

Dynamic Analysis of Chain Drive System for Scraper Conveyor Based on Amesim

Yanqing Hu*, Qingliang Zeng, Shoubo Jiang, Pengfei Yu and Zhikuan Yang

College of Mechanical and Electronic Engineering Shandong University of Science and Technology Qingdao, China

*Corresponding author e-mail: 799337130@qq.com

Abstract. According to the characteristic of the polygon effect in chain drive system for mining scraper conveyor, the dynamic analysis of chain drive system for scraper conveyor has been studied based on Kelvin-vogit model. Firstly, the Kelvin-vogit model which can withstand tension nor pressure has been established, and considering the polygon effect in chain drive system, the velocity signal based on the number of sprocket teeth is added to the driving sprocket. Then, the dynamic analysis is carried out for the whole model. The line velocity of the active sprocket and the velocities of four special concentrated masses are obtained. At the same time, the tensions of the four special concentrated masses are also obtained. It can be seen from the analysis results that chain model is subjected to one-side force, which is unachievable by the unprocessed Kelvin-vogit model. Meanwhile, it is verified that the polygonal effect has great influence on chain drive system's dynamics and cannot be simply ignored. This paper would provide some references on the design and analysis of scraper conveyor.

1. Introduction

As the only transportation equipment in long wall fully mechanized coal mining face, scraper conveyor is faced with complicated and changeable working condition and loading, so it is crucial to operate safely and reliably [1]. It is impossible to make a better description of operation state for scraper conveyor through the common static analysis, so it is necessary for scraper conveyor to carry out dynamic analysis. Chain drive system, as the core of scraper conveyor, is an important factor that affects the normal operation of scraper conveyor. Therefore, the dynamic analysis for scraper conveyor is focused on the analysis of chain drive system. While, sprocket and ring chains are the key parts of scraper conveyor [2], the analysis of chain drive system is based on sprocket and chain ring.

At present, the finite element method is widely used in dynamic analysis of chain drive system, and there has a lot of software for dynamic analysis based on finite element, such as Adams, RecurDyn, etc. These software have the advantage of high computing precision, however, when it comes to the special working environment of scraper conveyor, there will be large redundancy in accuracy and waste of computation resources as well. There are few studies on the analysis directly using Kelvin-vogit model. Professor MAO Jun [3] built a dynamic model of scraper conveyor based on Kelvin-vogit model in his doctoral dissertation. YANG Zheyong ECT [4] studied the working condition of scraper conveyor based on AMESim, but its AMESim implementation has not been explained



systematically in his paper. YANG Jianjian ECT [5] made analysis on the starting characteristics of scraper conveyor using AMESim. The theory in these papers is better, while, the simulation research is not completely enough, that is, the chain is only simplified as a viscoelastic model when it is analyzed, but it does not take into account the condition that the chains are only subjected to tension but not pressure. Moreover, the factor of the polygon effect for the chain drive system is not considered when the displacement signal is loaded into the model. It can be said that those models used in the above papers differ greatly from the actual situation, and it is difficult to meet the need of dynamic analysis of scraper conveyor. Therefore, in order to get closer to reality, systematic research has been carried out based on AMESim software for scraper conveyor in this paper.

2. Analysis of the transport capacity for scraper conveyor

Analysis based on a certain type of scraper conveyor has been done in this paper. The main parameters of this type of scraper conveyor are shown in Table 1.

Table 1. The main parameters of a certain type scraper conveyor

Name	Value	Name	Value
Quantity of shipping/ (T/h)	40	Rated revolution/(r/min)	1470
Length/ (m)	80	Size of ring /(mm)	Φ14*50
Speed of chain/ (m/s)	0.59	Reduction speed ratio	24.95

Parameters setting can't be completed only by the above parameters. Therefore, it is necessary to carry out some theoretical analysis. These analysis processes are as follows.

2.1. Analysis of running resistance

Line density of loading for scraper conveyor q is:

$$q = \frac{Q}{v} \quad (1)$$

Where, Q is quantity of shipments, v is chain speed of scraper conveyor.

According to the GB/T12718-2001 "High-strength chain ring for mining" [6], per unit length mass for the type of Φ14*50 is 4.0kg/m.

