Study on characteristics of external load of transmission system for cutting unit of shearer under multiple load cases

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Received 31 March 2014, www.cmnt.lv

Abstract

To improve the accuracy of dynamics analysis, anti-fatigue design and reliability calculation of transmission system for cutting part of shearer, the accurate external load model of transmission system for cutting unit is required to be firstly built. In this study, the system dynamics model of cutting unit including drum, transmission system and motor is built, the impact of drum load and motor on external load of transmission system is comprehensively considered, and external load characteristics of transmission system during tilt and straight cutting of front and rear drums are studied, when the model is built, the impact of changes in the actual attack angle caused by the axial tilt angle on the cutting resistance is considered. The case analysis is conducted with this model, and the impact of changes in the actual attack angle caused by the axial tilt angle on the cutting resistance is mainly considered, the result shows that: during tilt cutting, the external load acting on the transmission system gradually increases and the fluctuation range also increases; while during straight cutting, the external load acting on the transmission system remains stable; the load of transmission system of front cutting unit is worse than that of transmission system of back cutting unit.

Keywords: Shearer; Transmission System; External Load; Multiple Load Cases

1 Introduction

Drum shearer is one of the main equipment of the fully-mechanized coal mining outfit which is widely used in large-scale coal mining. The cutting unit is one of the main operating mechanisms of drum shearer, including the motor, transmission system and drum. When the drum cuts coal-rock mass, the strength in homogeneity and brittleness caving of coal-rock mass as well as hard inclusions and rock intercalations make the load acting on transmission system features randomness, large fluctuations and strong impact, and the long transmission chain and many transmission components of transmission system for cutting unit make transmission system become a weak part of cutting unit [1]. Therefore, obtaining a more accurate external load of transmission system is of great significance to dynamics study, fatigue lifetime calculation and reliability of transmission system.

Firstly, the pick cutting resistance and drum load should be obtained to get the external load of cutting transmission system. The Former Soviet Union has done a lot of research on a single pick cutting load [2], but external load is mostly obtained based on knife pick, currently the point-attack pick is mostly adopted for the shearer. Evans proposed computational equation of cutting force for point-attack pick, but there are some shortcomings for this equation has [3]: when pick cone angle is zero, cutting resistance is not zero; cutting resistance is inversely proportional to tensile strength of coal-rock mass. Considering these shortcomings, Goktan proposed semi-empirical equation of cutting force based on experiment [3], and considered the effect of attack angle and pick - friction angle of coal-rock mass on cutting force. Liu Chunsheng, etc. also proposed mathematical model of cutting resistance based on experimental conditions of a single pick cutting [4]. The predecessors have done a lot of research on drum load simulation. Li Xiaohuo conducted simulation study of hard inclusion distribution in coal seam, which laid foundation for simulation of drum load under the actual working conditions [5]. Wang Hongying built mathematical model of point-attack pick stress based on coal and rock cutting experiments, and conducted computer simulation of drum load [6]. Subsequently, Li Xiaohuo, etc. studied instantaneous load of shearer drum [7].

There are the characteristic such as the randomness, major fluctuations and strong impact for load acting on drum, the drum cutting depth gradually increases especially during tilt cutting, but the discontinuity of picks arranged in cutting depth direction makes not only the step characteristics of drum load but also even worse of load acting on transmission system. Currently the shearer has no speed control of cutting motor, so it leads to significant impact of motor mechanical characteristics on external load of transmission system, and it is necessary to build a model of multi-mass system because of impact of motor rotor quality and rotational inertia [8], therefore, in this study, the impact of motor mechanical characteristics on external load of transmission system is considered.

In this study, the dynamics model of cutting unit including drum, transmission system and motor is built, the impact of drum load and motor on external load of transmission system is comprehensively considered, the external load of transmission system during tilt and straight cutting of front and rear drums is analysed, which not only provides the precise external load for the dynamics analysis of transmission system of the cutting unit, but also lays the foundation for dynamic analysis, anti-fatigue design and reliability calculation of transmission system of the cutting unit.

