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DYNAMIC PROPERTIES OF CHAIN DRIVE SYSTEM CONSIDERING MULTIPLE IMPACT FACTORS

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Abstract
Chain drive system is the core subsystem of scraper conveyor. It is affected by the impact load caused by large coal when working, thereby seriously affecting its operation stability. A simulation model of the chain drive system is established by using joint simulation, and simulation scheme are introduced. The dynamic properties of chain drive system under three working conditions of different lumps and different heights of large coal and large coal impacting on different positions in the middle groove are simulated. Results show that when the chain ring is impacted, the vibration amplitude of the impacted chain is positively correlated with the lumpiness of the large coal, and the longitudinal vibration is the main reason for the failure of the chain drive system. With the increase in the impact height of large coal, the longitudinal vibration growth rate of the regional chain in front of the impacted chain is greater than that of the regional chain in rear. Under different position conditions, the stability of the chain drive system is greatly affected when the chain ring in the no load area is impacted. This study provides a reference for the theoretical study of the dynamic properties of chain drive system.
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Key Words: Scraper Conveyor, Dynamic Property, Impact Load, Joint Simulation

1. INTRODUCTION

Scraper conveyor is the only coal transportation equipment in longwall fully mechanized mining face. The scattered coal cut off from the coal wall by the shearer is transported from the working surface [1-3]. Chain drive system is the core subsystem of scraper conveyor, which is composed of front and rear sprockets, several scrapers, and chain rings. Chain drive system has been in contact with scattered coal at work and is one of the subsystems prone to failure on scraper conveyor.

The chain drive system is naturally affected by the impact load during operation due to the inherent properties of its polygonal effect [4]. The chain drive system is frequently affected by the irregular impact load in the operation process because the coal cutting by shearer is a nonlinear and time-varying load, thereby significantly affecting the dynamic properties of the chain drive system. In severe cases, the chain jam or chain break accidents occur [5]. The experimental space and cost are high due to the structural characteristics of scraper conveyor. Thus, performing large-scale impact characteristic experiments is unsuitable. Collecting the sensor signal is difficult due to the bad mining environment in coal mine, especially under the impact load condition, which has a high risk coefficient. Multibody dynamics software cannot simulate the real coal transportation process, and discrete element software cannot generate the complex motion process of the chain drive system. Therefore, a single simulation software cannot reflect the real dynamic properties of the chain drive system. Studying the dynamic properties of the chain drive system by using a variety of numerical simulation methods is necessary to simulate the real impact conditions.

This study adopts Adams-EDEM joint simulation to study the dynamic properties of the chain drive system of scraper conveyor under impact load. This method can simulate the real coal transportation process of scraper conveyor in the mine and obtain the dynamic response signal of chain drive system that is difficult to obtain by simulation. The dynamic properties of chain drive system under impact load and different working conditions are analysed and explored. This research is of great importance to improve the overall reliability and optimize the design of chain drive system.

2. STATE OF THE ART

Chain drive system is the core subsystem of scraper conveyor, and its dynamic properties determine the efficiency of coal transportation. Some scholars have observed and investigated the dynamic properties of chain drive system under normal working conditions. Zhuang et al. [6] found that the tension of the scraper chain can be effectively detected by monitoring the speed difference between the head and tail sprockets and the suspension of the scraper. Wang et al. [7] studied the crack initiation characteristics of the scraper chain by time-varying dynamic analysis method, obtained the dynamic tension of the scraper chain, and predicted the crack initiation life of the chain ring on the basis of multiaxial fatigue theory. Some scholars have explored the dynamic properties of abnormal conditions. Jiang et al. [8] studied the dynamic characteristics of scraper conveyor under abnormal working conditions by combining experiment and simulation. The acceleration of the scraper chain suddenly changes when the chain is broken. Zhang et al. [9] explored the influence of temperature on energy dissipation characteristics under different working conditions and found that temperature has minimal effect on the minimum steady-state stress. When the load suddenly changes, the plastic energy dissipation and internal energy increase with the load stabilizing. The above scholars ignored the contact effect between scattered coal and scattered coal, and between scattered coal and scraper conveyor structure when establishing the simulation model of scraper conveyor. The chain drive system under real working conditions is a nonlinear, time-varying, and strong coupling system composed of coal-scraper-chain-middle groove structure and discrete body. Therefore, the above method can still be improved in the reduction of real working conditions. The motion of the chain drive system is extremely complex at work, and simulating the real working environment through a single finite element, discrete element, and other simulation methods is difficult.

On the basis of the above difficulties, some scholars have obtained the dynamic properties of scraper conveyor by multisoftware co-simulation or building a test bench. Ren et al. [10] studied the dynamic properties of scraper conveyor under partial load and variable load by Adams-EDEM co-simulation method. Wang et al. [11] proposed a new method for the joint simulation of multibody dynamics by combining discrete element method and finite element method. This method solves the problem that the response data between scraper chain and bulk coal cannot be obtained when the scraper chain is stuck or broken. It provides a reference for the simulation and failure mechanism of scraper conveyor. Zhang et al. [12] established a scraper conveyor model by multibody dynamics and discrete element co-simulation, and studied the interaction between the scattered coal and scraper conveyor components. The results show that the coal particles stuck between the scraper and the vertical ring will have a strong interaction with the rigid parts of the scraper machine. The above scholars simulate the real working condition of scraper conveyor by joint simulation and fully utilized the advantages of each software. Some scholars have restored the working conditions of scraper conveyor under the mine by building a test bench. Jiang et al. [13] estimated the running state by building a test bench to detect the speed difference between the head and tail sprockets of the scraper conveyor under different chain speeds, terrains, and loads. Zhang et al. [14] analysed the vibration properties of the middle groove of the scraper conveyor and conducted fault diagnosis of the scraper chain by monitoring the vibration at different positions in the middle groove. Wojnar et al. [15] studied the dynamic properties of the scraper conveyor reducer through experiments and determined five positions on the reducer shell to describe the vibration of the reducer gear. Studying the dynamic properties of scraper conveyor by joint simulation or test bench is an effective method. However, the structure of scraper conveyor is special, and its working distance is usually more than 100 m. The above scholars often ignored the dynamic behaviour differences of scraper conveyor at different operating positions under different impact factors when they studied its dynamic properties under different working conditions. The dynamic properties of scrapers or chain rings at different positions are relatively different, especially when they are subjected to impact loads. Therefore, studying the dynamic behaviour of scraper conveyor at different operating positions under different impact factors is necessary.

