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Motion Analysis of a New Final Coal Sorter Based on Multi-Body Dynamics

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Abstract: Research has been conducted on dry coal selection technology to achieve efficient and clean utilization of coal and reduce water resource waste. To investigate the effective separation of 6–1 mm fine coal using this approach, the vibrating cascade sorter was examined, with particular attention given to its dynamic characteristics and motion behavior. Dry coal vibrating cascade sorter motion simulation experiments were carried out and the mechanical system motion characteristics of the vibrating cascade sorter were simulated and analyzed using multi-body dynamics software ADAMS, including the motion curve and spatial trajectory of the sorter body. Theoretical calculations of the sorter body's motion characteristics, including displacement amplitude, velocity amplitude, and acceleration amplitude, were compared with simulation results derived from multi-body dynamics. The comparison revealed a strong agreement between the computational model and analytical predictions, with a maximum deviation of less than 3.75%. The dynamic behavior of the vibrating cascade sorter at various rotational speeds was evaluated and contrasted against predictive models, with the highest discrepancy between the observed and predicted outcomes being less than 7.6%.

Keywords: Vibrating cascade sorter; Dry coal selection technology; ADAMS; Simulation; Motion characteristics

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1. Introduction

In China, over 60% of coal resources are distributed in the inland western regions with scarce water resources. Currently, wet coal washing technology is the main method, but it requires as much as 3 tons of water for each ton of coal processed. To reduce water waste, it is necessary to break through the technical difficulties of dry coal washing technology. Domestic and foreign scholars have carried out a large amount of research work in the field of dry coal washing desulfurization technology, including heavy medium separation, air separation, electrostatic separation and magnetic separation, etc.

Building on the technical architecture of the Clean Coal Center's research information management platform, this study integrates industrial software tools such as ANSYS, EDEM, and MATLAB to perform coupled screening simulation experiments. These simulations systematically examine the effects of various screening parameters on the looseness and stratification of coal seams while exploring the separation mechanism of the dry fine coal vibrating separation device. By combining vibration cascade separation theory with advanced numerical simulation methods, the study provides a comprehensive analysis aimed at improving the efficiency and effectiveness of fine coal dry separation processes.

2. Kinematics theory

The kinematic model of the vibrating cascade sorter is shown in **Figure 1**. Based on the kinematic model, displacement, velocity, acceleration, and other vibration parameters can be obtained. These parameters are natural properties of the vibrating cascade sorter and provide an important basis for evaluating its rationality and reliability [1]. During the operation of the vibrating cascade sorter, the heart shaft performs uniform circular motion while the sorting bed surface performs reciprocating motion similar to a straight line. The displacement, velocity, and acceleration of the sorting bed surface are constantly changing [2]. Therefore, it is of great significance to study the motion characteristics of the sorting bed surface. To study the motion characteristics of the bed surface, an absolute coordinate system OXY was established with the rotating center of the heart shaft as the origin O [3]. The X-axis is parallel to the bed surface and points in the direction of the material flow, while the Y-axis is perpendicular to the bed surface. According to the working principle of the vibrating cascade sorter, simplification and equivalent treatment were carried out on the heart shaft, eccentric sleeve, and spring plate. Meanwhile, e represents the eccentricity and ω represents the rotational speed of the heart shaft.