The running resistance of loading section for the scraper conveyor W_{zh} and the running resistance of unloading for the scraper conveyor W_k are as follows [7]:

$$W_{zh} = (q\omega + q_0\omega_0)Lg\cos\beta \pm (q + q_0)L\sin\beta \quad (2)$$

$$W_k = q_0Lg(\omega_0\cos\beta \mp \sin\beta) \quad (3)$$

Where, ω is friction coefficient between cargos and the middle grooves, and it is set as 0.5 in this paper; ω_0 is friction coefficient between chain and the middle grooves, and ω_0 is set as 0.33 in this paper; g is gravity acceleration, and it is set as 9.81kg/m² in this paper; L is the length of scraper conveyor; β is laying angle of the scraper conveyor, and it is set as 0°; "± / ∓" depends on the running direction of the scraper conveyor-uplink/downlink.

2.2. Preload analysis [8]

In order to limit pendency of scraper conveyor and ensure the smooth operation of the chain and the sprocket, the preload should be reasonably set for chain before the scraper conveyor is installed. And for the scraper conveyor studied in this paper, the tension of the minimum tension point of the chain

should take 2000N~3000N, this paper is taken as 2500N. Schematic diagram of the driving arrangement of the scraper conveyor is shown in Figure 1. Since the chain tension gradually increases from the separation point of the chain and the driving sprocket in the running direction of the chain, the tension at point 1 is the smallest, and the maximum tension is at point 4. Specifically, the tension at each point is expressed as follows:

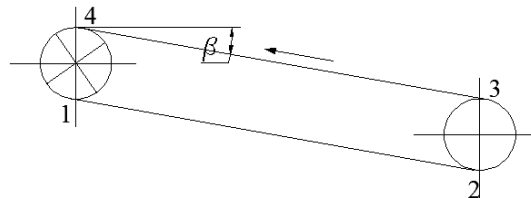


Figure 1. Schematic diagram of the driving arrangement of the scraper conveyor

$$\begin{aligned}
 S_1 &= S_{\min} \\
 S_2 &= S_1 + W_k \\
 S_3 &= S_2 + (0.05 \sim 0.07)S_1 \\
 S_4 &= S_3 + W_{zh}
 \end{aligned} \tag{4}$$

Preload of chain can be obtained through the following equation:

$$T = \frac{1}{4}(S_1 + S_2 + S_3 + S_4) + Lq_0g\omega_0\cos\beta \tag{5}$$

Assuming that each chain ring has a nominal length of L_1 and the whole chain has been divided into $2n$ discrete unit. Then, the number of chain rings contained in each discrete unit at the loaded side or unloaded side is as follows [9]:

$$n_0 = \frac{L}{nL_1} \tag{6}$$

According to the empirical formula, the stiffness coefficient of each discrete unit of the loaded chain or the unloaded chain is shown as follows:

$$k_i = \frac{k_0}{n_0} \tag{7}$$

Where, k_0 is the stiffness coefficient of chain ring, and it is equal to 1.27×10^9 N/m.

The mass of discrete chain unit is shown as follows:

$$m_0 = \frac{2Lq_0}{2n} \tag{8}$$

The mass of discrete unit composed of scraper chains and cargos is shown as follows:

$$m_1 = \frac{L(q_0 + q)}{n} \tag{9}$$

3. Modeling of chain drive system based on AMESim

3.1. Modeling of chain

Taking the chain of scraper conveyor as a viscoelastic element, the contact state between chains rings can be described accurately using the Vogit model [10]. The Vogit model is shown in Figure 2. Considering that pressure cannot be applied to chain in reality, the Vogit model of AMESim is shown as Figure 3.

