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Dynamic simulation of crawler excavator walking mechanism

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Abstract. In order to develop a mechanical simulation experiment, a dynamic simulation of crawler excavator walking mechanism is designed. The performance of walking mechanism of excavator is tested by dynamic simulation. According to the data analysis, it is known that crawler walking mechanism is an important part of mine excavator and a walking device with better adaptability than wheeled walking mechanism. The crawler can travel on a road with poor working conditions, such as deep snow, swamp, mud and sand, while the wheeled devices cannot work in these conditions. Therefore, in combination with the actual working conditions of excavators, two kinds of mines are simulated and studied. The dynamic simulation of the meshing force between the driving wheel and the track plate during the walking process is carried out, and the movement state of the driving wheel in the forward and backward conditions is simulated and analyzed. The experimental results show that the grounding of the crawler device is much smaller than that of the wheel type, and the load impact can be greater than that of the wheeled type. In addition, the working environment of the excavator is very bad, and it is often run in the mines in the sand and mud. Through simulation analysis, it is concluded that the walking mechanism of crawler excavator is more efficient and convenient than the traditional wheeled excavator.

Key words. Excavators, load impact, dynamics.

1. Introduction

China has vast land resources and rich mineral resources, and these abundant resources are the strong material base for building a modern and powerful country. China's mineral resources are mostly suitable for open pit mining. Only 65 % of the iron ore reserves are suitable for open-pit mining. Other large coal mines, non-metallic minerals and non-ferrous metal mines are also suitable for open-pit mining. At present, iron ore open-pit mining has accounted for 88.4 % and non-ferrous metal mine open-pit mining accounted for 47 %. In addition, chemical raw materials open-pit mining accounted for 50 % and construction materials open-pit mining accounted for more than 50 % [1]. Experience from all over the world has proved that the production capacity and the demand for minerals is increased because of the large

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mining equipment used in open pit mining [2]. The surface mining method is 5–10 times more efficient than the underground mining method, and the cost is 1–2 times lower than that of the underground mining method [3]. This method is easy to realize automatic mining. It has the advantages of safe production and high recovery rate. Its rapid and efficient economic results have promoted the rapid development of opencast mining [4]. For a long time, the development of all kinds of crawler excavators in our country, including crawler walking mechanism, have been dominated by the traditional mode [5]. The emergence of a new type of machine usually involves several steps, such as preliminary design, prototype production, industrial test, improvement, finalization and mass production [6]. The design and research model based on physical prototype has the disadvantages of high cost and long cycle, and it cannot be tested repeatedly on the physical prototype [7]. Therefore, our country's mechanical excavator product replacement is slow, it is difficult to adapt to the rapid changing market demand. At the same time, with the development of mining excavator toward large-scale, the structure of the product becomes more and more complex [8]. The manpower, material and financial resources invested in the development of a physical prototype are also increasing [9]. Therefore, the traditional way of product development is used to develop new large-scale mining excavators, the demand for funds is huge, but also difficult to adapt to market demand. Based on this, the dynamic simulation analysis of crawler excavator walking mechanism is studied [10].

2. Overview of crawler walking mechanism

The crawler walking device was invented in 1830s by Dimitri Chagyanskiy [11]. It moves the moving vehicle according to two closed parallel rotating tracks. It can travel on the roadlessness, snow, mud, swamp area where wheeled wheels are not available.

Although crawler walking device has been widely used in engineering, it is still not perfect. Compared with wheel walking device, it has low mechanical efficiency and working reliability as well as the complex mechanism. In addition, due to the complexity of crawler movement, previous studies often separate each link to simplify analysis [12]. Coupled with the uncertainty of ground mechanics, the design work relies too much on empirical data, empirical formulas, and the designer's own design experience.

