Design of Three-chamber Ball Mill

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Abstract: Ball mill is a kind of raw material processing machinery which plays the role of grinding. Its working principle is that the movement and force are transmitted to the barrel of ball mill through reducer, transmission shaft and hollow shaft by motor. Through the continuous turnover movement of the cylinder, the grinding medium inside the cylinder is driven to crush and grind the materials. So as to obtain the product with suitable particle size. According to the specifications and parameters of the ball mill, the general layout, grinding body, lining plate, partition device, support device, transmission part and feeding and discharging device of the ball mill are designed. In this paper, the design method of three chamber ball mill is introduced. Compared with the design of Φ 3.5 × 13m three-chamber ball mill, the design process of ball mill is described in detail.

1. Introduction

Ball mill is a kind of raw material processing machinery, not only widely used in building materials industry, but also in industrial production such as mineral processing, chemical industry, metallurgy, etc. The main function is to further crush and grind the raw materials processed by crushing machinery through the ball mill [1] . The low-speed rotating cylinder is the main working part of the ball mill. It is mounted on two large bearings. The cylinder has a grinding body responsible for crushing and grinding. The inner wall of the cylinder is equipped with various forms of lining plates, whose function is to prevent the cylinder from being damaged by the grinding body and material wear [2] . The grinding body has two kinds of motion states: sliding and rolling, so that the material, the liner, and the grinding body have a grinding effect to grind the material. Since the material is always forced to feed at the feed port, and then follow the cylinder to make a rotary motion, there is a difference in material level between the feed end and the discharge end. Therefore, although a ball mill shell arrangement is placed horizontally, however the moving direction of material flow is slow discharge end. The three-chamber ball mill designed in this paper can improve production efficiency, improve product quality, and reduce production costs. It is of great significance in industrial production such as mineral processing, chemicals, building materials, and metallurgy [3] .

2. The Overall Layout and Structure of the Ball Mill

As a raw material processing machine, the ball mill does not exist alone. In the entire grinding system, including crushing machinery, grinding machinery and ultra-fine grinding machinery, in cement, chemical and other building materials industries, it is often used in conjunction with drying equipment. Therefore, not only the design of the mechanical equipment itself must be considered, but also various factors must be considered comprehensively, such as: the process of the grinding workshop, the design of the civil engineering and the drainage channel, and the production management. Only by designing a
reasonable overall layout and structure of the ball mill can the ball mill take advantage of the machine's advantages and produce qualified products.

When determining the center height of the mill, not only the requirements of the transmission device of the ball mill must be considered, but also the convenient operation when cleaning and pouring the grinding body. \( \Phi 3.5 \times 13 \) m three-chamber ball mill height of the center of the diameter of the mill taken 0.8 times.

\[ h = 0.8D = 2.8 \text{(m)} \]

In a grinding workshop, the distance between the two equipment directly affects the installation, operation and maintenance of the ball mill. Generally the spacing of the diameter of the ball. 3-5 times \( \Phi 3.5 \times 13 \) m three-chamber ball mill pitch diameter of the mill taken 4 times.

\[ l = 4D = 14 \text{(m)} \]

The turning of the ball mill refers to the turning of the barrel of the ball mill when it is working normally. In order to ensure the direction specification, it is stipulated to look from the discharge end to the feed end. In the design of the \( \Phi 3.5 \times 13 \) m three-chamber ball mill, clockwise is selected as the normal ball mill steering at work.

![General arrangement of the mill](image)

**Figure 1. General arrangement of the mill**

### 3. Process Parameters and Specifications of Ball Mill

#### 3.1. The appropriate speed of the ball mill

When the ball mill is working normally, the motion state of the grinding body of the ball mill is related to its speed. Different speeds correspond to different forms of motion of the grinding body. Therefore, the design of the speed is very important for the ball mill. It determines the normal operation of the ball mill, and it also affects the output of the ball mill, the type of grinding body, wear of liner and cylinder.