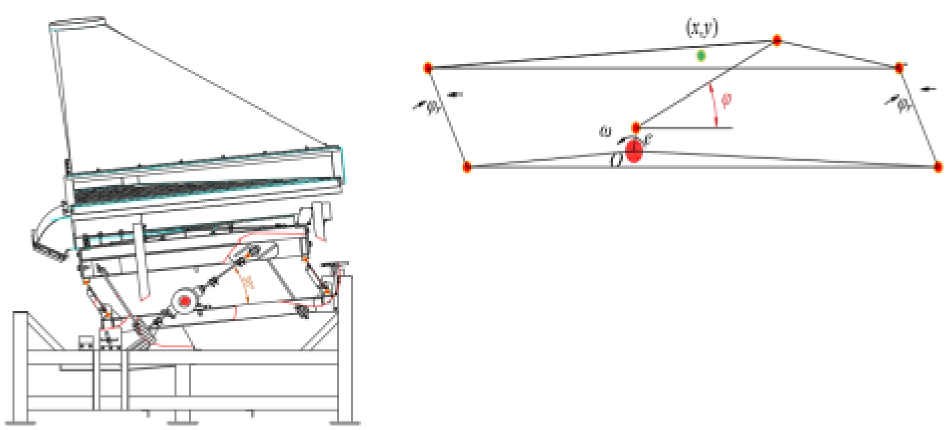

Figure 1. Schematic diagram of motion of vibrating cascade sorter

The vibrating screen of the sorting machine transmits the rotation of the eccentric wheel to the surface of the bed and the rising airflow causes the mixed material to move up and down and flip on the bed surface, causing the material on the bed surface to move towards the discharge end at a constant speed [4]. The material on the bed surface is given a certain amount of kinetic energy while being screened, so the difference in its mass results in different amounts of kinetic energy [5]. The mixed coal with a larger mass has greater kinetic energy, allowing it to overcome the frictional force given by the bed surface and the frictional force between particles to move to the right, while the coal powder with a smaller mass has less kinetic energy, causing them to move to the far left due to the interaction of forces [6]. As a result, the mixed coal is sorted by particle size and discharged from left to right at the outlet, ultimately completing the screening process. The main idea behind the design of the sorting machine is to use the different particle sizes of the mixed coal to discharge the suitable material from the far left into the selection process, while the gangue and large impurities are discharged from the right side.

When the eccentric shaft rotates, there is displacement in the *X* and *Y* direction of the sorting bed surface.

$$x = e\cos\varphi\cos\omega t \tag{1}$$

$$y = e\sin\varphi\cos\omega t \tag{2}$$

In the formula, e is the eccentricity of the heart axis rotation, m; φ is the angle between the plate spring and the sorting bed surface, °; ω is the rotational speed of the heart axis, r/min; t is the time, s. The expressions of velocity and acceleration on the sorting bed can be obtained by calculating the first and second derivatives of equations (1) and (2) with respect to time t respectively.

$$\dot{x} = -e\omega\cos\varphi\sin\omega t \tag{3}$$

$$\ddot{x} = -e\omega^2\cos\varphi\cos\omega t \tag{4}$$

$$\dot{y} = -e\omega\sin\varphi\sin\omega t \tag{5}$$

$$\ddot{y} = -e\omega^2\sin\varphi\cos\omega t \tag{6}$$

The formula below can be used to calculate the amplitude in *X* and *Y* directions of the sorting bed surface.

$$A_x = e\cos\varphi \tag{7}$$

$$A_y = e\sin\varphi \tag{8}$$

3. Establishment of multi-body dynamics simulation model

Under the interface of ADAMS software, a simplified simulation model of a vibration cascade sorter was established, as shown in **Figure 2** and **Figure 3**. The eccentricity distance *e* is 8 mm, and the inclination angle φ of the plate spring is 30 degrees. The spring stiffness is set according to theoretical calculations. To overcome the influence of gravity, the spring is preloaded before the simulation. The gravity acceleration is set to 9.81 m/s^2. The material selected is steel, with a corresponding density of 7.82×10^3 kg/m^3 [7]. The constraint relationships among the heart shaft and the eccentric sleeve, the eccentric sleeve and the plate spring, the plate spring and the sorting bed surface, and the sorting bed surface and the support frame are all defined as joint rotational pairs. A motion rotational drive is applied to the joint rotational pair between the heart shaft and the eccentric sleeve, with the rotational speed function specified as STEP(time, 0, 0, t0, ω0), indicating that the rotational speed increases smoothly from 0 to ω0 within the first t0 seconds. After this period, the heart shaft rotates at a constant angular velocity. In this study, the total simulation time, acceleration time (t0), target angular velocity (ω0), and simulation step size are set to 20 s, 10 s, 38.7 rad·s^{-1} (equivalent to 370 r·min^{-1}), and 0.002 s, respectively, with experimental data recorded at every 0.002-second interval.