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2 Drum load model

2.1 AVERAGE CUTTING RESISTANCE OF A SINGLE PICK

In this study, a semi-empirical equation proposed by Goktan based on extensive experiments is selected to calculate the average cutting resistance of a single pick, which is as shown in equation (1), the impact of attack angle and pick-friction angle of coal-rock mass on cutting resistance is considered for the equation [3,9].

$$Z_m = \frac{4\pi\sigma_t h_m^2 \sin^2[0.5(90-\alpha)+\psi]}{\cos[0.5(90-\alpha)+\psi]}, \quad (1)$$

where, σt is tensile strength of coal-rock mass; ψ is pick-friction angle of coal-rock mass (°); α is cutting front angle (°), reflecting impact of attack angle γ on cutting resistance, as shown in Figure 1, β is back angle, 2θ is pick cone angle, Z is cutting force, Y is traction; hm is pick average cutting thickness, it's calculated according to equation (2) [10].

$$h_m = \frac{1-\cos\varphi_u}{\varphi_u}\frac{2\pi v_q}{wm}, \quad (2)$$

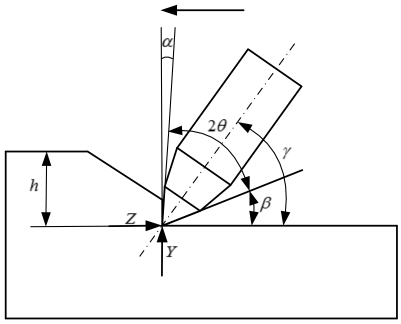

FIGURE 1 Cutting geometry of point-attack pick

Where, φu is surrounding angle of coal body to drum (rad), φu = π is for front drum, φu = arcos [(3Dd/2-H)/(Dd/2)] is for back drum, Dd is diameter of drum, H is thickness of coal seam, vq is pulling speed (m/s), m is number of pick installed on the same drum cutting line, ω is the angular speed of drum (rad/s).

Generally the picks with axial tilt installation on drum end plate make the actual attack angle of pick change, which is as shown in Figure 2, β0 is tangential installation angle, γ0 is nominal attack angle, γ is actual attack angle, β′0 is axial tilt angle, actual attack angle γ is calculated as equation (3).

$$\gamma = \arctan\sqrt{(\tan\gamma_0)^2 + \left(\frac{\tan\beta_0'}{\cos\gamma_0}\right)^2}, \quad (3)$$

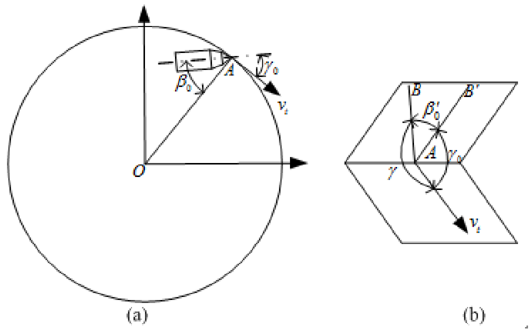

FIGURE 2 The Assembly Drawing of Point-attack Pick

2.2 DRUM LOAD

During cutting of coal-rock mass by the drum, the total load acting on drum can be considered to follow normal distribution [2], so drum load can be simulated with superposition of drum average load and random fluctuating load.

During tilt cutting of coal-rock mass by the drum, its cutting depth dc is variable, which is as shown in Figure 3, drum load makes step change due to discontinuity of picks arranged in drum axial direction. When drum cuts coal-rock mass straightly, its cutting depth remains the same, and average drum load is more stable.

During tilt cutting, average drum load Mdm is calculated as equation (4), during lj≤dc< lj+1:

$$M_{dm} = \sum_{i=1}^{j} Z_{mi} N_{cti}, \quad (4)$$

where, lj is the distance of the j-th cutting line from end face, Zmi is the average cutting load of pick on the i-th cutting line, Ncti is number of pick involving in cutting on the i-th cutting line, Ncti=0.5(φu/π)Nci, Nci is the total number of pick on the i-th cutting line, with cutting depth dc=∫vhdt sinδ, δ is tilt angle of shearer during tilt cutting.

During straight cutting, average drum load Mdm is calculated as the following equation (5),

$$M_{dm} = \sum_{i=1}^{N_{cl}} Z_{mi} N_{cti}, \quad (5)$$

where, Ncl is the total number of cutting line.