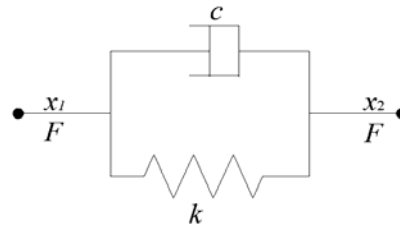


Figure 2. The model of Vogit

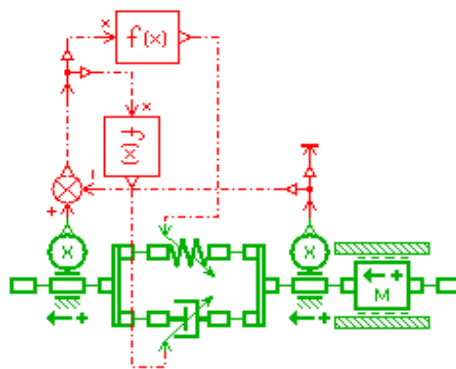


Figure 3. The Vogit model of chain in AMESim environment

Where, the preload of the chain is applied by setting the initial displacement of spring module. The spring stiffness and damping coefficient of the chain, while, are set to the piecewise function, and the function is ' $0*(x \leq z) + K*(x > z)$ '. In this function, x represents relative displacement; z represents the initial displacement of the spring caused by the preload; K refers to spring stiffness of the chain when it is pulled. When the relative displacement of the chain is not enough to offset the initial displacement of the spring, the spring stiffness is set to zero, while, the relative displacement of the chain is larger than the spring initial displacement, the spring stiffness is set to the non-zero value, that is, K . The damping coefficient is also set in this way.

3.2. Modeling of chain motion signal

The chain drive system is driven by motor through a coupling to drive the reducer and then to drive the sprocket shaft. The motion signal model of chain drive system for this scraper conveyor is shown as Figure 4, in which the coupling is described by the rotating spring and the rotational damping, and the output end of reducer and the input end of the sprocket are connected through angular velocity signal and torque signal, that is, the speed signal of the reducer output end is transmitted to the sprocket, and the torque of the sprocket is transmitted back to the output end of the reducer. Meanwhile, in order to simulate the polygon effect, the angular velocity of the output end for the reducer is transformed into a periodic signal through function module. And the function is ' $x*\cos(y-\pi/3*\text{round}(3*y/\pi))$ ', where x refers to angular velocity, y refers to angular displacement, both x and y are in radians, ' $y-\pi/3*\text{round}(3*y/\pi)$ ' makes the angular always in the interval of $0 \sim \pi/3$.

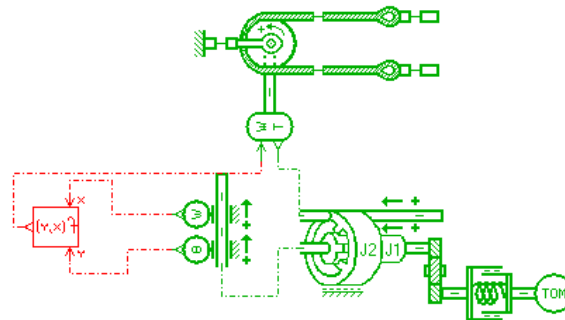


Figure 4. The motion signal model of chain drive system

3.3. Modeling of chain drive system

The number of discrete units has been set to 10 in this paper. And considering that the scraper conveyor is a single drive, the motion signal shown in Figure 4 is only added to the left sprocket. At the same time, the polygon effect of the right sprocket is ignored to reduce the complexity of the whole model. Then, the Vogit models of the loaded side and the unloaded side are connected and integrated with the sprocket module. Finally, the whole model is obtained. For the convenience of the following description, some tags are added to the model. Among them, the discrete unit separating from the active sprocket is marked as 1, the discrete unit engaging with the driven sprocket is labeled as 2, the discrete unit separating from the driven sprocket is marked as 3, the discrete unit engaging with the active sprocket is labeled as 4, and the active sprocket is marked as 5. The whole model is shown as Figure 5.