When the grinding body in the ball mill can work at the maximum production capacity, that is, the cylinder body brings the steel ball to the highest point, and then the steel ball falls to crush the ground material. At this time, the rotation speed of the cylinder body is called the appropriate rotation speed of the ball mill:

\[ n = \frac{32}{\sqrt{D}} = 17.105(\text{r} \text{/ min}) \]

#### 3.2. The power of the ball mill

According to the calculation of the ball mill power at home and abroad, the correction formula of the former Soviet Union’s Tovalov formula is adopted:

\[ P_0 = 0.184DV\eta\phi(6.16 - 5.75\phi) = 1680.456(\text{kW}) \]

In actual production practice, consider not only the theoretical power mill, but also the ball mill grinding method and transmission mode into account, which requires the introduction of the power factor \( K \), determining a power coefficient \( K \) ranges 1.30 - 1.35. Calculated as follows:

\[ P = KP_0 = 2184.593(\text{kW}) \]

According to the required power of the ball mill to select the appropriate motor, the selection is the formula:

\[ W > P = 2184.593(\text{kW}) \]

The motor model of \( \Phi3.5 \times 13 \) m three-chamber ball mill is Y2500-12/2150 large asynchronous motor.
3.3. Production capacity of ball mill
The production capacity of the ball mill is the grinding capacity of the ball mill. Now the common general calculation method is used to determine the production capacity of the ball mill. The formula is as follows.

\[ Q = P_0 \times q_0 = 101(t/h) \]  

(7)

The calculation formula for the annual production capacity of the ball mill is as follows:

\[ Q_n = 8760Q = 7.08 \times 10^5(t/\text{y}) \]  

(8)

3.4. Grinding body of ball mill
Ball mill is the use of grinding body in the ball mill barrel movement and then grinding and grinding materials, so in production practice, the consumption of grinding body is very serious, accounting for about 80% to 90% of the total metal consumption. Therefore, it is very important to correctly select the abrasive body of each chamber, reasonably determine the filling rate of the abrasive body, and reasonably determine the gradation of the abrasive body. This not only helps to reduce the metal content, but also improves the production efficiency and ensures the normal operation of the ball mill. According to the shape of grinding body, it can be divided into ball type, segment type and bar type. In the \( \Phi 3.5 \times 13 \)m three chamber ball mill, ball grinding body is selected for the first and second chamber, and the average ball diameter of the second chamber is smaller than that of the first chamber, and the segment type grinding body is selected for the third chamber.

The filling rate of the grinding body is the ratio of the volume of the grinding body in the ball mill to the effective volume of the ball mill. According to the investigation and research of ball mills at home and abroad, the filling rate of grinding body of \( \Phi 3.5 \times 13 \)m three-chamber ball mill is determined by using similar analogy method, as shown in Table 1.

| Chambers name | Grinding body filling rate (%) |
|---------------|-------------------------------|
| No.1 chamber  | 30                            |
| No.2 chamber  | 27                            |
| No.3 chamber  | 24                            |

Table 1. Filling rate of grinding body in each chamber of ball mill

When the ball mill is in normal operation, due to the frequent direct contact between the grinding body and materials and lining plate, different degrees of wear will occur, resulting in different diameters of grinding bodies in each chamber. Therefore, when adding new grinding bodies, the grading of grinding bodies in each chamber should maintain the stable state during normal operation, that is, several grinding bodies of different specifications should be selected for use together.

The grading selection of each chamber is shown in Table 1.
Table 2. Selection of grading and ball diameter for each chamber of ball mill

| Chambers name | Grinding body grading (mm) | Average ball diameter (mm) |
|---------------|----------------------------|---------------------------|
| No.1 chamber  | Φ90, Φ80, Φ70, Φ60          | Φ70                       |
| No.2 chamber  | Φ50, Φ40, Φ30              | Φ40                       |
| No.3 chamber  | Φ25×25, Φ20×25             | —                         |

4. Grinding Body of Ball Mill

The grinding body is an important component of ball mill, which mainly plays a bearing role. The load mainly includes: self weight of grinding body, lining plate and its connecting parts, grinding body, partition plate, discharge grate plate, transmission connecting pipe, connecting flange, discharging mechanism and dynamic load in grinding process. The grinding body is composed of the barrel and grinding head (cylinder end cover and hollow shaft) and its connecting parts. In the design, the requirement is that it can keep continuous operation for a long time under the alternating stress of low speed and heavy load.

4.1. Cylinder

The cylinder of Φ3.5×13m three-chamber ball mill is an integral structure, which is conducive to reduce manufacturing and assembly errors and reduce production costs. The thickness of the cylinder is determined to be 35mm. The end covers at both ends are directly connected with the cylinder, and the connection form between the end cover and the cylinder is flange connection. The advantages of this welding structure are convenient manufacturing, simple structure and long service life.