The main cause of drum load fluctuation is the following factors: structural factor making picks periodically contact with coal-rock mass, the factor can be evaluated with average load variable coefficient v1, its value range is v1=0.015~0.2; load fluctuations during one pick cutting can be evaluated with variable coefficient vp, vp = 0.5 ~ 1; changeability of anti-cutting strength in coal crushing area is described with variable coefficient vAi, its value is as literature; changeability caused by uneven traction speed is described with variable coefficient vΣz, its value is as literature [2].

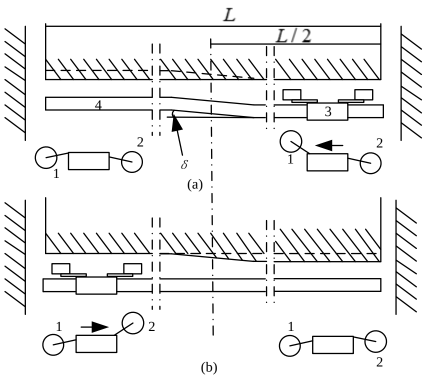

FIGURE 3 Mining by the Method of Inclined Cutting

The total variable coefficient vΣ of drum load is calculated as equation (6),

$$v_{\Sigma}^2 = v_1^2 + v_p^2 / N_{ct} + v_{Ai}^2 / N_{ct} + v_{\Sigma h}^2 \,, \tag{6}$$

where, Nct is the total number of pick involving in cutting.

Therefore, drum instantaneous load Md is:

$$M_d = M_{dm} + M_{dm} v_{\Sigma} randn \,, \tag{7}$$

where, randn is pseudo-random number that follows N (0, 1) distribution.

3 Mechanical characteristics of motor

Currently the shearer has no speed control of cutting motor, so as prime motor, the motor mechanical characteristics have significant impact on external load of transmission system [11], the output torque of changes in angular speed for three-phase asynchronous motor is as shown curve in Figure 4, A, B, C and D in Chart are the motor's maximum torque point, rated operating point, synchronous speed point and starting point respectively, AD segment is simulated with straight line, ABC segment is simulated with curve of second degree.

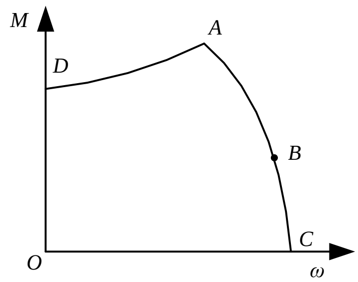

FIGURE 4 Mechanical Property of the Electromotor

4 System dynamics model of cutting unit

In this study, the system dynamics model of cutting unit including drum, transmission system and motor is built, the impact of drum load and motor on external load of transmission system is comprehensively considered, which is shown as Figure 5, its mathematical model is as equation (8),

$$\begin{cases} J_m \ddot{\theta}_m + c_{mt}(\dot{\theta}_m - \dot{\theta}_t) + k_{mt}(\theta_m - \theta_t) = M_m \\ J_t \ddot{\theta}_t - c_{mt}(\dot{\theta}_m - \dot{\theta}_t) - k_{mt}(\theta_m - \theta_t) \\ + \dfrac{c_{td}(\dfrac{\dot{\theta}_t}{i} - \dot{\theta}_d)}{i} + \dfrac{k_{td}(\dfrac{\theta_t}{i} - \theta_d)}{i} = 0 \\ J_d \ddot{\theta}_d - c_{td}(\dfrac{\dot{\theta}_t}{i} - \dot{\theta}_d) - k_{td}(\dfrac{\theta_t}{i} - \theta_d) = -M_d \end{cases} , \tag{8}$$

where, Jm, θm and Mm are rotational inertia of motor rotor, rotor angular displacement and motor driving torque respectively, Jt, θt and i are rotational inertia of transmission system converting at the input axis, input axis angular displacement and overall transmission ratio respectively, see the literature for Jt conversion method [12,13,14], Jd, θd and Md are drum rotational inertia, drum angular displacement and drum load respectively, km t and cmt are torsional stiffness and damping coefficient of connection unit for motor and transmission system respectively , ktd and ctd are torsional stiffness and damping coefficient of connection unit for motor and drum respectively.