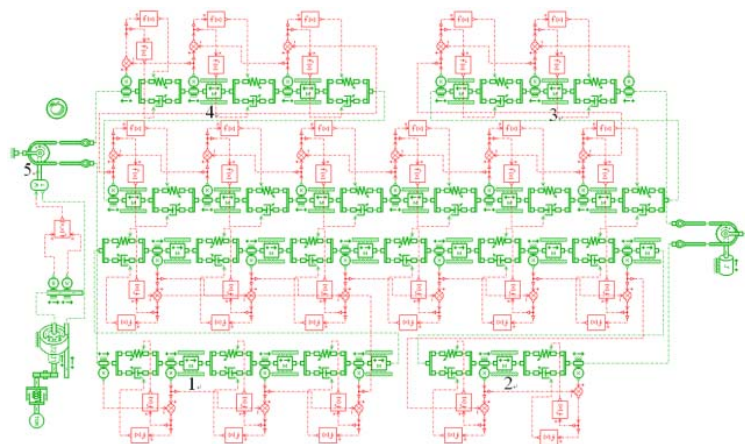


Figure 5. The whole model of chain drive system

4. Simulation results and analysis

The parameters which should be set to the model can be obtained from Table 1 and theoretical calculation. After setting the model parameters, the simulation time and print interval should be set reasonably. After that, the model is simulated and simulation results can be obtained. Considering that there are many discrete units in the model, it is not suitable to analyze them one by one. Therefore, only the discrete units which are marked are analyzed.

The velocity of each marked discrete unit changes with time is shown in Figure 6. From the Figure, it can be concluded that the sprocket linear velocity is a periodic signal, which proves the accuracy of motion signal. This is because the output motion signal of the reducer has been converted into a periodic signal to simulate the polygon effect of the chain drive system, and this also proves the

accuracy of the motion signal added to sprocket. With the movement of the sprocket, the velocity of 1 discrete unit rises rapidly and presents an obvious fluctuation with a certain lag. Its value is not significantly different from the sprocket line speed when it reaches a steady state. This is mainly because the discrete unit 1 is closer to the active sprocket, the speed of this point is almost the same as the active sprocket at the steady state. While, in the beginning, the unloaded side chain is relaxed immediately with the start of the scraper conveyor, and the discrete unit 1 is quickly approached to the middle of the chain under the preload; then, due to the large static friction on the loaded side, the driving force of the sprocket for the chain cannot be immediately passed to there, the velocity of this discrete unit is slowed down after a certain displacement until the sprocket driving force is sequentially transmitted to there, and then a wave occurs.

From Figure 6, the velocity changes of marked point 2 can be obtained. The velocity of this point decreases slightly to a negative value at the beginning, and then a wave occurs. After a moment of stability, it rises again and reaches a maximum value. Its velocity fluctuates greatly and lags behind the sprocket generally under steady state. This is because the unloaded side is relaxed when the scraper conveyor starts to move, and chain is retracted toward the middle of the chain under the preload. The direction of movement in point 2 is opposite to the overall movement direction of the chain at this moment. And then the driving force of the sprocket is transmitted to there, the mass overcomes the frictional force and produces a speed fluctuation. Meanwhile, the unloaded side chain begins to be stretched and moves accordingly. Due to the viscoelastic effect of the chain, the velocity fluctuation at this point away from the drive sprocket is much larger than velocity fluctuation at sprocket under steady state. And its velocity lags behind the sprocket generally under steady state.

The velocity of point 3 is generally similar to the velocity of point 2. The velocity of the point 3 is zero at the beginning. And then it steadily increases to the maximum which is slightly less than the maximum at 2. But the velocity amplitude of the point 3 is slightly larger than the velocity of the point 2 under the steady state. The zero value at the beginning is mainly caused by the static friction of the chain. Subsequently, the transmission of the driving force to the sprocket causes a velocity fluctuation, which makes the velocity fluctuation of the point 2 greater than the velocity fluctuation of the point 3. However, due to the velocity change trend of point 2 is reduced by the inertia of driven sprocket under the steady state, the velocity fluctuation of the point 2 is less than the velocity fluctuation of the point 3. Point 4 is close to driving sprocket and directly affected by the velocity of the driving sprocket. The velocity of this point is consistent with the velocity of the driving sprocket. However, it is inevitable that small speed fluctuation occurs at start-up phase. The movement of this point has a slight lag behind the driving sprocket in steady state, which is caused by the elastic energy storage of the chain.