4.2. Grinding head

The part composed of the cylinder end cover and hollow shaft is called the grinding head of the ball mill, which is the weakest link of the ball mill. The reason is that it needs to bear the dynamic load of the grinding body and the grinding body, and needs to work continuously under the action of alternating stress. Therefore, it is very important to consider the reliability and production cost of grinding head. The connection mode of cylinder end cover and hollow shaft is welding.

The end cover of Φ3.5×13m three-chamber ball mill is cast end cover, which is characterized by easy modeling and low cost. QT40-17 nodular cast iron is selected as the casting end cover material of flange connection, which is characterized by high toughness, which is conducive to improving its service life. ZG230-450 cast steel is selected as the material of the hollow shaft of grinding head. After normalizing treatment, it is characterized by good welding performance.

4.3. Transmission connecting pipe

The application of transmission connecting pipe is central transmission, its function is: transfer
movement and force, transport materials and ventilation. Both ends of the transmission connecting pipe are designed with connecting flanges, which are respectively connected with the hollow shaft and transmission shaft of the ball mill.

![Figure 3. Transmission connecting pipe](image)

5. Lining Plate
When the ball mill is in normal operation, the relative movement of the grinding body will cause impact damage to the cylinder and even affect the normal operation of the equipment. Therefore, a kind of part is needed to isolate the grinding body from the cylinder, and play the role of crushing and grinding, so as to improve the production efficiency. Therefore, the design of ball mill liner plays an important role in the overall design. Fatigue wear, fatigue fracture and plastic deformation are the main failure modes of ball mill liner.

In the design of Φ3.5×13m three-chamber ball mill, the lining plate is made of high manganese steel, the step lining plate is selected for the first and second chamber, and the flat lining plate is selected for the third chamber. The grinding head liner is designed as triangular thickened grinding head liner. The triangular method is adopted to thicken the grinding head liner in the maximum wear area, which greatly improves the service life of the liner, improves the production efficiency and reduces the production cost. The step lining plate and grinding head lining plate are fixed with bolts; the flat lining plate is fixed without bolts.

6. The Obstructing Equipment
Φ3.5×13m three-chamber ball mill consists of three compartments: coarse grinding chamber, transition chamber and fine grinding chamber. The obstructing plate plays a very important role in the normal operation of ball mill. Its functions are: first, separating the grinding body; second, preventing large particles from channeling to the discharge end; third, adjusting the flow rate of materials; fourth, acting as the support of the cylinder. The connection mode between the obstructing plate and the ball mill cylinder is bolt connection. In the selection of the obstructing plate, the double-layer obstructing plate is selected between the coarse grinding chamber and the transition chamber, and the single-layer obstructing plate is selected between the transition chamber and the fine grinding chamber.

7. Supporting Device
The main motion of the ball mill is the rotary motion of the cylinder, so it is very important to design the supporting device of the rotary part. The support device of ball mill adopts outer spherical sliding main bearing, which is characterized by high reliability, stable movement, low noise, strong vibration absorption capacity, large impact load, strong heat dissipation capacity and long-term normal operation.

8. Transmission
As a kind of raw material processing equipment, the working environment of ball mill is relatively bad. It needs to be able to realize long-term full load continuous operation under the conditions of low speed, heavy load and constant speed. Therefore, the requirements for the transmission device of ball mill are relatively high, so the design of transmission device is an important part of ball mill design. There are two kinds of transmission modes of ball mill: edge drive and center drive. The center drive is selected in the design of Φ3.5×13m three-chamber ball mill. Compared with the edge drive, the center drive has the advantages of compact structure, high space utilization rate and high transmission efficiency. However, there are also some shortcomings, such as high requirements for manufacturing accuracy, high requirements for material quality and heat treatment.
9. Feed and Discharge Devices
The screw feeding device is selected for the feeding device of $\Phi3.5\times13m$ three-chamber ball mill. It is a forced feeding device with large feeding amount, which is conducive to improving the production efficiency [5]. The discharging device is the tail discharge device. The sealing device adopts felt sealing mode, which is simple in structure, low in price and easy to replace. It is a very economical and widely used sealing method.

6. Conclusion
In this paper, the design requirements of each part of the ball mill are briefly described. At the same time, the design calculation of $\Phi3.5\times13m$ three-chamber ball mill is carried out. The production efficiency and production cost of the ball mill are comprehensively considered, so that it can achieve continuous and stable operation under the maximum power operation requirements.

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