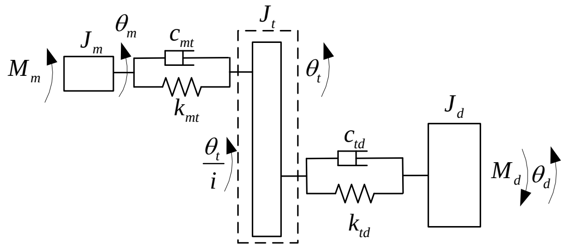

FIGURE 5 Dynamic Model of the Cutting Part

5 Case analysis

As for cutting unit of a certain type of shearer, its motor rated power is 300kW, synchronous speed of 1500r/min, rotor rotational inertia of 31.3657 kg·m2, transmission system gear ratio of 38.5, rotational inertia of 2.1345 kg·m2 after transmission system conversion, drum rotational inertia of 400 kg·m2, drum pick arrangement is as shown in Table 1, pick cone angle is 75 °, pulling speed during tilt cutting is 2m/min, pulling speed during straight cutting is 3m/min, with tilt angle δ = 2 °.

During tilt cutting of front drum, the load characteristics of transmission system are as shown in Figure 6, Figure 6.a and Figure 6.b are input and output torques of transmission system respectively. During tilt cutting of back drum, the load characteristics of transmission system are as shown in Figure 7, Figure 7.a and Figure 7.b are input and output torques of transmission system respectively. It can be seen from Figure 6 and Figure 7 that during tilt cutting, external load acting on transmission system gradually increases and fluctuation range also increases, because number of front drum pick involving in cutting is more than that of back drum, external load suffered by transmission system of front cutting unit is worse than that suffered by transmission system of back cutting unit.

TABLE 1 The Distribution of the Picks

	NO. of Cutting Line	Diameter of Pick (m)	Tangential Installation Angle (°)	Axial Tilt Angle (°)	Number of Pick	Distance between Cutting Line (m)
Drum End Plate	1	1.515	50	25	5	0
	2	1.53	50	20	4	0.01
	3	1.554	50	15	3	0.02
	4	1.575	50	10	3	0.03
Blade	5	1.59	50	0	3	0.1
	6	1.59	50	0	3	0.1
	7	1.59	50	0	3	0.1
	8	1.59	50	0	3	0.1
	9	1.59	50	0	3	0.1
	10	1.59	50	0	3	0.1
	11	1.59	50	0	3	0.1
	12	1.59	50	0	3	0.1

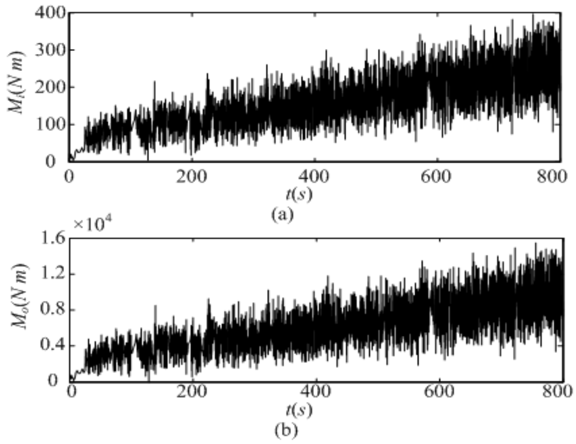

FIGURE 6 Load of transmission system when the front drum is cutting aslant

During straight cutting of front drum, the load characteristics of transmission system are as shown in Figure 8, Figure 8.a and Figure 8.b are input and output torques of transmission system respectively. During straight cutting of back drum, the load characteristics of transmission system are as shown in Figure 9, Figure 9.a and Figure 9.b are input and output torques of transmission system respectively. It can be seen from Figure 8 and Figure 9 that during straight cutting, because number of drum pick involving cutting is substantially constant, the mean value of external load acting on the transmission system also remains stable, because number of front drum pick involving in cutting is more than that of back drum, external load suffered by transmission system of front cutting unit is worse than that suffered by transmission system of back cutting unit.

