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DESIGN AND ANALYSIS OF AUTOMATIC OPENING AND CLOSING MANIPULATOR FOR ORE CRUSHING BALL MILL COVER

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The automatic design of cap opening and closing of steel slag ball mill is the key to solve a series of problems caused by frequent cap opening and closing. In this paper, the automatic capping manipulator is designed for a steel slag ball mill in a factory, especially for the automatic tightening and loosening of the cap bolt, the grasping and transporting device of the cap, to ensure the safety and reliability of the design.

Keywords: ore processing; ball mill; stress; strain; Finite Element Analyses (FEA)

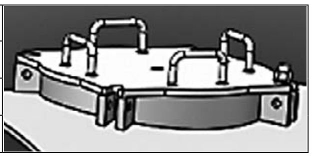
INTRODUCTION

In the metallurgical industry, the steel slag ball mill plays a crucial role in ore grinding and metallurgical waste treatment by effectively crushing ores or waste materials to achieve the desired particle size and chemical composition. Currently, the ball mill features a high head and heavy cover, necessitating frequent manual opening and closing during feeding and retrieval processes. [1] This approach is not only inefficient but also highly inconvenient. Moreover, due to the elevated temperature inside the ball mill cylinder, opening the cover poses potential risks. Therefore, it is imperative to automate the lid opening and closing mechanism. [2]

The grinding cover of a ball mill in a factory serves as an example. Table 1 presents the relevant technical parameters. The objective is to design a manipulator positioned directly above the grinding cover for automated opening and closing operations.

Table 1 **Technical parameters**

Param	Data
Mess/kg	95
Handlebar spacing/m	0,42
Bolt spacing/m	0,641



Overall design scheme

Automatic opening and closing requirements: screw out the four bolts on the feeding flange of the ball mill; Grab the mill cover and move it to the predetermined position; Screw in the four bolts and attach the grinding cover to the flange seat. [3] The design difficulty of the lifting and closing manipulator is the automatic tightening and loosening of the bolt device and the grasping device of the grinding cap.

According to the technical parameters and practical requirements, a two-degree-of-freedom cartesian coordinate type automatic opening and closing manipulator of the ball mill is designed, as shown in Figure 1. The main structure consists of two parts: a walking mechanism and an end effector. 1 and 2 are travelling mechanisms that transport the grinding cover to a given position along the X and Y axes. [4] Gripper 3 and tightening device 4 form the end actuator, tighten or loosen the connecting bolt of the grinding cover, and grab the grinding cover and place it in the specified position.

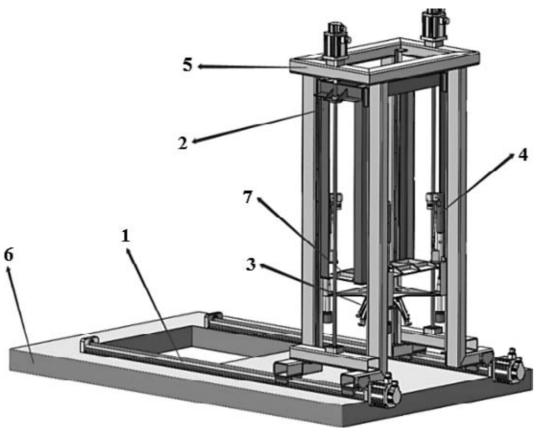


Figure 1 Automatic opening and closing manipulator.
1-X axis mechanism; 2-Z axis mechanism;
3-Gripper; 4-Tightening device; 5-rack; 6 -Platform;
7- Supporting plate

MANIPULATOR STRUCTURE DESIGN

Walking mechanism

The X and Z-axis mechanisms are composed of servo motors, linear guides and ball screw drives. Linear

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guides guide and support the manipulator, so the ball screw is not subject to radial forces. The Z-axis screw drives the Z-axis mechanism and the bracket, which is equipped with an end effector.

End effector

As shown in Figure 2, the manipulator end actuator realizes the screwing in and screwing out of the four slipknot bolts on the grinding cover and grabs the grinding cover and places it in the designated position.