The working principle of the crawler type walking device is shown in Fig. 1: the whole caterpillar vehicle is supported on the caterpillar trolley; the rear end of the track trolley is a driving wheel 1, the front end is a guide wheel 2, the middle part is a supporting wheel 3. The crawler passes the load to the lower track of the crawler through these wheels. The track 4 is an endless chain with an upper branch supported on the idler pulley 5. When the driving cycle is turned, the tracks engaged with the drive wheel have a tendency to move [13]. However, because the adhesion between the lower track branches and the soil is greater than that of the driving wheel, the guide wheel and the supporting wheel, the track does not move [14]. The caterpillar wheel, guide wheel and supporting wheel roll along the caterpillar track, and the whole caterpillar vehicle walks forward [15].

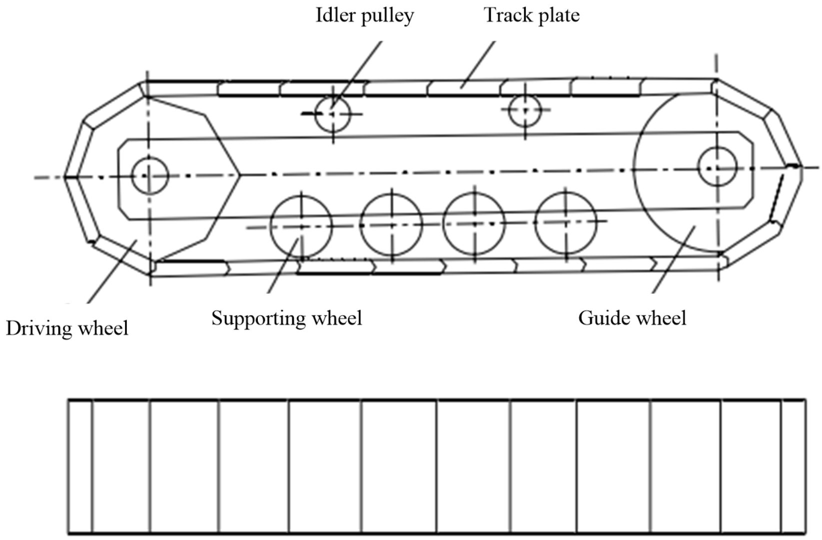

Fig. 1. Sketch of working principle of crawler walking device

3. Method

Before establishing the virtual prototype of crawler walking mechanism, it is necessary to analyze the structure and working principle of the crawler walking mechanism.

The crawler walking mechanism is composed of a driving wheel, guide wheel, caterpillar plate, supporting wheel and plate. The function is to change the torque from the motor to the traction force. Working principle: when the drive wheel turns, it needs to pull out the track below the support wheel. But because the weight of the whole machine makes the track and the ground engage tightly, the soil produces shearing stress, forming the traction force that makes the tracked vehicle advance. This pressure can also be interpreted as the force exerted on the track by the ground, which is transmitted to the whole by the caterpillar through the drive wheel, and the whole machine is moved. The root of the movement of the whole machine comes from the friction of the ground facing the track plate.

The function of the track is to ensure the high pass of the vehicle on various complicated ground, reduce the running resistance and increase the adhesion to the ground. By interaction with the ground, it can generate traction and braking force of the crawler propulsion device. Different soil conditions will affect the interaction of the entire machine and the ground, and ultimately affect the whole machine, such as driving resistance and other driving performance. Therefore, a suitable vehicle ground mechanical model must be established according to the actual soil conditions. In the prototype model, considering the actual working environment of the excavator, the focus of the simulation analysis, the complexity of the simulation and the ground mechanical model are calculated according to the rigid soil road.

In the ground model, the pressure between the tracked plate and the ground is defined by the impact force, the impact force generated by the interaction force between the track and the ground. In ADAMS, the contact force is a special force acting on the component. The contact force is generated when the two members contact each other and deform. The magnitude of contact force is related to the size of deformation and the speed of deformation. If the two components are separated from each other without contact, the contact force is zero. The impact force) can be expressed by the following formula

$$F = -k\left(q - q_0\right)^n - cq\,. \tag{1}$$

In the formula, F is the ground force, k stands for the stiffness coefficient, $q - q_0$ is the penetration, n is the deformation index, C is the damping coefficient and q is the deformation speed.