Some scholars have improved the dynamic properties of chain drive system from the perspective of optimization design. To improve the reliability of the scraper, Zhang et al. [16] used Ansys and SolidWorks to establish a 3D model of the scraper and optimized it. The designed reinforcement can effectively improve the mechanical properties of the scraper and increase its service life. Some scholars have optimized and improved the motor drive mode. Shprekher et al. [17, 18] analysed the dynamic properties of the motor of dual-drive scraper conveyor and found that the motor load is uneven when two motors were driven by one inverter. Therefore, the drive mode of the motor is optimized, and a drive mode that can automatically balance the load of two motors is proposed, and its feasibility is verified on Matlab/Simulink. Subsequently, a simulation model of dual-drive scraper conveyor is built on Matlab/Simulink. The results show that the optimized simulation model can effectively improve the simulation speed and the accuracy is within the error range. To improve the start-up properties of scraper conveyor, Li et al. [19] optimized the motor start-up mode based on the analysis of the influence of start-up time, load value, and rotational inertia on the soft start-up characteristics, and established a two-parameter control model that can control the soft start-up time, which can greatly improve the start-up properties of the motor. The above research can effectively improve the reliability and intelligence of scraper conveyor. However, it focuses on the stable working condition of scraper conveyor. For the impact condition, the existing research ignores the difference in the dynamic properties of the chain drive system that is different from the stable condition under different impact heights and lumps.

When the scraper conveyor is working, the chain drive system is always in contact with the middle groove, and considerable friction occurs. Therefore, some scholars have investigated the dynamic properties of the scraper conveyor from the perspective of tribology. To study the wear properties of the middle groove, Xia et al. [20] established a coal-central groove simulation analysis model by using the discrete element method and explored the wear situation under different working conditions. The results show that the higher the coal gangue content, the greater the coal particles, and the more serious the wear of the central groove. Li et al. [21] established a discrete element model of the middle trough blanking area by using the discrete element method and investigated the mechanical and impact wear properties of the scraper conveyor when the chain pitch and scraper pitch were different. This study provides theoretical guidance for the improvement of the middle groove and mechanical analysis. The above scholars used the discrete element method to simulate the coal particles more realistically, but ignored that the chain drive system is a complex multibody dynamics system, without considering the force between the chains. Ma et al. [22] established a friction simulation model of the middle groove by using the joint simulation of discrete element and multibody dynamics. The wear of the middle groove is mainly caused by three-body wear on the basis of the analysis of the stress change in the scraper, the wear form of the middle groove, and the operation condition of the scraper conveyor. The above scholars studied and optimized the wear properties of scraper conveyor through joint simulation and experiment. However, the difference in wear properties of the middle groove at different positions of the fully mechanized working face is ignored.

This study uses the multibody dynamics-discrete element method to simulate the dynamic properties of scraper conveyor under impact load. The influence on chain drive system is studied by simulating the impact of large coal on different regions of the middle groove and changing the lumpiness and impact height of large coal. The acceleration of the chain ring and the scraper on two sides of the chain ring are used for numerical analysis. This research is of great importance to the optimization design of chain drive system.

The rest of this article is organized as follows. Section 3 introduces the simulation model and contact model, as well as the simulation variables and schemes. Section 4 conducts the simulation analysis on three types of working conditions, namely, the lump coal impact to the different positions of the middle groove, changing the lump coal block and falling height, and studying the chain and scraper acceleration change rule. Section 5 provides the conclusions.

3. METHODOLOGY

3.1 Contact model

The contact model is an important factor to determine whether the simulation results are accurate. This study involves severe impact collision problems, the Hertz–Mindlin (no slip) model is extremely suitable for the calculation of collision problems. Therefore, this contact model is adopted between coal particles, coal particles, and geometric entities [10]. Assuming that the contact between two spheres with radii R_1 and R_2 is elastic contact. The normal force between particles can be obtained by using Eq. (1):

$$F_n = \frac{4}{3} E^* \sqrt{R^* \alpha^3} \tag{1}$$

where, E^* is equivalent Young's modulus, [Pa]; R^* is equivalent particle radius, [m]; α is normal overlap, [m]. α can be obtained by using Eq. (2):

$$\alpha = R_1 + R_2 - | r_1 - r_2 | \tag{2}$$

where r_1 is position vector of the sphere centre of particle 1; r_2 is position vector of the sphere centre of particle 2.

The normal damping force between particles can be obtained by using Eq. (3):

$$F_n^d = -2\sqrt{\frac{5}{6}} \beta \sqrt{S_n m^*} v_n^{rel} \tag{3}$$

where, β is coefficient related to recovery coefficient; S_n is normal stiffness, [n/m]; m^* is equivalent mass, [kg]; v_n^{rel} is normal component of relative velocity, [m/s].

