Study on Kinematics Law of Grinding Medium in Ultra-speed Ball Mill

Shiying Zhao [a], Lin Chang, Xuebin Liu, Mengchao Zhang, Jixiu Xu

College of Mechanical and Electronic Engineering, Shandong University of Science and Technology.

Qingdao 266590, China.

[a]2546190056@qq.com

Abstract

Three stages of grinding media movement for super-speed ball mill:Circular motion phase、sliding along the guide plate、 parabolic impact ore phase，The motion law of grinding medium in super-speed ball mill was studied.The trajectory equation of the grinding medium of the super-speed ball mill, the impact velocity of the ore, the impact force formula and the number of impacts are obtained.

Keywords

Super-speed ball mill,grinding medium, kinematics.

1. Introduction

Studying the movement mode of grinding media in the ball mill and its influencing factors is one of the main contents of grinding theory research. The grinding power consumption, steel consumption and grinding production index are directly related to the movement mode of the medium in the mill.The super-speed ball mill is a new type of grinding equipment based on the theory of super-gravity. It guides the steel ball and ore through the guide plate of the guiding mechanism of the ball mill cylinder, and makes the movement of the steel ball and ore under supercritical speed. It is a parabolic trajectory that is beneficial to the grinding process, so that the ore is ground efficiently and quickly, and the grinding production capacity and grinding efficiency are greatly improved. It is the guiding mechanism that enables the super-speed ball mill to grind normally at critical speeds, but the state of movement of the grinding media is quite different from that of conventional ball mills. Through the study of the kinematics of grinding media, the motion law of grinding medium in super-speed ball mill is discussed.Promote the industrial design and production of ultra-fast ball mills.

2. Grinding Principle of Super Fast Ball Mill

As a new type of grinding equipment, the super-speed ball mill has a very different grinding principle than conventional ball mills. When the super-speed ball mill is operated at the specified supercritical speed, the ore and grinding medium are rubbed by gravity, the friction between the ball mill liner and the grinding medium, and the centrifugal force generated by the rotation of the ball mill cylinder. The mineral medium and the ore together make a circular motion with the wall of the cylinder. When moving to the highest point of the barrel of the ball mill, the grinding medium and the ore hit the guiding mechanism, and the guiding plate will change the grinding medium and the ore to change the original centrifugal trajectory, so that According to the designed parabolic trajectory, when thrown into the corner area of the barrel of the ball mill, it will impact the ore in the area of the drop point with a large impact force, so that the ore is subjected to a large impact and is ground. It is the unique grinding principle of the super fast ball mill.

Fig.1 shows the three main stages of the grinding medium and ore in the super-speed ball mill under normal conditions: The first stage is that under the action of the above three forces, the steel ball moves circumferentially with the mill barrel to the highest point of the barrel of the ball mill; the second stage is that the steel ball slides over the surface of the guide plate of the guiding mechanism;

After the steel ball is separated from the surface of the guide plate, it is parabolically moved to the bottom of the cylinder to impact the ore in the falling area at a large impact speed.

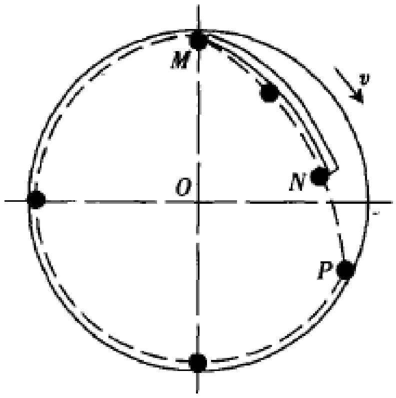

Fig.1 The trajectory of the steel ball in the super fast ball mill

3. Stress Analysis of Grinding Medium in the Stage of Circular Motion

When the super-speed ball mill is working, the steel ball in the cylinder is subjected to the other two forces in addition to its own gravity G . One is the friction between the steel ball and the cylinder liner and the relative sliding between the steel ball and the steel ball. The force f , the second is the normal reaction force N of the lining on the steel ball.