The friction between the tracked plate and the ground is obtained by the formula

$$F_{\mathrm{f}} = \mu F\,, \tag{2}$$

where F_{f} is the ground friction and μ represents the friction coefficient between ground and track plate.

In the hard ground model, the ground is assumed to have stiffness and damping.

4. Results and discussion

4.1. Excavator driving analysis

As the initial speed of the machine is zero, and the resistance is certain, a certain drive torque is needed, and the drive torque is estimated according to the resistance and drive wheel parameters: $T_{\mathrm{T}} = 800\,\mathrm{kN\,m} \geq T_{rmf}$.

Since the Z axis is in the opposite direction to the track, the speed curve is negative as it moves forward. It is shown by the curves in Figs. 2 and 3 that the horizontal change of the center of mass of the driving wheel is relatively steady. Some periodic fluctuations of velocity and acceleration are caused by sudden force when engaged with the track plate. As the dynamics model is built, there is a small gap between the ground and the track system. Therefore, the simulation has just started and the tracks will suddenly fall to the ground. It can be seen from the curve that there is a certain impact between the two projects. The damping in the contact force will soon consume this part of the shock, so this part of the shock will not affect the analysis later.

When driving at a constant speed, the drive force is the same as the resistance, and the speed is constant. Therefore, a driving pair is added to the driving wheel to replace the driving torque so as to drive at a uniform speed. Accord-

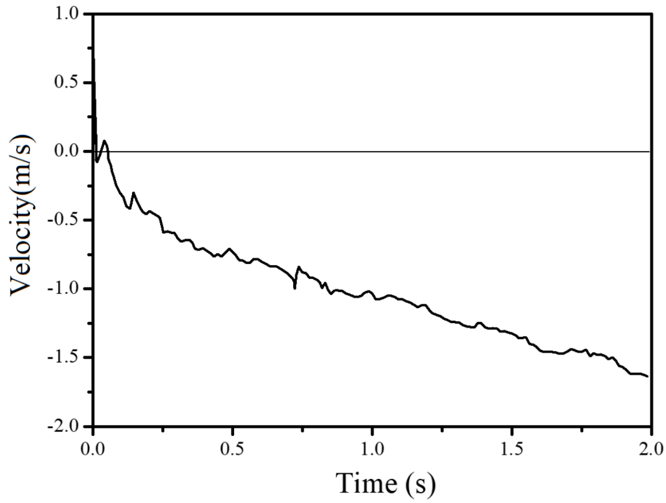

Fig. 2. Horizontal speed of the center of mass of the driving wheel

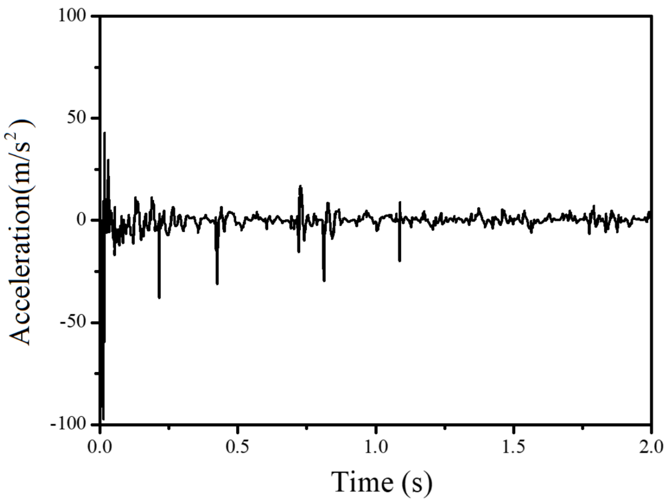

Fig. 3. Acceleration in the horizontal direction of the center of the wheel

ing to the maximum speed of walking, the maximum angular velocity of the driving wheel is calculated: $\omega_{\rm T} = v/R$, $R = 1.1\,\rm m$, $v_{\max} = 1.6$ km/h $= 0.4444\,\rm m/s$, $\omega_{\rm T} = 0.4444/1.1 = 0.404 = 23.16^\circ/\rm s$.