The shear force between particles can be obtained by using Eq. (4):

$$F_t = -S_t \delta \tag{4}$$

where, S_t is shear stiffness, [n/m]; δ is shear overlap, [m].

The shear damping force between particles can be obtained by using Eq. (5):

$$F_t^d = -2\sqrt{\frac{5}{6}} \beta \sqrt{S_t m^*} v_t^{rel} \tag{5}$$

where, β is coefficient related to recovery coefficient; S_t is shear stiffness, [n/m]; m^* is equivalent mass, [kg]; v_n^{rel} is shear component of relative velocity, [m/s].

3.2 Adams-EDEM joint simulation model

In this study, the chain drive system is reasonably and necessary simplified, and its simulation model is established on the basis of the real scraper conveyor. The model includes main and driven sprockets, 10 scrapers, 120 chain rings, and middle grooves. A bottom plate is added to the model to ensure the stability of the chain ring at operation. This process is performed because the chain ring under the middle groove will droop under the action of gravity during the operation of the model. The Adams-EDEM co-simulation method is used to establish a virtual prototype and simulate the real coal transportation environment more realistically. In Adams, the motion simulation of the scraper conveyor is completed. In EDEM, the coal particles are generated by adding a particle factory to complete the load loading.

The simulation model is shown in Fig. 1. Particle factory 1 is used to generate the scattered coal cut by the shearer from the coal wall to simulate the real coal conveying environment. Particle factory 2 is used to produce large coal to achieve impact on the chain ring. The shapes of bulk coal and large coal are composed of four circular particles. The operation direction of scraper conveyor is X direction, the direction perpendicular to the middle groove is Y direction, that is, longitudinal direction, and the direction perpendicular to X and Y directions is Z direction.

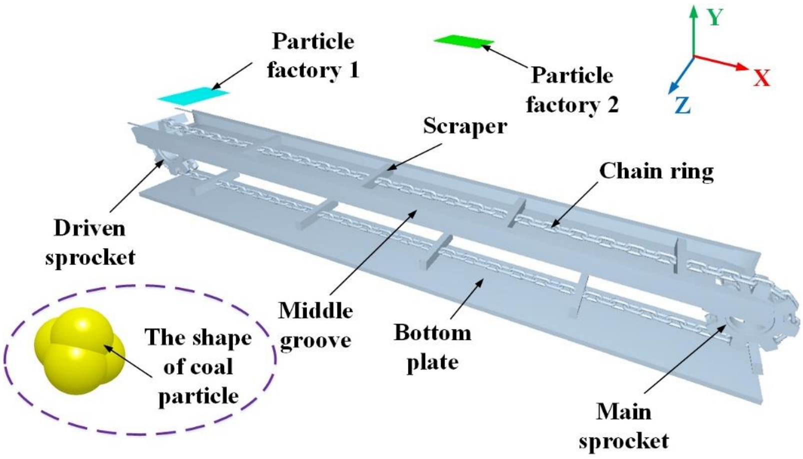


Figure 1: Schematic of simulation model.

3.3 Simulation scheme

When working, the shearer drum dumps the cut scattered coal to the scraper conveyor, which then carries the scattered coal away, and the position relationship diagram is shown in Fig. 2. Taking the shearer drum as the dividing point, the middle grooves can be divided into unloaded area and coal transportation area. The adjacent two scrapers and the chain rings between them are defined as a chain ring group, as shown in Fig. 3. The chain drive system can be considered to be composed of multiple chain ring groups, and in the direction of operation, the rear scraper is scraper 1, the front scraper is scraper 2. The area between scraper 2 and large coal is the front area, and the area between scraper 1 and large coal is the rear area.

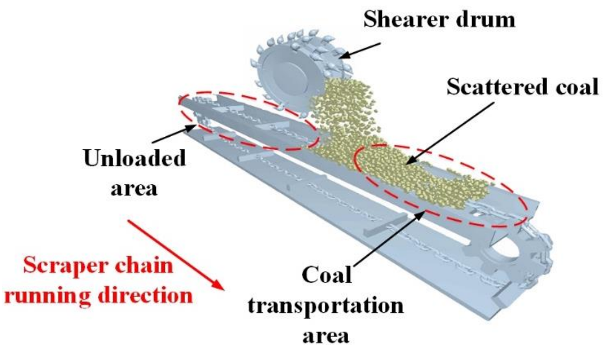


Figure 2: Diagram of the relative relationship.

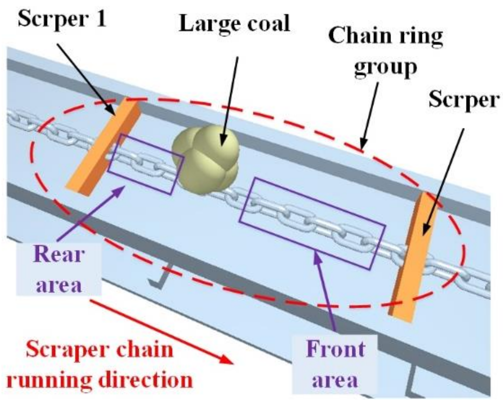


Figure 3: Chain ring group.