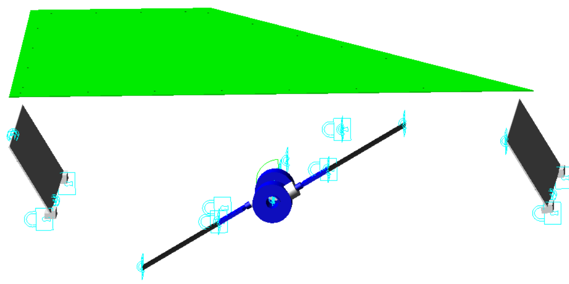

Figure 2. Multi-body dynamic simulation model of vibration cascade sorter

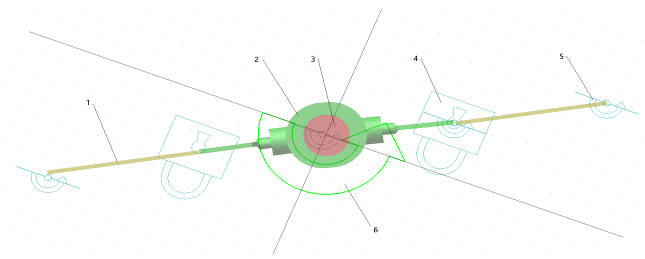

Figure 3. Simulation model driven settings; (1) Plate spring, (2) Eccentric bushing, (3) Manshaft, (4) Fixed pair, (5) Rotating pair, (6) Drive the vice

4. Multi-body dynamics simulation analysis

The time-domain response curve of the sorting bed displacement is shown in **Figure 4**. As illustrated, from 0 to 1.4 seconds, the vibrating cascade sorter operates in the startup phase, during which the vibration frequency of the bed surface gradually increases. After 1.4 seconds, the system reaches stable operating conditions, and the time-domain response curve reflects the displacement behaviour of the bed surface in both the *X* and *Y* directions. Under these stable conditions, the displacement of the sorting bed surface exhibits smooth and periodic variations, with a consistent phase difference of zero between the *X* and *Y* directions. The displacement amplitude of the sorting bed surface is 7.01 mm in the *X* direction and 3.85 mm in the *Y* direction.

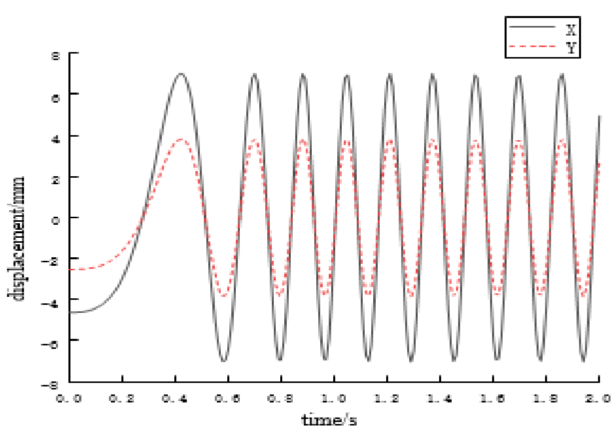

Figure 4. Based on the time domain response curve of the displacement characteristics of the sorting bed surface of MBD vibration cascade sorter

Figure 5 presents the spatiotemporal characteristic curve and the displacement Lissajous figure corresponding to the 0–20 second displacement-time domain response. The spatiotemporal characteristic curve reveals that the spatial displacement of the sorting bed is initially irregular and chaotic but gradually transitions to a stable state. Once stable operating conditions are reached, the Lissajous figure shows that the displacement trajectory of the sorting bed forms a tilted straight line, indicating a consistent and periodic motion pattern.