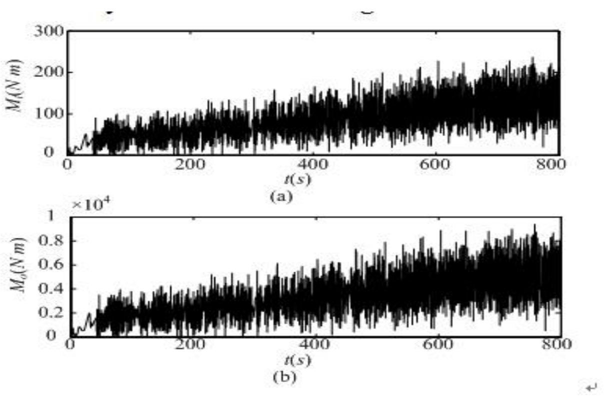

FIGURE 7 Load of transmission system when the back drum is cutting aslant

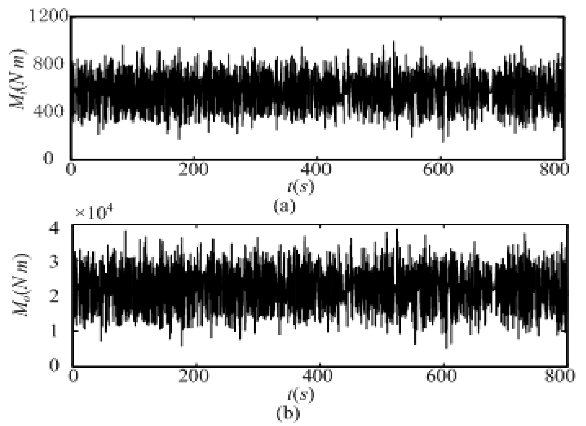

FIGURE 8 Load of transmission system when the front drum is cutting straightly

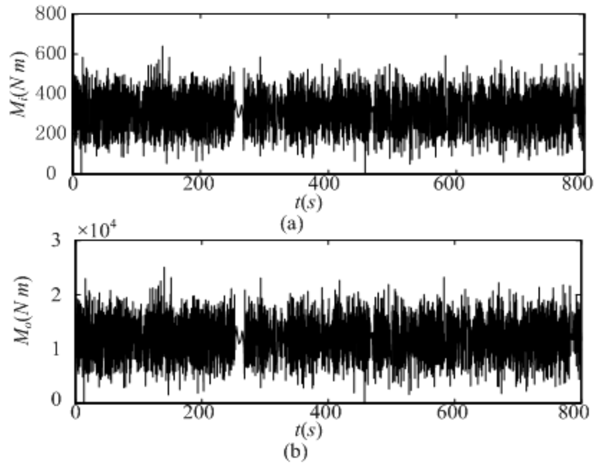

FIGURE 9 Load of transmission system when the back drum is cutting straightly

6 Conclusions

The external load characteristic of transmission system is obtained by establishment of dynamics model of cutting unit including drum, transmission system and motor. The impact of drum load and motor on external load of transmission system is comprehensively considered for this model. When the model is built, the impact of changes in the actual attack angle caused by the axial tilt angle on the cutting resistance is considered.

The external load on transmission system during tilt and straight cutting of front and back drums is analysed with the model, which provides the external load to establish a fine dynamics model of transmission system for cutting unit and lays the foundation for dynamics analysis, anti-fatigue design and reliability calculation of transmission system for cutting unit.

Both the external load acting on the transmission system and its fluctuation range gradually increase during tilt cutting,; while the external load acting on the transmission system remains stable during straight cutting; the load ratio of transmission system of front cutting unit is worse than that of transmission system of back cutting unit.

Acknowledgments

The authors would like to express thanks to those who helped in the research work and the preparation of this paper, and acknowledge the support from the State Key Lab of Mechanical Transmission, Chongqing University, China. This work was supported by the National Major Basic Research Program of China (973 Program, Grant no. 2014CB046304) and Scientific and Technological Research Program of Chongqing Municipal Education Commission (No. KJ1402903).

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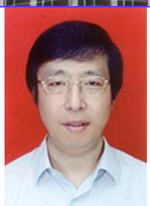

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