Simulation Analysis of Cavity Shape of Compound Pendulum Jaw Crusher

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Abstract. Taking the working device of PE1500 × 1800 compound pendulum jaw crusher as the research object, 3D model of working devices of four different cavity shape compound pendulum jaw crushers is carried out by using SolidWorks, and then the kinematic simulation software ADAMS is imported to carry out the kinematic simulation, and the horizontal and vertical displacement change curves of four characteristic points of the lower part of the crushing cavity are obtained. According to the simulation results, the relative production capacity and the block-up coefficient of each broken layer of the jaw crusher are calculated under the same spindle speed and different cavity shape. The results show that the block-up coefficient of the crusher with curved crushing chamber is smaller and its relative production capacity is larger.

1. Introduction
The compound pendulum jaw crusher is a kind of common crushing equipment which can simulate the movement of animal's two jaws and complete the medium-sized particle size crushing of solid materials[1]. The crusher is easy to produce blocking phenomenon when crushing materials, and the closer it is to the discharge opening, the higher the incidence of blocking phenomenon is. The clogged material is repeatedly rubbed with the liner, which not only reduces the service life of the liner, but also increases the useless work of the crusher. The main reason of blocking phenomenon is that the material quality of each broken layer in the crushing chamber is not equal. Therefore, the use of a suitable cavity shape to make the material quality of each broken layer in the crushing chamber tend to be equal is an important way to reduce the phenomenon of blockage and improve the production capacity of the crusher.

In this paper, PE1500 × 1800 compound pendulum jaw crusher is taken as the research object, the simplified 3D model of the working mechanism of different cavity crushers is established, and the motion simulation analysis is carried out based on ADAMS. Through the simulation results, the relative production capacity and block-up coefficient of the crusher under the same spindle speed and different cavity shape are calculated, so as to obtain the higher relative production capacity of the crusher cavity shape.

2. Analysis of Crushing Process of Compound Pendulum Jaw Crusher

2.1. Theory of Stratified Crushing
According to the cavity shape and the track performance value of the moving jaw tooth surface, the crushing cavity of the jaw crusher is divided into several broken layers in the vertical direction. The divided broken layer is shown in figure 1[2-3]. When the crusher is working, the moving jaw is
periodically close to and far away from the fixed jaw under the drive of the motor. When the moving jaw completes a periodic movement, the materials in the discharge layer (0 layer in figure 1) are discharged from the discharge port under the action of its own gravity, and the materials in the upper layers slide down one layer in turn and wait for the next cycle to be crushed.

The longitudinal section shape of each broken layer can be approximately regarded as trapezoid, as shown in Figure 1. For any broken layer, the material mass is:

$$M_i = \mu_i \rho A_i L (i=1,2\ldots n)$$  

(1)

Where $\mu_i$ is the filling factor of the i-th layer; $\rho$ is material density; $A_i$ is the layer area of the i-th layer; $L$ is length of feed inlet.

2.2. Area Calculation of Each Broken Layer

When the moving jaw is in the open position, the filling degree of the material in the crushing chamber is not directly related to the performance value of the liner surface, and the change along the cavity height is small. Therefore, when calculating the relative production capacity and block-up coefficient of the crusher under different cavity shapes, it can be assumed that the filling degree of each layer below the crushing chamber is equal.

As shown in figure 2, for any row of material layers in the crushing chamber, the layer height of the i-th layer by the geometric relationship is:

$$H_i = \frac{s_i + h'_i \tan \alpha}{\tan \alpha}$$  

(2)

The layer bottom width of the i-th layer is:

$$b_{i+1} = b_i + H_i(tan \alpha + tan \beta)$$  

(3)

The layer area of the i-th layer is:

$$A_i = b_i H_i + \frac{H_i^2(tan \alpha + tan \beta)}{2}$$  

(4)

Where $s_i$ is Horizontal stroke of $F'_i$ point on moving jaw tooth surface; $h'_i$ is difference in vertical height corresponding to $s_i$.

The mass ratio of the material in the i-th layer of the crushing chamber to the material in the adjacent (i-1) layer as the blocking coefficient. That is:

$$d_i = \frac{M_i}{M_{i-1}} = \frac{\mu_i \rho A_i L}{\mu_{i-1} \rho A_{i-1} L} = \frac{A_i}{A_{i-1}}$$  

(5)
3. Kinematic Simulation Analysis of Compound Pendulum Jaw Crusher

3.1. Selection of Cavity Shape Scheme

Taking the current common cavity shape scheme as the research object, and the dip of fixed and moving jaw are treated according to the intermediate value. The schematic diagram of various schemes is shown in figure 3.