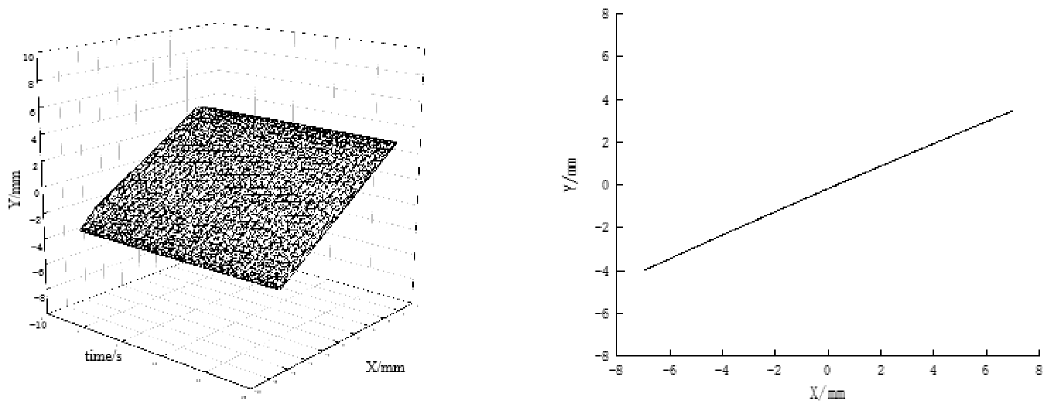

Figure 5. Space-time characteristic curve and displacement Lissajous of the sorting bed surface based on MBD vibration cascade sorting machine

Figure 6 illustrates the time-domain response curve of the sorting bed surface velocity. As shown in the figure, during the start-up phase (0–1.4 s), the velocity amplitude of the sorting bed surface gradually increases in both the *X* and *Y* directions. After 1.4 seconds, the velocity amplitude stabilizes, indicating the transition to steady-state operation. Under stable conditions, the velocity amplitude of the sorting bed surface reaches 271.7 $mm \cdot s^{-1}$ in the *X* direction and 149.3 $mm \cdot s^{-1}$ in the *Y* direction. Throughout this stable phase, both the magnitude and direction of the velocity remain consistent.

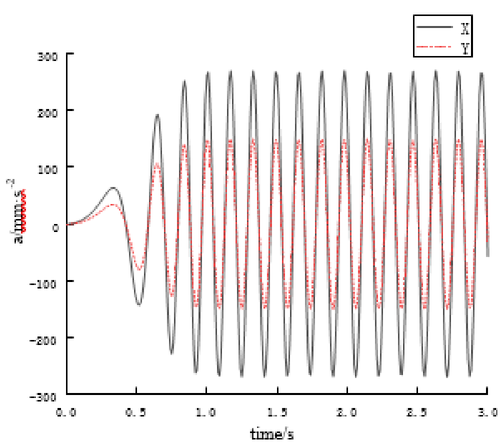

Figure 6. Time domain response of velocity characteristics based on MBD vibration cascade sorter

Figure 7 shows the time-domain response curve of the sorting bed surface acceleration. From the figure, it can be seen that during the start-up phase (0–1.4 s), the amplitude of the acceleration of the sorting bed surface along the X and Y directions gradually increases. After 1.4 s, the amplitude reaches the maximum and begins to operate stably. In the stable state, the amplitude of the sorting bed surface acceleration along the X direction is 10.6 mm·s^{-2}, and the amplitude of the acceleration along the Y direction is 6.0 mm·s^{-2}. Under stable operating conditions, the acceleration direction of the sorting bed surface along the X direction remains the same [9].