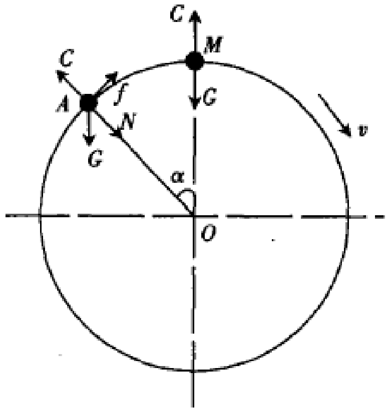

Fig.2 Stress state of steel ball in circular motion

The super-speed ball mill has a radius R and a rotation speed of n . A steel ball in the outermost layer of the ball mill cylinder is taken as the research object. The angle α between the steel ball and the vertical axis at any instantaneous position in the cylinder For a, the force state of the steel ball as it moves in the cylinder is as shown in Fig. 1.

$$N + G\cos\alpha = C \tag{1}$$

For the outermost steel ball, because the friction is very large, the sliding relative to the cylinder wall can be neglected, so the movement path of the steel ball at this stage is an arc, and the speed is the circumferential linear velocity.

Since the speed of the super-speed ball mill is more than 1 times of the critical speed of the conventional ball mill, the steel ball in the super-speed ball mill can make a circular motion along the cylinder.

4. Motion Analysis of Steel Ball Sliding Through Guide Plate Stage

When the steel ball runs along the cylinder to the guiding mechanism of the super-speed ball mill cylinder, it is assumed that there is no friction and energy loss during the whole process of the steel ball sliding from the guide plate, and the steel ball is subjected to its own gravity and the guide plate is reversed. The role of force. The steel ball medium is regarded as a mass point, and the guide plate is regarded as a rigid body, and the center point O of the super-speed ball mill cylinder is taken as the coordinate origin. The two axes are in the horizontal direction and the y axis is in the vertical direction. Fig.2 is a schematic diagram of the motion analysis of the steel ball in the stage of sliding over the guide plate.

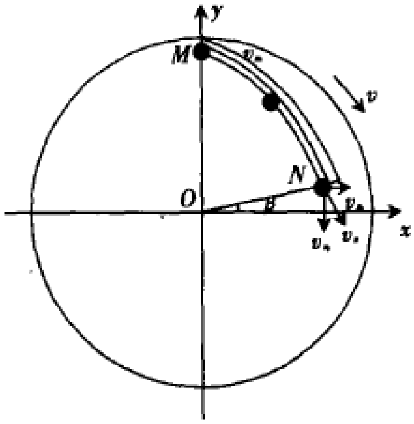

Fig.3 Motion analysis of steel ball sliding over guide plate

Can find the speed of the steel ball at the N point

$$v_N = \sqrt{v^2_M + 2gH} = \sqrt{v^2_M + 2g(R - y_0)} \tag{2}$$

After the steel ball is disengaged from the guide plate, since it is only subjected to the action of gravity, the steel ball will make a parabolic motion and enter the third stage of the super-speed ball mill, that is, the parabolic motion stage.

5. Motion Analysis of Steel Ball During Parabolic Motion

Similarly, the steel ball medium is regarded as a mass point, and the end point N of the guide plate is taken as the coordinate origin, and the inferior coordinate system is shifted by x_0 and y_0 units in the horizontal direction and the vertical direction, respectively, and the new coordinate system $x'Ny'$ is set up.In the new coordinate system, the motion law of the steel ball during the entire parabolic motion phase is analyzed. Fig.3 is a schematic diagram of the motion analysis of the steel ball during the parabolic motion phase.

The trajectory equation for the ball drop in the xoy coordinate system can be found as:

$$y - y_0 = -\frac{1}{2} g \frac{x_0^2 + y_0^2}{y_0^2[v^2_M + 2g(R - y_0)]}(x - x_0)^2 - \frac{x_0}{y_0}(x - x_0) \tag{3}$$

It can be known from formula (3) that when the position of the super-speed ball mill guide plate in the ball mill cylinder is different, the parabolic trajectory of the steel ball movement is also different, that is, the parabolic trajectory equation and the super-fast ball mill guide plate are in the ball mill barrel. The location of the body is related.

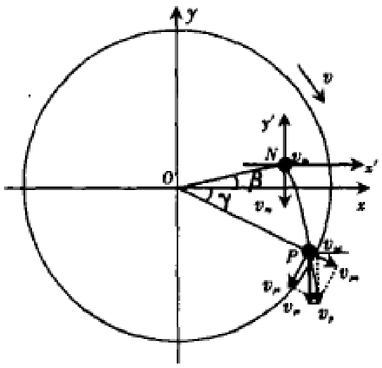

Fig.4 Motion analysis of steel ball during parabolic motion

6. Calculation of Impact Velocity and Impact Force of Steel Ball Against Falling Ore Area

In the schematic diagram of the mechanical analysis of the parabolic motion phase of the steel ball as shown in Fig. 4, the equation of the super-speed ball mill cylinder in the xoy coordinate system can be expressed by the following formula：

$$x^2 + y^2 = R^2 \tag{4}$$

In the middle: R——The barrel radius of the super fast ball mill.