The tension of each point of the chain is shown in Figure 7. From the figure, it can be concluded that the initial tension at each point is the set value of the chain preload, and then the tension of the point 1 and the point 2 located on the unloaded side is reduced causing that the chain rings of the unloaded side are relaxed. During the start-up process, the tension of the point 1 is zero for a while, which is likely to cause excessive loosening of the chain during actual production, resulting in accidents such as blocking of chain and jumping of chain. The maximum tension at point 4 is almost 2 times that of the average in the stable condition at the starting stage. Although the elastic coupling is used in the scraper conveyor to relieve the tension of the chain, the changes of tension cannot be ignored. It can be clearly seen that the point 4 tension is the largest, the tension of point 3 is smaller than the point 4, the tension of point 2 is smaller than the tension of point 3, and the tension of point 1 is the minimum at the steady state, which is in accordance with the actual situation. Moreover, it can be clearly seen from the Figure that the polygon effect of chain transmission is more significant to the fluctuation of chain tension as well, and the fatigue failure of the chain is easily caused by the fluctuating load. The influence of dynamic load is often ignored in classical method of analysis, which is not rigorous and unwise.

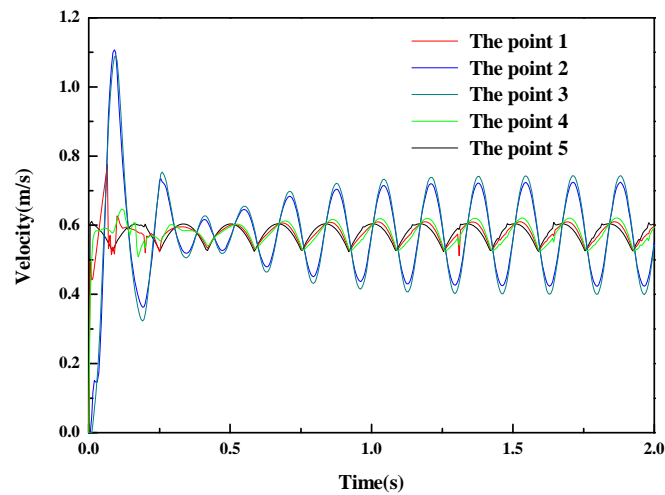


Figure 6. The velocity of each marked discrete uni

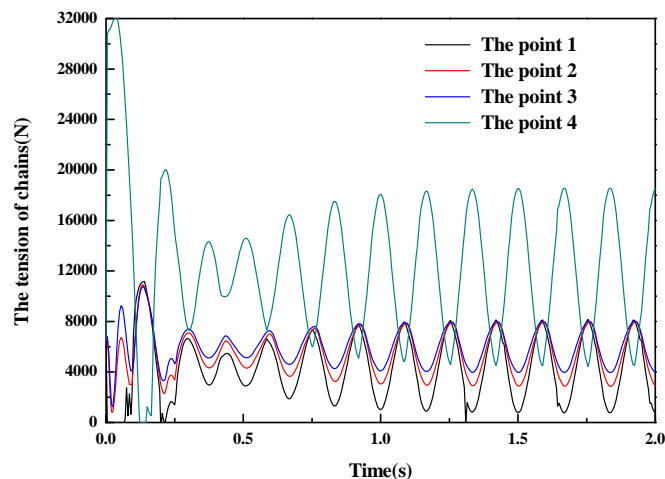


Figure 7. The tension of each marked discrete unit

5. Conclusion

Considering the complex dynamic situation of chain transmission system of scraper conveyor, it is difficult to get a relatively real situation by the conventional method. In addition, professional dynamics analysis software often has some unnecessary computation redundancy and time-consuming. The AMESim model that can withstand tension and cannot withstand pressure is applied to the dynamic analysis of the scraper conveyor. The characteristic that can withstand tension and cannot withstand pressure is consistent with actual situation of the chain and is neglected in the models involved in previous papers. In addition, adding a speed signal to the whole model according to the principle of polygon effect can reflect the movement of the scraper conveyor realistically. Through the analysis of the simulation results, it can be found that the polygon effect has a significant influence on the speed fluctuation and tension changes of the chain drive system, which cannot be simply ignored. The model built in this paper not only has certain value for the follow-up research of the scraper conveyor, but also has certain reference significance for other chain drive systems.

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