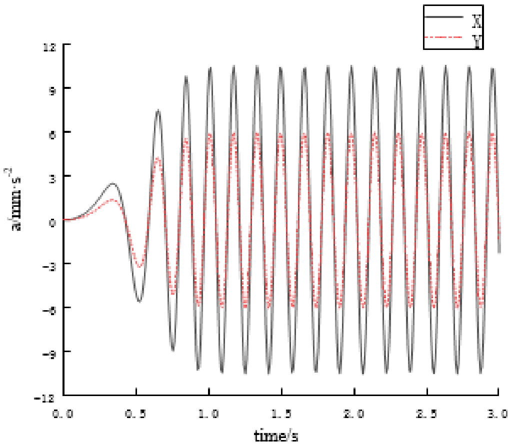

Figure 7. Time-domain response curve of acceleration characteristics based on MBD vibration cascade sorter

The theoretical calculation results of the motion characteristics, such as displacement amplitude, velocity amplitude, and acceleration amplitude of the vibrating cascade sorter bed surface based on the kinematic model are compared with the simulation results based on multi-body dynamics (MBD), as shown in **Table 1**. From the data presented, it is evident that the computational outcomes align closely with the predicted values. The highest discrepancy stands at just -3.75%, demonstrating the high reliability and precision of the theoretical predictions [10].

Table 1. Comparison between theoretical results and simulation results

Parameter		Theoretical result	Simulation result	Relative error
Sort the bed surface	$\lvert x \rvert$/mm	6.93	7	1.01
	$\lvert \dot{x} \rvert$ /mm s^{-1}	268.1	271.7	1.34
	$\lvert \ddot{x} \rvert$ /mm s^{-2}	10.4	10.6	1.92
	$\lvert y \rvert$ /mm	4.0	3.85	-3.75
	$\lvert \dot{y} \rvert$ /mm s^{-1}	154.69	149.3	-3.49
	$\lvert \ddot{y} \rvert$ /mm s^{-2}	5.98	6.0	0.33

5. Conclusion

This article first analyzed the motion theory of the vibrating cascade sorter and obtained the motion characteristic parameters of it. The motion characteristics of the vibrating cascade sorter were simulated and analyzed using the multibody dynamics software ADAMS. The correctness and feasibility of the theoretical model calculation and analysis method were verified. The motion characteristics of the sorter body, including displacement amplitude, velocity amplitude, and acceleration amplitude, show a clear dependence on eccentricity and rotational speed. As the eccentricity increases, all three amplitudes increase correspondingly. However, when the rotational speed of the heart shaft increases, the displacement amplitude of the sorter body remains constant, while both the velocity and acceleration amplitudes gradually increase.

Using principles of complex system mechanics, a digital model of the vibrating cascade sorter was created. Simulations were conducted to derive the movement patterns and three-dimensional paths of the sorter's body. The predicted values for key dynamic properties, including displacement range, velocity range, and acceleration range, were compared against the computational outcomes. The findings from the simulations closely matched the analytical predictions, showing a highest discrepancy of under 3.75%.

The parametric study showed that the motion characteristics of the sorter body, including displacement amplitude, velocity amplitude, and acceleration range, all rise with greater eccentricity. When the rotational speed of the central shaft increases, the displacement range of the sorter body stays constant, while the velocity and acceleration ranges progressively grow. The motion characteristics of the vibrating cascade sorter are optimal for the separation device load screening efficiency when the separation bed inclination is 30°, the amplitude is 8mm, and the heart axis rotation.

The article analyzes the dynamic characteristics and motion laws of the vibrating cascade sorter as the research object. To lay the foundation for the further design of large-scale coal sorting equipment and explore the working mechanism of the vibrating cascade sorter, the next step will focus on improving the screening efficiency and accuracy. This will be achieved through optimizing the structural design of the vibrating sorter, as well as the shape and material of the screen, among other aspects. For example, using high-strength and wear-resistant materials to make the screen can prolong the service life of the vibrating sorter and improve screening efficiency.

In summary, the next research directions for the vibrating sorter include improving screening efficiency and accuracy, reducing energy consumption and noise, expanding application fields, and achieving automation control.

Disclosure statement

The authors declare no conflict of interest.

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