In this study, the dynamic characteristics of large coal impacting on the chain drive system are investigated by controlling a single variable. The controlled variables are shown in Table I. Considering the efficiency of simulation, the middle groove length of the model is 6 m. Considering the accuracy of the simulation results, unloaded area and coal transportation area cannot occur simultaneously in one simulation. The length of the two areas in the simulation model is extremely short to simulate the real coal transportation area and the unloaded area, so the two areas are simulated separately. When simulating the unloaded area, particle factory 1 does not produce scattered coal particles, and only particle factory 2 produces large coal to simulate impact load. Large coal impact is generated to the middle position of chain ring group through continuous simulation debugging. When simulating the coal transportation area, particle factory 1 produces the scattered coal particles at the speed of 100 kg/s to simulate the scattered coal cut by the shearer, and the chain speed is 0.8 m/s. Particle factory 2 generates large coal to simulate the impact load. Different simulation impact conditions are simulated by adjusting the position of particle factory 2.

Table I: Simulation variables.

Lumpiness (kg)	**Height** (m)	**Position**
20, 30, 40, 50	1, 1.5, 2, 2.5, 3	Chain ring of unloaded area Chain ring of coal transportation area Coal piles

4. RESULTS AND DISCUSSION

4.1 Variable lump condition

The chain drive system is simulated by using 20, 30, 40 and 50 kg of large coal. The impact height is 1.5 m, and the impact position is the chain ring in the unloaded area. When the chain ring is impacted by 20 and 40 kg large coal, the change in 3D acceleration of the chain ring is shown in Fig. 4.

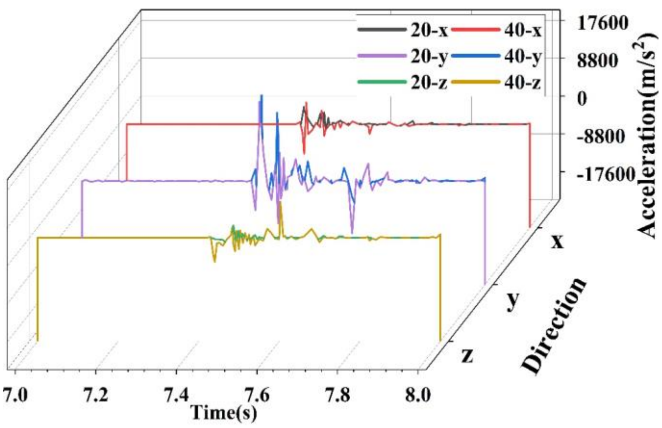


Figure 4: Changes in chain ring acceleration.

As shown in Fig. 4, the 3D acceleration of the chain is zero when the chain ring is not subjected to the impact load, indicating that the chain ring runs smoothly and the simulation model meets the requirements. When the chain ring is affected by the impact load, the chain ring vibrates violently, which is likely to cause chain deformation, even chain clamping, chain breaking, and other faults. When the lump of large coal enlarges, the amplitude increases accordingly. When the large coals with different lumps impact the chain ring, the standard deviation of the acceleration of the chain ring is analysed to study the stability of the chain, as shown in Fig. 5.

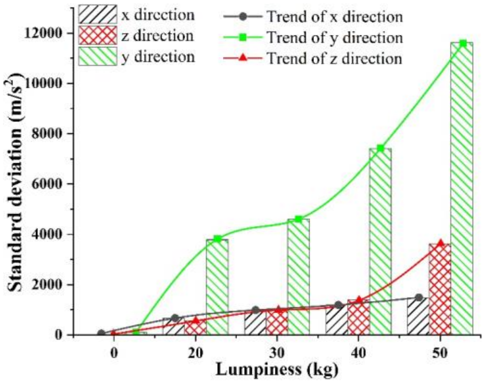


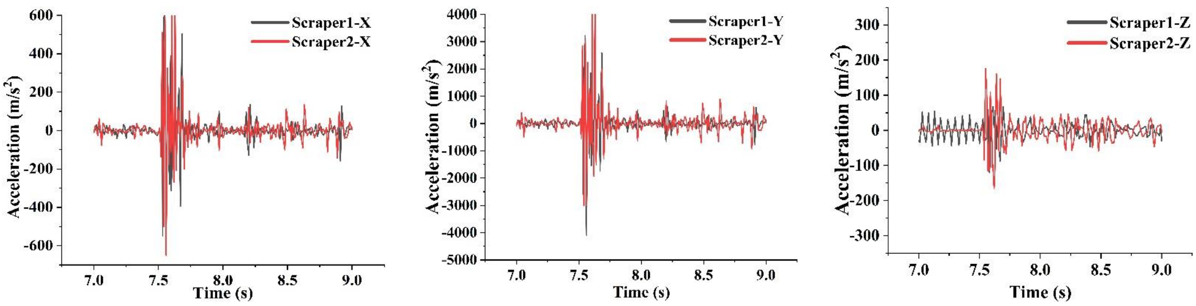
Figure 5: Variation trend of chain acceleration standard deviation.

As shown in Fig. 5, the standard deviation of the 3D acceleration of the chain ring is small when it is not impacted, indicating that the chain ring runs smoothly. When the chain ring is impacted, the vibration in the Y direction is the strongest, which is higher than the sum of the standard deviation of the X and Y directions. This condition is mainly because the large coal impacts the chain ring from Y direction, and the kinetic energy is large, so the vibration is large. When the lumpiness of large coal increases, the vibration amplitude in three directions of the chain ring increases accordingly. This condition is extremely unfavourable for the smooth and safe operation of the chain ring, so the impact of large coal on the chain ring should be avoided.

4.2 Variable height condition

In Section 4.1, the influence of impact load on the impacted chain ring itself is analysed. When the chain ring is subjected to impact load, its influence on itself is extremely unfavourable. Therefore, this section will study the impact load on the overall chain ring group. The vibration of the scraper is continuously passed through the chain ring of the chain group when the chain is subjected to impact load. The vibration of the scraper reflects the vibration of the chain between the impacted chain and the scraper. Therefore, the more intense the vibration of the scraper, the more intense the vibration of the chain ring group.

