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Effects of hoisting parameters on dynamic contact characteristics between the rope and friction lining in a deep coal mine

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ABSTRACT

Effects of hoisting parameters (effective load, acceleration and deceleration) on dynamic contact characteristics between the rope and friction lining in a deep coal mine were analyzed in this study. Effects of hoisting parameters on dynamic tensions during hoisting with variable acceleration and deceleration were explored employing Simulink simulations. Roles of hoisting parameters on contact states, slip amplitude and stress distributions along the contact path were investigated using finite element analyses. The results show distinct tensions and tension differences at both rope ends with different hoisting parameters. Dynamic contact states consist of sticking, slip and mixed regimes during hoisting. Increases of hoisting parameters induce overall increased possibilities of the gross slip, increased stress concentrations and accelerated wear between contacting bodies.

1. Introduction

The multi-rope friction hoist system is widely employed in deep coal mines to lift and lower the coal, gangues, equipment and workers [1–3]. The system operates by friction between multiple ropes and friction lining on the friction pulley [4–6]. The rope bending over the friction lining around the friction pulley subjected to tensions at both ends results in the elastic deformation of bending rope, and thus an elastic slip between the rope and friction lining occurs [7,8]. During hoisting in deep coal mines, the hoisting system vibration, induced by the changing vertical rope length and inertial load, will result in dynamic tensions of the rope at both ends [1,9,10], which will cause dynamic three-dimensional contact characteristics throughout the contact region between the rope and friction lining (stress distributions, local slip states, etc.). Abnormal contact and excessive slip may induce the rope skid accidents due to the insufficient friction transmission capacity, which will cause damages of containers and wellbore facilities, and casualties [4]. Meanwhile, different hoisting parameters (effective payload, acceleration and deceleration, maximum speed, etc.) of the mine hoist result in distinct fluctuating loads of the rope at both ends [1], and thereby cause different dynamic contact properties between the rope and friction lining. Therefore, it is of great importance to investigate effects of hoisting parameters on dynamic three-dimensional contact characteristics between the rope and friction lining in deep coal mine hoist systems.

In recent years, many scholars have carried out research on sliding friction between the rope and friction lining. Ge [11,12] investigated the probability distribution of coefficients of friction between the rope and the friction lining, and studied roles of contact pressure and sliding velocity on coefficients of friction, respectively. He found that the coefficients of friction presented a log-normal distribution, and decreased with increasing contact pressure and sliding velocity, respectively. Peng et al. [13] explored effects of thermo-mechanical properties of linings on the coefficient of friction between the rope and friction lining. Ma et al. [14] investigated effects of friction-increasing greases on sliding friction and wear properties of friction linings. Considering rope skid properties between the rope and friction lining, Chen et al. [15] employed a wireless detection system to monitor the difference between velocities of guide pulley and the rope, and thus the rope skid phenomenon could be detected. Zhao [16] recorded speeds of the rope and pulley to avoid the rope skid. According to dynamic friction transmission and creep characteristics between the rope and friction lining, Wang et al. [4] explored effects of hoisting parameters on the creep amplitude and creep velocity employing two-dimensional contact and friction transmission theories. From literature studies mentioned above, previous research mainly focuses on sliding friction and antiskid properties, and two-dimensional analyses of dynamic creep characteristics between the rope and friction lining. However, the effects of hoisting parameters on dynamic three-dimensional contact characteristics (stress distributions and contact states) have not been previously reported.

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The objective of the present study is to explore effects of hoisting parameters on dynamic contact properties between the rope and friction lining in a deep coal mine. Section 2 presents dynamic simulations of hoisting rope tensions during lifting and lowering processes employing acceleration and deceleration curves with smooth transitions between adjacent stages. Effects of effective payload, acceleration and deceleration on tensions and tension differences of the rope at both ends of the friction pulley are explored. Section 3 exhibits effects of effective payload, acceleration and deceleration on the contact states, slip amplitude and stress distributions throughout the contact region between the rope and friction lining, employing the three-dimensional contact finite element model.

2. Dynamic tensions of the hoisting rope

2.1. Theoretical models

Ignoring the unbalancing effect of multi-rope tensions and assuming the same friction transmission capacity, dynamic contact properties between a rope and the corresponding groove of friction lining are explored for convenience. As the friction pulley rotates in the clockwise direction as shown in Fig. 1 in Ref. [1], the rope lifts full loaded and empty containers on the left and right sides, respectively. Left and right moving coordinates have origins located at the left and right tangents of the friction lining over the friction pulley, respectively, and present positive directions of coordinate axes pointing upwards and downwards, respectively.

Table 1 shows reference hoisting parameters of a multi-rope friction hoist system in Huainan Mining Corporation in China. Full-loaded and empty containers move up and down according to curves of the speed, acceleration and deceleration as shown in Fig. 1a. During stages of acceleration and deceleration, variable acceleration and deceleration with a constant change rate are introduced in order to avoid abrupt changes of acceleration and deceleration [17]. Therefore, the hoisting speed curve exhibits smooth changes between adjacent hoisting stages. Evolutions of vertical rope lengths, L_i and L_x, are shown in Fig. 1b.