Scheme 1: Both the fixed and the moving jaws adopt a linear cavity shape, with the fixed jaw dip $\beta = 0^\circ$ and the moving jaw dip $\alpha = 22^\circ$. Because the shape of moving and fixed jaw cavity is straight, the nip angle of each broken layer in the crushing chamber is $22^\circ$.

Scheme 2: The fixed jaw adopts straight cavity shape, the upper part of the moving jaw adopts straight cavity shape and the lower part of the moving jaw adopts curved cavity shape, in which the fixed jaw dip $\beta = 0^\circ$, the moving jaw dip $\alpha = 12^\circ \sim 20^\circ$. The average nip angle of each broken layer in the lower part of the crushing chamber is: $\alpha_{L0} = 12^\circ$, $\alpha_{L1} = 15^\circ$, $\alpha_{L2} = 18^\circ$, $\alpha_{L3} = 21^\circ$.

Scheme 3: The upper part of the fixed and the moving jaw are curved cavities with the lower part of the straight line, in which the dip of the fixed jaw $\beta = -5^\circ \sim 0^\circ$ and the dip of the moving jaw $\alpha = 10^\circ \sim 16^\circ$. The average nip angle of each broken layer in the lower part of the crushing chamber is: $\alpha_{L0} = 12^\circ$, $\alpha_{L1} = 15^\circ$, $\alpha_{L2} = 18^\circ$, $\alpha_{L3} = 21^\circ$.

Scheme 4: The fixed jaw adopts straight cavity shape, the upper part of the moving jaw adopts straight cavity shape and the lower part of the moving jaw adopts curved cavity shape, in which the fixed jaw dip $\beta = -5^\circ$, the moving jaw dip $\alpha = 12^\circ \sim 20^\circ$. The average nip angle of each broken layer in the lower part of the crushing chamber is: $\alpha_{L0} = 17^\circ$, $\alpha_{L1} = 20^\circ$, $\alpha_{L2} = 23^\circ$, $\alpha_{L3} = 25^\circ$.

![Figure 3. Schematic diagram of cavity scheme.](image)

3.2. Modeling of Compound Pendulum Jaw Crusher

The working device of compound pendulum jaw crusher is mainly composed of eccentric shaft, moving jaw and toggle plate, which is a kind of crank-rocker mechanism [4]. The structural diagram of the crusher is shown in figure 4, in which the crank, the connecting rod and the rocker are the specific parts of the eccentric shaft, the moving jaw and the toggle plate of the crusher respectively.
Figure 4. Structure diagram of compound pendulum jaw crusher.

This paper studies the PE1500×1800 compound pendulum jaw crusher, its structural size[5] is: crank length“L₁ = 32mm”; connecting rod length“L₂ = 2730mm”; rocker length“L₃ = 895mm”; frame length“L₄ = 2290mm”. Only kinematics-related factors are considered in the kinematic analysis, regardless of the specific shape of the component[6], so the crusher working device is simplified during modeling. The simplified 3D models of four kinds of cavity working devices are established by using the 3D modeling software, and then imported them into the kinematics simulation software ADAMS. According to the working principle of the crusher, the kinematic pairs are added between the components, and the rotational speed of the eccentric shaft is set to180r/min. The simulation models of different schemes are shown in figure 5.

Figure 5. Simulation model of working device.

3.3. Kinematic Simulation Analysis of Compound Pendulum Jaw Crusher
For scheme 1, firstly, the discharge layer of the crushing chamber is analyzed, and a marked point is set up at point “F₀” of the moving jaw discharge port, and the horizontal and vertical displacement changes of the point are obtained through simulation. As shown in figure 6, the horizontal displacement and vertical displacement curves of the point F₀.
According to the simulation results, the horizontal stroke of $F_0$ is as follows: $s_0 = 46.7564\, \text{mm}$; The difference of the vertical height corresponding to $s_0$ is: $h_0 = 108.0457\, \text{mm}$; According to formula (2), the layer height of discharge layer is obtained: $H_0 = 223.79\, \text{mm}$; According to formula (4), the layer area of discharge layer is obtained:

$$A_0 = b_0H_0 + \frac{h_0\tan\alpha}{2} = 70\, \text{mm} \times 223.79\, \text{mm} + \frac{223.79^2\times\tan\alpha}{2} = 25782.51\, \text{mm}^2$$  \hspace{1cm} (6)

Find the coordinate value of the lower end point $F_1$ of the first layer on the moving jaw according to the layer height of the discharge layer, and establish a marker point to generate the displacement curve of the point in the ADAMS post-processing module.