Assume that the steel ball impacts the falling point P on the ball mill cylinder along the parabolic trajectory.Its coordinates are($R\cos\gamma, R\sin\gamma$),The impact velocity when the steel ball is thrown to the P point is obtained by the law of conservation of energy:

$$v_p = \sqrt{\frac{n^2\pi^2R^2}{900} + 2gR(1-\sin\gamma)} = \sqrt{\frac{n^2\pi^2R^2}{900} + 2g(R-y_p)} \tag{5}$$

It can be seen from equation (5) that the impact velocity of the steel ball on the ore is determined by the rotational speed of the ball mill, the radius of the cylinder, and the position of the falling point of the steel ball.

The impact force F is:

$$F = \frac{m^{3/5}v_{pn}{}^{6/5}}{4.37k^{2/5}} = 0.23[(m^3 v_{pn}{}^6)/k^2]^{1/5} \tag{6}$$

In the middle : m——Single steel ball quality, kg ;

v_{pn}——The initial velocity of the steel ball in the direction of the normal direction of the impact， m/s ;

k——Calculation coefficien $k = (0.665\alpha)^{3/2}(\frac{1-v_1^2}{E_1} - \frac{1-v_2^2}{E_2})\left(\frac{2R_2 - R_1}{R_2R_1}\right)^{0.5}$;

In the middle:

R_1——Steel ball radius, m ; R_2——Effective radius of the cylinder, m ;

α——coefficient， $\alpha = [\frac{1}{2}(\frac{1}{R_1 - R_2})]/(1/2R_1) = 1 - \frac{R_1}{R_2}$;

When R_1 and R_2 are very different, you can think $\alpha \approx 1$;

v_1——Poisson's ratio of steel ball material;

v_2——Poisson's ratio of the liner material;

E_1——The modulus of elasticity of the steel ball material, MPa;

E_2——Elastic modulus of the cylinder liner material， MPa.

7. The Number of Steel Ball Impacts in the Super Fast Ball Mill

Let t_1 be the time for the steel ball to make a circular motion, t_2 is the time when the steel ball slides over the guide plate, and t_3 is the time when the steel ball breaks off the guide plate and hits the ore.The time required for the steel ball to circulate once is:

$$t = t_1 + t_2 + t_3 = \frac{30}{n} + \frac{15\sqrt{3}}{n\pi} + \frac{15}{2n} = \frac{15(5\pi + 2\sqrt{3})}{2n\pi}$$

The number of impacts of the super-speed ball mill in one week is:

$$J = \frac{60/n}{t} = \frac{8\pi}{5\pi + 2\sqrt{3}} \quad (7)$$

It can be seen from the formula (8) that the number of impacts of the steel ball when the super-speed ball mill rotates one week is a certain value, and has nothing to do with the cylinder radius R and the rotational speed n.

8. Conclusion

By discussing the kinematics of the grinding medium of the super-speed ball mill, the following conclusions are drawn:

1.The grinding medium movement of the super-speed ball mill is divided into three stages: a circular motion phase, a sliding phase along the guide plate, and a parabolic impact phase;

2.The trajectory equation of the parabolic motion phase of the grinding media of the super-speed ball mill is:

$$y - y_0 = -\frac{1}{2} g \frac{x_0^{\ 2} + y_0^{\ 2}}{y_0^{\ 2}[v^2{}_M + 2g(R - y_0)]}(x - x_0)^2 - \frac{x_0}{y_0}(x - x_0)$$

The impact speed of the steel ball is:

$$v_p = \sqrt{\frac{n^2\pi^2R^2}{900} + 2gR(1 - \sin\gamma)} = \sqrt{\frac{n^2\pi^2R^2}{900} + 2g(R - y_p)}$$

The impact is:

$$F = \frac{m^{3/5} v_{pn}^{\ 6/5}}{4.37k^{2/5}} = 0.23[(m^3 v_{pn}^{\ 6}) / k^2]^{1/5}$$

3.The super-speed ball mill rotates for one week, and the impact of the steel ball on the ore is:

$$J = \frac{60/n}{t} = \frac{8\pi}{5\pi + 2\sqrt{3}}$$

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