During hoisting stages of acceleration, constant speed and deceleration, differential equations of tensions of hoisting rope at the left and right tangents of friction lining, i.e. F_1 and F_2, are written by [3,18]

$$\ddot{F}_1=\left\{ES(g+a)-\left[\frac{ES}{m_1+\rho L_i/3}+a\right]F_1-2v\dot{F}_1\right\}/L_i \qquad (1)$$

$$\ddot{F}_2=\left\{ES(g-a)-\left[\frac{ES}{m_2+\rho L_x/3}+a\right]F_2-2v\dot{F}_2\right\}/L_x \qquad (2)$$

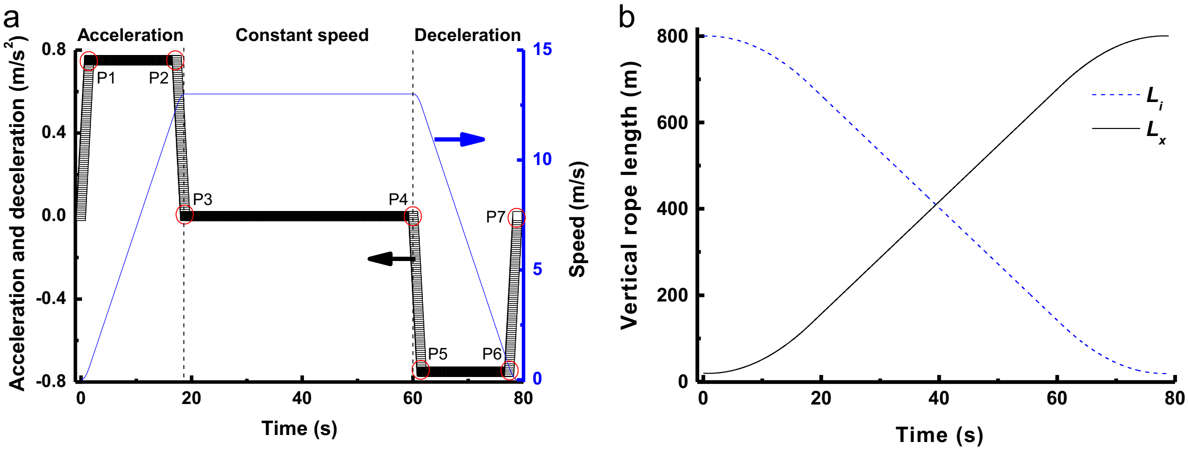
where E is the elastic modulus of hoisting rope, S denotes the sum of cross-sections of all wires in a rope, g is acceleration of gravity (9.8 m/s^2), a represents the acceleration and deceleration, m_1 and m_2 are the mass of a container filled with coal and the mass of an empty container, respectively, ρ is mass of a rope per unit meter, L_i and L_x are vertical rope lengths between containers and tangents of friction lining on both sides, respectively, and v is the hoisting speed. The Rayleigh–Ritz method [1] is employed to deal with the hoisting rope as shown in Eqs. (1) and (2).

The acceleration and deceleration, a, during hoisting can be given by [18]

$$a=\begin{cases} a_r t & 0<t\le t_1\\ a_c & t_1<t\le t_2\\ a_c-a_r(t-t_2) & t_2<t\le t_3\\ 0 & t_3<t\le t_4\\ -a_r(t-t_4) & t_4<t\le t_5\\ -a_c & t_5<t\le t_6\\ -a_c+a_r(t-t_6) & t_6<t\le t_7 \end{cases} \qquad (3)$$

Table 1
Hoisting parameters of a multi-rope friction hoist system.

Shaft parameters	Hoisting height (m)	781
	Derrick height (m)	25
Multi-rope friction hoist	Type	JKMD-5 × 4(III)
	Friction pulley diameter (m)	5
	Coefficient of friction between the rope and friction lining	0.25
	Wrap angle (deg)	180
Hoisting rope	Type	6V × 37S+FC
	Diameter (mm)	52
	Mass per unit meter (kg m^{-1})	11.3
	Ultimate strength (MPa)	1670
	Elastic modulus (MPa)	120,000
	Minimum breaking force (kN)	1700
	Number	4
Kinetic parameters	Mass of container (kg)	39,000
	Effective payload (kg)	28,000
Kinematic parameters	Maximum hoisting speed (m s^{-1})	13
	Acceleration and deceleration (m s^{-2})	0.75
	Change rates of acceleration and deceleration (m s^{-3})	0.5



Evolutions of acceleration, deceleration and speed

Evolutions of vertical rope lengths

Fig. 1. Motion curves (a) evolutions of acceleration, deceleration and speed and (b) evolutions of vertical rope lengths.