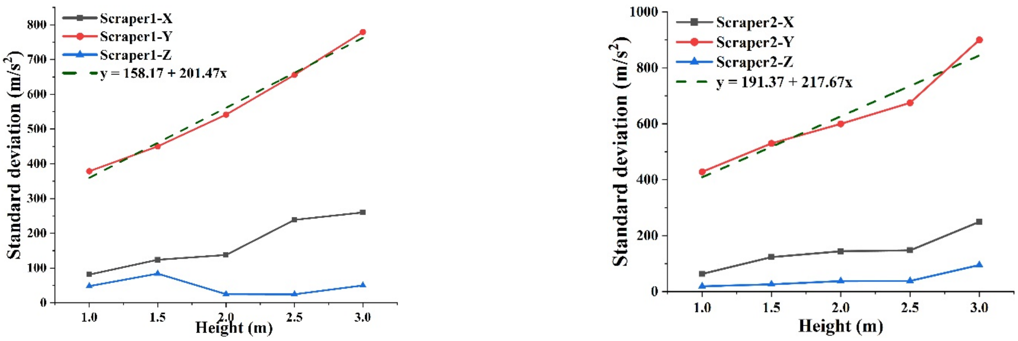
The impact simulation of chain drive system with 40 kg large coal is conducted, and the influence of large coal on the chain ring group is analysed when it was impacted from 1, 1.5, 2, 2.5, and 3 m height. Taking the impact height of 2 m as an example, the acceleration vibration of the scraper in the time domain is counted when the chain is subjected to the impact load, as shown in Fig. 6.



a) 2 m-X b) 2 m-Y c) 2 m-Z

Figure 6: Acceleration changes of scrapers 1 and 2.

As shown in Fig. 6, the accelerations in each direction of the two scrapers are close to zero without impact, indicating again that the scraper runs smoothly and the simulation model meets the requirements. When subjected to the impact load, the two scrapers of the chain ring group produce severe vibration. The maximum amplitude in the X direction is 650.43 m/s^2, the maximum amplitude in the Y direction is 4088.853 m/s^2, and the maximum amplitude in the Z direction is 175.79 m/s^2, indicating that the impact load has a severe impact on the scraper, in which the Y direction is the most obvious. The standard deviations of scraper acceleration vibration at the heights of 1, 1.5, 2, 2.5, and 3 m are analysed, as shown in Fig. 7.



a) Scraper 1 b) Scraper 2

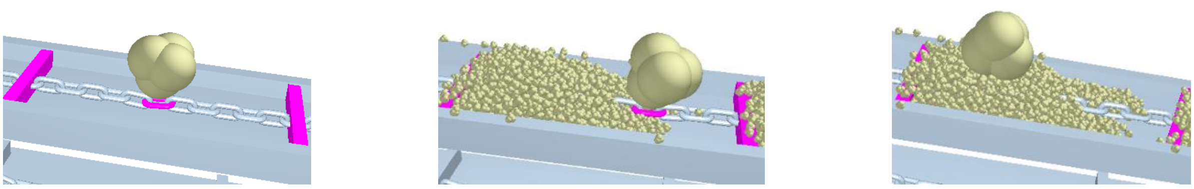
Figure 7: Standard deviation of scraper acceleration.

As shown in Fig. 7, the chain ring group produces severe fluctuations in different directions when the chain ring is impacted, and the vibration is different, where Y > X > Z. This phenomenon is due to the large coal impact from the Y direction to the chain ring. Therefore, the vibration generated by the vertical impact force is large, and the vibration in the Y direction is the most intense. The standard deviation of the Y direction is larger than the sum of the X and Z directions, so the vibration of the Y direction is the main cause of the chain failure. With the increase in impact height, the standard deviation of acceleration in Y and X directions increases, and at the same height, the standard deviation of scraper 2 is always greater than that of scraper 1, but the increase in Z direction is unremarkable. This finding is because the movement of scraper in Z direction is inhibited by the middle groove, so the middle groove can improve the operation stability of the chain ring group.

Considering that the impact load in the Y direction is the most influential, the function fitting is performed to analyse the change rule in the Y direction. As shown in Fig. 7, the standard deviation of scraper 2 is greater than that of scraper 1 at the same height. This finding indicates that when the chain ring of the chain ring group is impacted, the influence on the chain ring in the front area is large. The fitting growth rate of scraper 1 is 201.47, and the fitting growth rate of scraper 2 is 217.67 by fitting the standard deviation of Y direction. This finding shows that with the increase in impact height, the vibration growth rate of the chain ring in the front area is greater than that in the rear area. This condition again shows that the chain ring in the front area of the chain ring group is more vulnerable to damage. The chain ring in the front area should be optimized and strengthened.