According to the simulation results, the horizontal stroke of $F_1$ is as follows: $s_1 = 41.5835\, \text{mm}$; The difference of the vertical height corresponding to $s_1$ is: $h_1 = 104.5802\, \text{mm}$; According to formula (2), the layer height of first layer is obtained: $H_1 = 207.49\, \text{mm}$; According to formula (3), the layer width of first layer is obtained: $b_1 = 160.42\, \text{mm}$; According to formula (4), the layer area of first layer is obtained:

$$A_1 = b_1H_1 + \frac{h_1\tan\alpha}{2} = 160.42 \times 207.49 + \frac{207.49^2\times\tan\alpha}{2} = 41982.63\, \text{mm}^2$$  \hspace{1cm} (7)

According to the above method, the layer area of each broken layer in the lower part of the crushing cavity of four cavity shape schemes are calculated in turn, and the area of each broken layer is shown in table 1:

| Scheme | Layer area(\text{mm}^2) | 1       | 2       | 3       | 4       |
|--------|------------------------|---------|---------|---------|---------|
| $A_0$  | 25782.51               | 34399.43| 40841.06| 39106.77|         |
| $A_1$  | 41982.63               | 43494.14| 52887.18| 53449.21|         |
| $A_2$  | 54690.82               | 48552.18| 59849.94| 60597.81|         |
| $A_3$  | 63747.10               | 53863.38| 63319.42| 67305.90|         |
The average nip angle of broken layer in various schemes is shown in table 2:

**Table 2. Average nip angle of each broken layer.**

| Scheme | 1   | 2   | 3   | 4   |
|--------|-----|-----|-----|-----|
| Nip angle(°) | 0   | 22  | 12  | 12  | 17  |
|         | 1   | 22  | 15  | 15  | 20  |
|         | 2   | 22  | 18  | 18  | 23  |
|         | 3   | 22  | 21  | 21  | 25  |

According to the calculation of formula (5), the blocking coefficient of each discharge layer under different schemes is shown in table 3, where $d_1$ is the ratio of the material mass of the first layer to the discharge layer; $d_2$ is the ratio of the material mass of the second layer to the first layer; $d_3$ is the ratio of the material mass of the third layer to the second layer. The blocking coefficient of each broken layer and the relative production capacity of crusher under different schemes are shown in table 3:

**Table 3. Blocking coefficient and relative production capacity of each layer.**

| Scheme | $d_1$ | 1.63 | 1.26 | 1.29 | 1.36 |
|--------|-------|------|------|------|------|
| Block-up coefficient | $d_2$ | 1.30 | 1.17 | 1.13 | 1.14 |
| Relative production capacity(%) | $d_3$ | 1.17 | 1.11 | 1.06 | 1.11 |
|                  | 100   | 133.42 | 158.41 | 151.68 |

According to the crushing process of the crusher, when $d = 1$, the materials in the crushing chamber can enter the next layer smoothly, and when $d > 1$, the blocking will occur, and the larger the $d$ value is, the more serious the blocking will be. From the data in table 3, it can be seen that scheme 1 has the most serious blockage, scheme 2, scheme 3 and scheme 4 have little difference and are all better than scheme 1; scheme 1 has the smallest relative production capacity and scheme 3 has the largest relative production capacity.

### 4. Kinematic Simulation Analysis of Compound Pendulum Jaw Crusher

From the above analysis of the cavity shape of the compound pendulum jaw crusher, it can be concluded that:

1. In scheme 1, both moving jaw and fixed jaw are in straight cavity shape, which is lower in production capacity, more serious in blocking, so it is not suitable to select.

2. In scheme 2, the lower curved cavity shape and the upper straight cavity shape of the moving jaw are adopted, while the fixed jaw adopts the straight cavity shape. The blocking is relatively slight and the relative production capacity is high, so the cavity shape scheme is preferable.

3. In Scheme 3, both the moving and fixed turns are in the shape of the lower curved cavity and the upper curved cavity. The blocking is relatively slight, and the relative production capacity is the highest among the four schemes. In addition, and the dip angles of moving and fixed jaws can be adjusted at the same time to reduce the blocking of crusher. Therefore, the cavity shape is the best among the four schemes.

4. In scheme 4, the lower curved cavity shape and the upper straight cavity shape of the moving jaw are adopted, while the fixed jaw adopts the inclined straight cavity shape. The relative production capacity is high, which has relatively high production capacity, but its high production capacity is obtained at the expense of large nip angles, which is not conducive to the crushing of materials, so this scheme is not advisable.
5. References

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