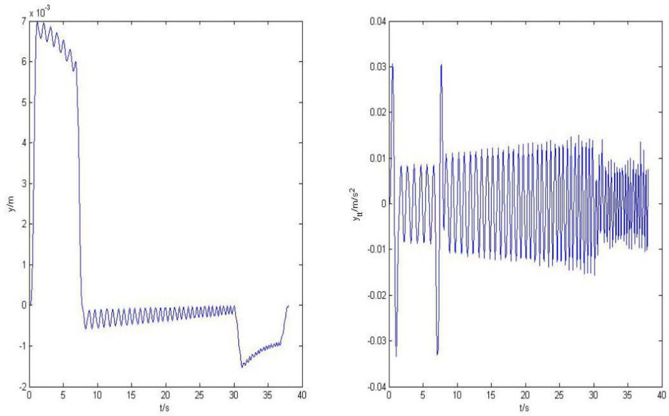


Fig. 3. Dynamic characteristics of longitudinal vibration of elevator up to $E = 9\times10^{10}\, N/m^2$

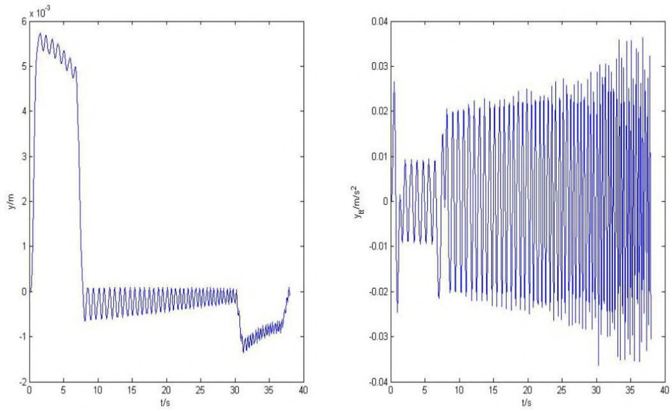


Fig. 4. Dynamic characteristics of longitudinal vibration of elevator up to $E = 11\times10^{10}\, N/m^2$

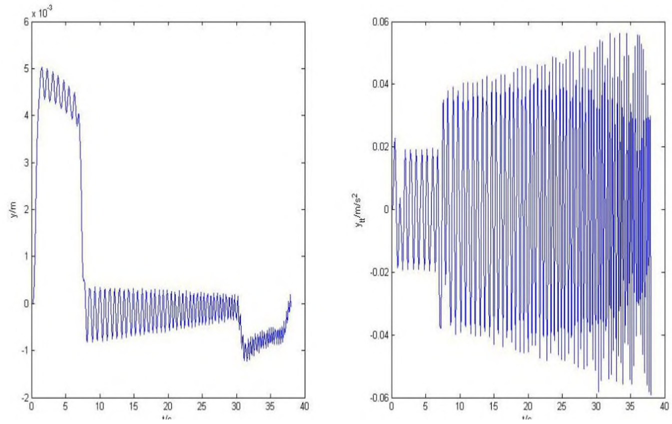


Fig. 5. Dynamic characteristics of longitudinal vibration of elevator up to $E = 13\times10^{10}\, N/m^2$

As shown in Figs. 3, 4 and 5 above, the upward longitudinal vibration displacement and acceleration of the elevator uplink at elastic modulus of $E = 9\times10^{10}$、11×10^{10}、$13\times10^{10}\, N/m^2$ are respectively. It is not difficult to find that with the increase of the elastic modulus of the rope, the displacement amplitude of the longitudinal vibration of the elevator gradually decreases, and the amplitude of the ascending longitudinal vibration acceleration increases gradually with the comparison of the Figs. 3, 4 and 5.

V. Conclusion

(1) According to the time-varying characteristics of the wire rope of high speed elevator system, the discrete model of the distribution parameters of the longitudinal vibration of the wire rope of the high speed elevator hoisting system is established by using the energy method and the Hamliton principle.

(2) The use of five polynomial fitting ideal operation curve of high speed elevator uplink process, and as the input parameters of simulation model, simulation analysis, the model by Matlab software. The results show that the elastic modulus of steel wire rope and the size of the elevator vibration displacement size was inversely correlated, positively correlated with the size of the elevator vertical vibration acceleration.

(3) In this paper, the elastic modulus analysis of longitudinal vibration wire rope of high speed elevator hoisting system is provided, which provides some reference value for the manufacture of elevator wire rope and the selection of elevator wire rope.

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