As can be seen from Figs. 4 and 5, when the driving wheel is applied with a constant rotational speed, the horizontal velocity and the acceleration are not uniform and are periodically changed. The reason is that when each crawler plate is engaged, the whole force is uneven. In the crawler walking mechanism, the periodic variation of speed is inevitable. The smaller the length of the caterpillar track is, the closer it becomes. Compared with the simulation video, the maximum speed and acceleration in the curve is perpendicular to the mass center of the driving wheel when the crawler plate runs. When the crawler plate is vertical below the driving wheel, the driving wheel and the pedrail plate have a great force in the horizontal direction.

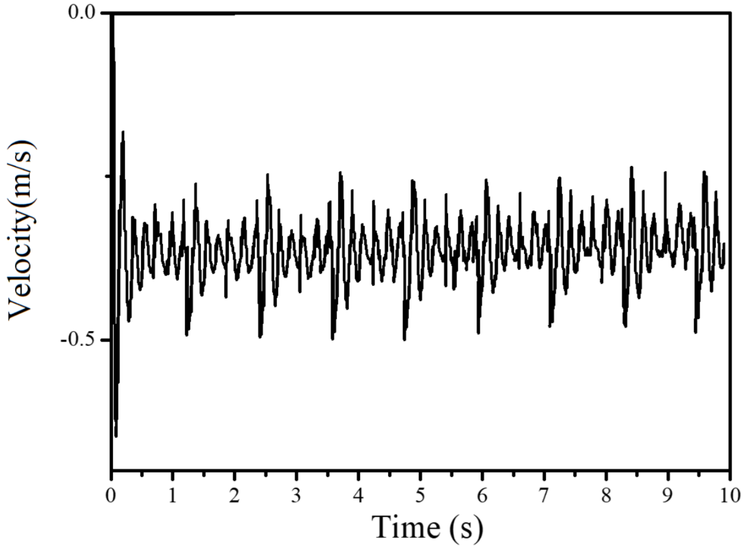

Fig. 4. Speed of the drive wheel in the horizontal direction

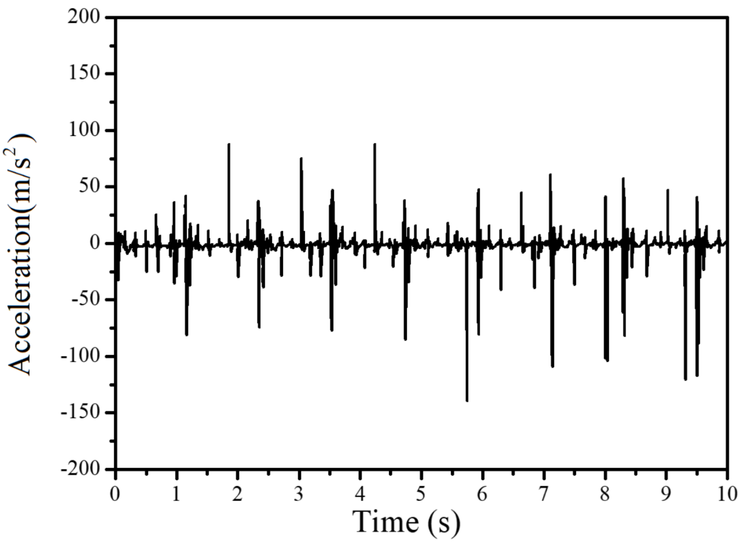

Fig. 5. Acceleration of the drive wheel in the horizontal direction

When the speed of the drive wheel is constant, the horizontal acceleration changes periodically, but the change is great and the impact is great. In each period of change there are some sudden increases with irregular change. Because in simulation, the contact surface between the driving wheel and the track plate appears the phenomenon of edge contact with the plane, so the force suddenly increases. But in real environments, this absolute edge and plane contact do not exist, so these can be ignored.