4.3 Variable position condition

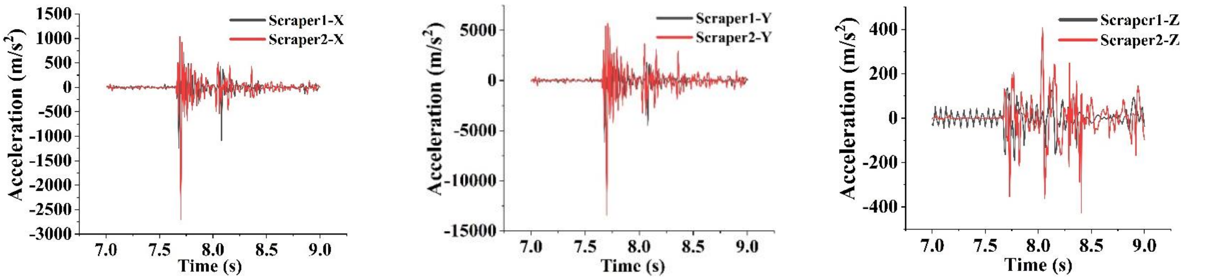
In this section, 40 kg large coal is used to simulate the impact of chain drive system. The impact height of large coal is 3 m, and the working conditions at different positions are shown in Fig. 8.



a) Chain ring of unloaded area b) Chain ring of coal transportation area c) Coal pile working condition

Figure 8: Working conditions of different impact positions.

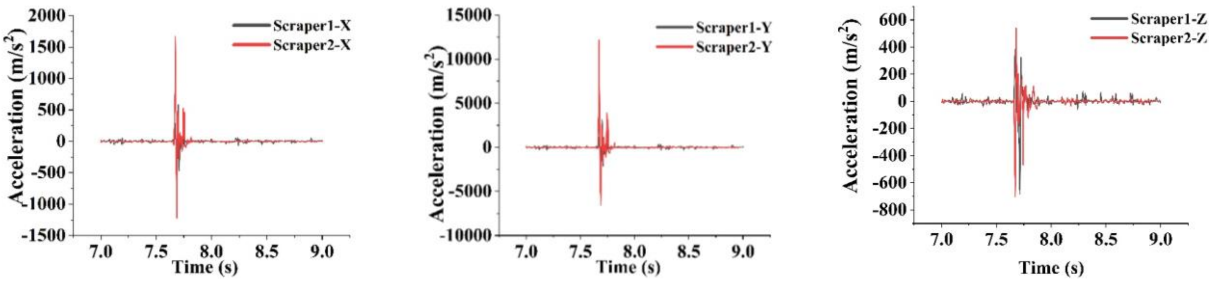
When the above three positions are subjected to impact load, the 3D acceleration vibration curves of scrapers 1 and 2 are analysed, as shown in Figs. 9 to 11.



a) X direction b) Y direction c) Z direction

Figure 9: Chain ring of unloaded area.

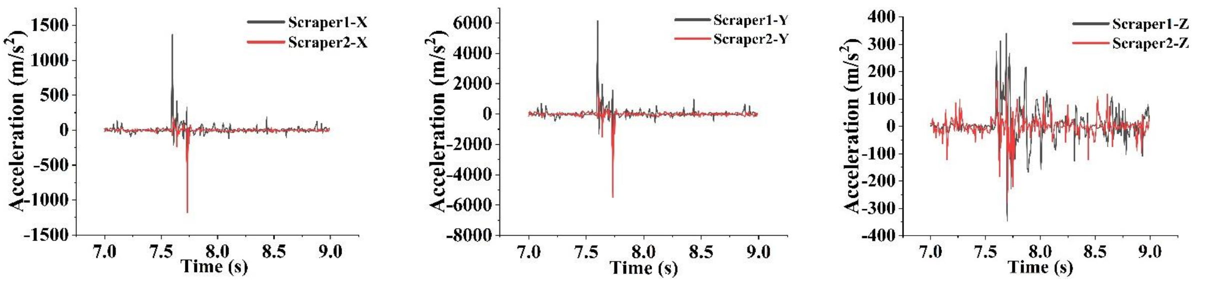
As shown in Fig. 9, the two scrapers in the chain ring group will produce severe vibration under condition a when the large coal impacts the chain ring at 7.7 s, with the maximum amplitude of 13535.65 m/s^2 and action time of 0.32 s. Subsequently, a secondary impact will occur on the scraper at 8.06 s. This condition is because when the large coal first impacts the chain ring, it is still on the middle groove, and the scraper moves forward to impact the large coal twice, so the impact load is generated again. The impact effect is small, and the maximum amplitude is 4437.61 m/s^2.



a) X direction b) Y direction c) Z direction

Figure 10: Chain ring of coal transportation area.

As shown in Fig. 10, the maximum amplitude can reach 12290.61 m/s^2 when large coal impacts the chain under working condition b, and the action time is only 43.75 % under working condition a. The impact on the chain ring group is short and strong. The influence on scraper 2 is obvious, which again indicates that the chain ring in the front area of the chain ring group should be optimized and strengthened.



a) X direction b) Y direction c) Z direction

Figure 11: Coal pile working condition.

As shown in Fig. 11, the impact time is 59.38 % of that under condition a when the large coal impacts the coal pile under condition c, and the maximum amplitude is 6244.48 m/s^2. In the X and Y directions, the scraper 1 first generates vibration, and then the scraper 2 generates severe vibration. The maximum amplitude of scraper 1 is larger than that of scraper 2 in three directions. This condition is mainly because the large coal impact on the chain ring group is closer to the scraper 1, and the vibration is intense under this condition. The vibration is transmitted to the scraper 2 through the chain ring, and the vibration is weak and delayed.

The standard deviation of the acceleration of the scraper under the above three conditions is analysed to study the influence of the impact load on the chain ring group under different position conditions, as shown in Fig. 12.