4.2. Excavator astern driving

Different from the forward driving, the internal resistance of the whole track system in astern driving will become larger, and the force acting on the track will change. Drive torque $T_T = 980\,\text{kN·m}$.

As shown in Figs. 6 and 7, excavators are inevitably retrograde at work. Compared to the forward constant torque, the speed of the astern constant torque varies greatly, and the overall trend is accelerated retreat. Compared with the simulation animation, the peak of the speed curve is the maximum of the tangential force of the driving wheel after the contact between the crawler plate and the driving wheel. The acceleration of a constant torque moving in the horizontal direction fluctuates frequently.

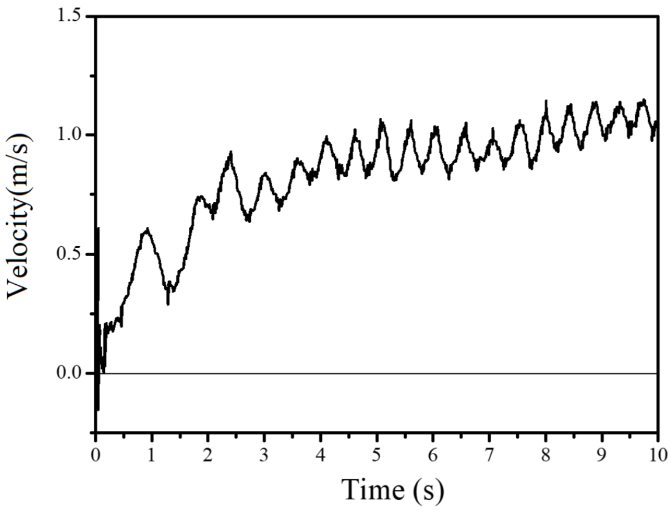

Fig. 6. Speed of the constant torque of the drive wheel in the horizontal direction

When driving back at a uniform speed, a reverse motion pair is needed at the driving wheel. The maximum speed is $v_{\max} = 1.6\,\text{km/h}$, and the maximum angular velocity is $\omega_T = 0.4444/1.1 = 0.404 = 23.16°/\text{s}$.

As shown in Figs. 8 and 9, when the driving wheel rotates in the uniform direction, the horizontal speed and the acceleration of the driving wheel center are relatively smooth. When retracting, the engagement of the track shoe with the drive wheel is not affected by external forces such as the ground, and the engagement is more

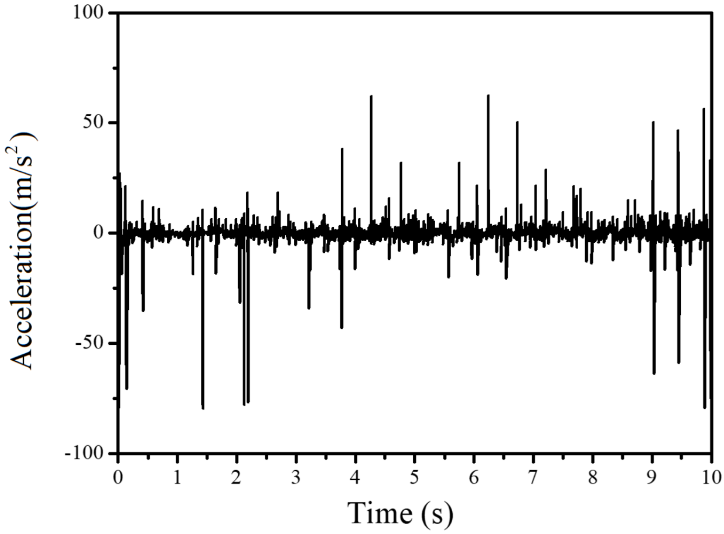

Fig. 7. Acceleration of the constant torque of the drive wheel in the horizontal direction

stable. However, there are ground-facing pressure and horizontal frictional forces when engaging forward. Complex forces lead to greater volatility.