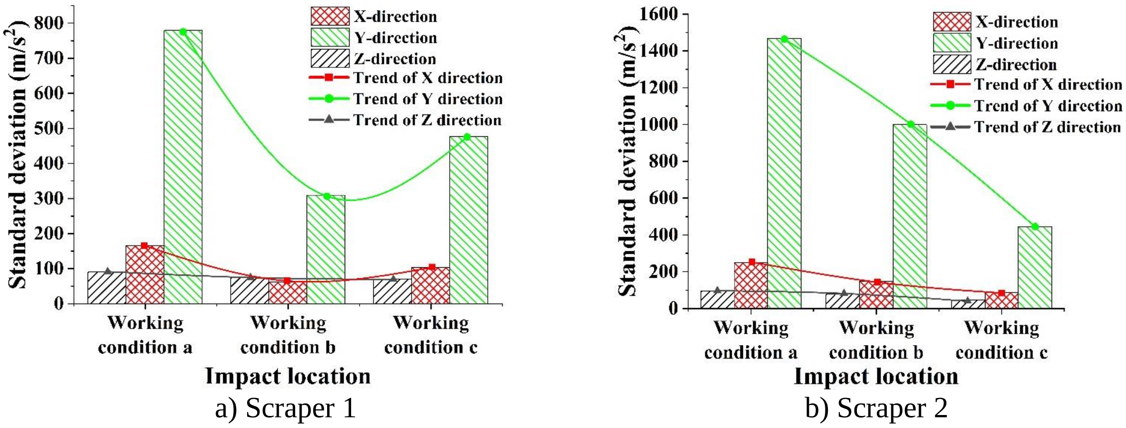


Figure 12: Standard deviation of scraper acceleration.

As shown in Fig. 12, the standard deviation of the acceleration of scrapers 1 and 2 is the largest when large coal is impacted under condition a, indicating that the damage to the chain ring group is the largest, and that coal particles can reduce the damage to the chain ring group caused by impact load.

When the large coal is impacted under working condition b, the standard deviation of the 3D acceleration of scraper 2 is greater than that of large coal under working condition c. The standard deviation of the Y direction of large coal impact on condition b is 2.24 times greater than that of large coal impact on condition c.

Given that the acceleration standard deviation of scraper 1 in X direction and Z direction is the same in conditions b and c, the standard deviation in Y direction is only 1.53 times of that in condition b when the large coal impacts on condition c. Under working conditions b and c, the acceleration standard deviation of scraper 1 in X direction and Z direction is the same when the large coal impacts on working condition c. The standard deviation of scraper 1 in Y direction is only 1.53 times that of large coal impact on working condition b. Combined with the analysis of time domain in Figs. 10 and 11, the damage degree of the three position conditions to the chain group is as follows: condition a > condition b > condition c.

5. CONCLUSION

This study adopts the multibody dynamics-discrete element method co-simulation method to explore the dynamic properties of the chain drive system of scraper conveyor under impact load. The impact simulation of large coal on the chain drive system under three working conditions of variable lump, variable height, and variable position is conducted, and the acceleration changes in the chain ring and scraper are obtained. The conclusions are summarized as follows:

(1) When the chain ring is subjected to the impact load from large coal, the chain produces severe vibration. The longitudinal vibration is the main cause of the chain drive system failure. The vibration amplitude is positively correlated with the lumpiness of large coal, and the middle groove can improve the operation stability of the chain drive system.

(2) When the large coal impacts the chain ring in the unloaded area from different heights, the chain vibration in the front area of the chain ring group is the most intense. With the increase in impact height, the longitudinal vibration growth rate of the chain ring in the front area is greater than that of the chain ring in the rear area, so the chain ring in the front area should be optimized.

(3) The large coal impacting the chain ring in the unloaded area causes secondary impact on the chain drive system, seriously affecting its stability. The normal transportation of scattered coal particles can reduce the impact of impact load on the chain drive system. When the large coal impacts the three position conditions, the degree of damage to the chain drive system from high to low is as follows: chain ring of unloaded area, chain ring of coal transportation area, and coal pile.

In this study, the impact load under various working conditions is investigated in detail, which is of great importance to the optimization of chain drive system. However, the length of the chain drive system model is limited and cannot simulate the situation of unloaded area and coal transportation area at the same time due to the limitation of hardware facilities. Therefore, the simulation analysis method that can simultaneously simulate the unloaded area and the coal transportation area should be found under the premise of ensuring the simulation efficiency.

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REFERENCES

[1] Wieczorek, A. N.; Wójcicki, M. (2021). Synergism of the binary wear process of machinery elements used for gaining energy raw materials, *Energies*, Vol. 14, No. 7, Paper 1981, 15 pages, doi:10.3390/en14071981

[2] Zhang, X.; Li, W.; Zhu, Z.; Jiang, F. (2020). Fault detection for scraper chain using an observer-based tension distribution estimation algorithm, *Current Science*, Vol. 118, No. 11, 1792-1802, doi:10.18520/cs/v118/i11/1792-1802

[3] Lu, Z. X.; Guo, W.; Zhao, S. F.; Zhang, C. W.; Wang, Y.; Jia, Y. P. (2020). A cross-platform Web3D monitoring system of the three-machine equipment in a fully mechanized coalface based on the skeleton model and sensor data, *Journal of Sensors*, Vol. 2020, Paper 3147352, 14 pages, doi:10.1155/2020/3147352

[4] Fedorko, G.; Necas, J.; Zegzulka, J.; Gelnar, D.; Molnar, V.; Tomaskova, M. (2021). Measurement of amount for steel abrasive material transported by special scraper conveyor, *Applied Sciences*, Vol. 11, No. 4, Paper 1852, 15 pages, doi:10.3390/app11041852

[5] Zhao, S. F.; Wang, P. F.; Li, S. J. (2020). Study on the fault diagnosis method of scraper conveyor gear under time-varying load condition, *Applied Sciences*, Vol. 10, No. 15, Paper 5053, 20 pages, doi:10.3390/app10155053