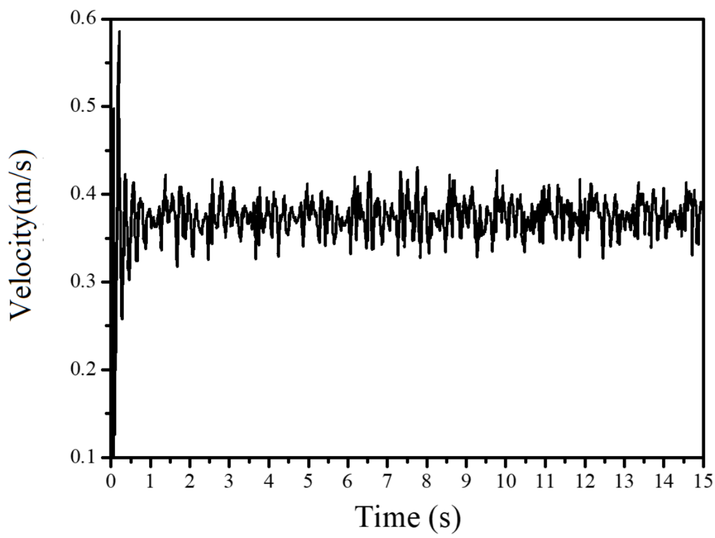

Fig. 8. Speed of the wheel center in horizontal direction

4.2.1. Design of Backstepping controller

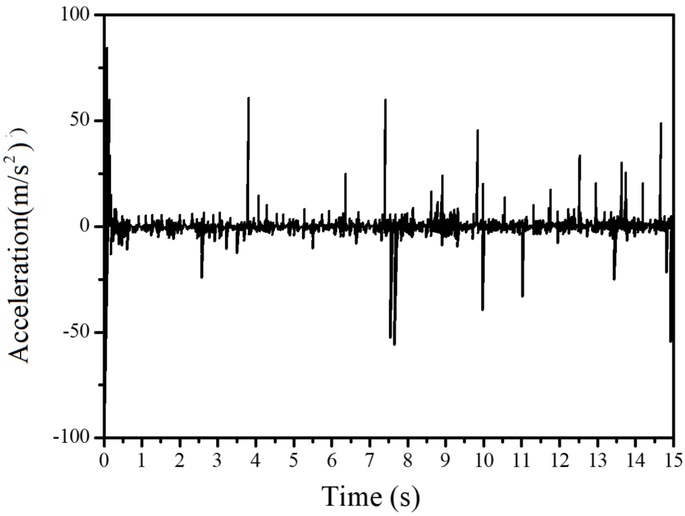

Fig. 9. Acceleration of the wheel center in horizontal direction

5. Conclusion

The dynamic simulation of the crawler type walking device is carried out by using the crawler traveling mechanism of the mining machine and the actual walking condition. Some problems of dynamic modeling of track walking mechanism are solved by self-programming. The dynamic simulation analysis of excavator crawler walking system is carried out, and the two conditions of forward and backward are analyzed, respectively. In each case, the constant speed and constant torque are compared and analyzed. In the forward condition, a continuous four track shoe meshing with the drive wheel is selected. The simulation results show that the four track shoes and the driving wheel are in the horizontal and vertical direction. During the running of the track, the engagement force curve fluctuates periodically due to the periodic engagement of the drive wheel and the track shoe. In addition, the abrupt change in the constant speed exceeds the constant torque force mutation because of the initial conditions of the ADAMS calculation equation. In the retreating condition, the running resistance of the backward traveling crawler device is greater than the running resistance of the forward traveling. Through the simulation of the horizontal movement of the wheel center, the constant speed of the recursive torque is larger than the constant speed, but the speed change is stable and the impact is less compared with constant speed.

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