[6] Zhuang, M.; Li, G.; Ding, K. X.; Xu, G. S. (2021). Optimized design of mechanical chain drive based on a wireless sensor network data algorithm, *Journal of Sensors*, Vol. 2021, Paper 2901624, 13 pages, doi:10.1155/2021/2901624

[7] Wang, D. G.; Zhang, J.; Zhu, Z. C.; Gang, S.; Xiang, L. (2019). Crack initiation characteristics of ring chain of heavy-duty scraper conveyor under time-varying loads, *Advances in Mechanical Engineering*, Vol. 11, No. 9, 11 pages, doi:10.1177/1687814019880366

[8] Jiang, S. B.; Ren, W. J.; Mao, Q. H.; Zeng, Q. L.; Yu, P. F.; Gao, K. D.; Wang, L. (2021). Dynamic analysis of the scraper conveyor under abnormal operating conditions based on the vibration and speed characteristics, *Shock and Vibration*, Vol. 2021, Paper 8887744, 17 pages, doi:10.1155/2021/8887744

[9] Zhang, Q.; Gu, J. Y.; Liu, J. M.; Tian, Y. (2021). Temperature effect on the impact characteristics of mine ring chain under different working conditions, *Strength of Materials*, Vol. 53, No. 1, 189-197, doi:10.1007/s11223-021-00275-1

[10] Ren, W. J.; Wang, L.; Mao, Q. H.; Jiang, S. B.; Huang, S. (2020). Coupling properties of chain drive system under various and eccentric loads, *International Journal of Simulation Modelling*, Vol. 19, No. 4, 643-654, doi:10.2507/IJSIMM19-4-535

[11] Wang, Z. S.; Li, B.; Liang, C.; Wang, X. W.; Li, J. H. (2021). Response analysis of a scraper conveyor under chain faults based on MBD-DEM-FEM, *Strojniski vestnik – Journal of Mechanical Engineering*, Vol. 67, No. 10, 501-515, doi:10.5545/sv-jme.2021.7300

[12] Zhang, P. L.; Li, B.; Wang, X. W.; Liu, C. Y.; Bi, W. J.; Ma, H. Z. (2020). The loading characteristics of bulk coal in the middle trough and its influence on rigid body parts, *Strojniski vestnik – Journal of Mechanical Engineering*, Vol. 66, No. 2, 114-126, doi:10.5545/sv-jme.2019.6267

[13] Jiang, S. B.; Lv, R. B.; Wan, L. R.; Mao, Q. H.; Zeng, Q. L.; Gao, K. D.; Yang, Y. (2020). Dynamic characteristics of the chain drive system of scraper conveyor based on the speed difference, *IEEE Access*, Vol. 8, 168650-168658, doi:10.1109/ACCESS.2020.3023551

[14] Zhang, X.; Li, W.; Zhu, Z. C.; Yang, S. G.; Jiang, F. (2019). Fault detection for the scraper chain based on vibration analysis using the adaptive optimal kernel time-frequency representation, *Shock and Vibration*, Vol. 2019, Paper 6986240, 15 pages, doi:10.1155/2019/6986240

[15] Wojnar, G.; Burdzik, R.; Wieczorek, A. N.; Konieczny, L. (2021). Multidimensional data interpretation of vibration signals registered in different locations for system condition monitoring of a three-stage gear transmission operating under difficult conditions, *Sensors*, Vol. 21, No. 23, Paper 7808, 22 pages, doi:10.3390/s21237808

[16] Zhang, Q.; Zhang, R. X.; Tian, Y. (2020). Scraper conveyor structure improvement and performance comparative analysis, *Strength of Materials*, Vol. 52, No. 4, 683-690, doi:10.1007/s11223-020-00218-2

[17] Shprekher, D. M.; Babokin, G. I.; Kolesnikov, E. B.; Ovsyannikov, D. S. (2021). Research of load unbalance of a two-motor variable frequency Dtive for scraper conveyor, *Russian Electromechanics*, Vol. 64, No. 4-5, 37-45, doi:10.17213/0136-3360-2021-4-5-37-45

[18] Shprekher, D. M.; Babokin, G. I.; Zelenkov, A. V.; Ovsyannikov, D. S. (2021). Universal computer model for studying the dynamics of a two-motor scraper conveyor, *Russian Electromechanics*, Vol. 64, No. 2, 56-64, doi:10.17213/0136-3360-2021-2-56-64

[19] Li, L.; Cui, H. W.; Lian, Z. S.; Wang, Q. L. (2019). Modeling and optimization of soft start-up for hydroviscous drive applied to scraper conveyor, *Mathematical Problems in Engineering*, Vol. 2019, Paper 6131364, 14 pages, doi:10.1155/2019/6131364

[20] Xia, R.; Wang, X. W.; Li, B.; Wei, X.; Yang, Z. J. (2019). The prediction of wear on a scraper conveyor chute affected by different factors based on the discrete element method, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 233, No. 17, 6229-6239, doi:10.1177/0954406219861130

[21] Li, J. X.; Liang, S. W. (2019). Impact and friction of bulk material on the blanking area in the middle trough of scraper machine, *Journal of Coastal Research*, Vol. 93, Special Issue 1, 947-952, doi:10.2112/SI93-137.1

[22] Ma, H. Z.; Wang, X. W.; Li, B.; Liu, Z. Y.; Bi, W. J.; Wei, X. (2021). Study on the mechanical effect and wear behaviour of middle trough of a scraper conveyor based on DEM-MBD, *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, Published online, doi:10.1177/13506501211059259