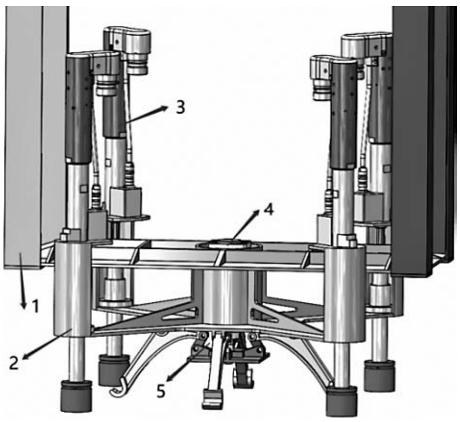


Figure 2 End-effector. 1-Bracket; 2-Supporting plate; 3-Bolt tightening device;4-Grip cylinder; 5-Manipulator

Bolt tightening device

Pre-tightening force and tightening moment are the key factors in bolt tightening process. [5] In order ensure that there is no gap or loosening of the connected part, the thread should be pre-tightened. The tightening torque is the most important parameter to measure the tightening effect. The tightening torque consists of two parts: the friction torque T_1 between the support surface and the nut and the friction torque T_2 between the threads, then the tightening torque is:

$$T = T_1 + T_2 = F' \cdot \frac{d_2}{2} \tan(\psi + \rho_v) + \mu F' \frac{D_0^3 - d_0^3}{3(D_0^2 - d_0^2)} = K_t F'd \quad (1)$$

Where: T is bolt tightening torque/$N \cdot m$, F' is preload/N, K_t is the Tightening torque factor is related to the thread rise angle and contact friction parameters, d is nominal diameter of the screw/mm.

The key to tightening and loosening the nut is precise torque control. The design bolt tightening device is shown in Figure 3, which is composed of tightening shaft unit, connecting support and sleeve unit. The tightening shaft unit consists of a servo motor, a torque sensor, a laser sensor and an encoder to provide the torque required for bolt tightening. The sleeve unit magnetically holds the bolt for tightening. The sleeve can be replaced according to the bolt type.

In order to ensure that the front end sleeve of the tightening shaft accurately wraps the nut, a laser sensor is installed in one of the four bolted tightening shafts. When unscrewing the nut, tighten the shaft and turn at a

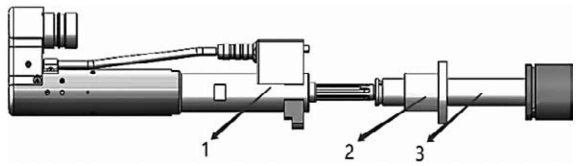


Figure 3 Bolt tightening device. 1-Tighten the shaft; 2-Connecting support; 3-Magnetic sleeve

low speed until the torque value is not less than 5 N*m. Drag torque is also measured when the nut is inserted. If the torque increases sharply, it indicates that the bolt is stuck, and the tightening shaft will stop working and issue a warning.

Manipulator

After the bolt is tightened and the bolt is removed, the grinding cover is separated from the ball mill cylinder by a mechanical gripper. Figure 4 shows the working condition of grasping the grinding cover. The gripper is composed of a drive cylinder and a hinge four-bar mechanism, a total of four groups, corresponding to four lifting lugs. When the cylinder is working, the four-bar mechanism moves, the rocker hooks the lifting lug, and the Z-axis screw starts to lift the grinding cover.

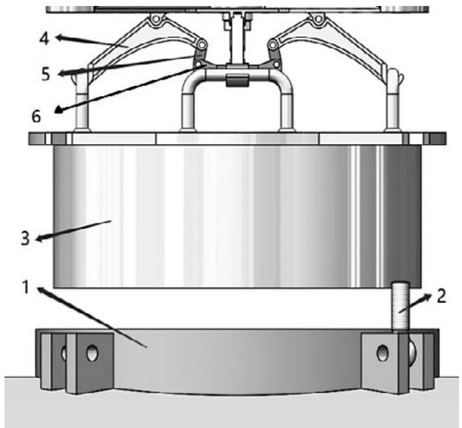


Figure 4 Manipulator. 1-ylinder; 2-slipknot bolt; 3-Grinding the lid; 4-Gripper rocker; 5-connecting rod; 6-cylinder push rod

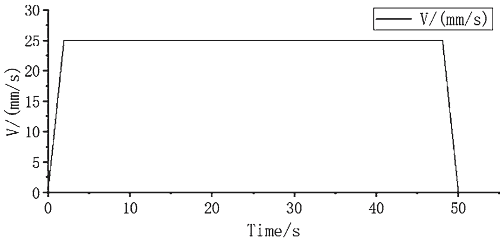
Kinematic analysis

Kinematic analysis of the automatic opening and closing process was performed in SolidWorks Motion module. Figure 5 shows the Z axis velocity and acceleration curve.

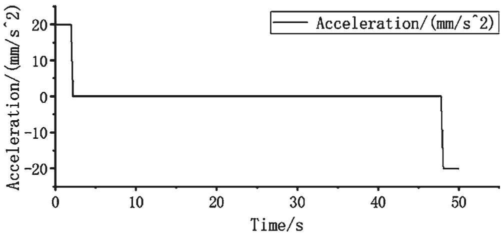
Finite element analysis

The end actuator is responsible for opening the cover, and the key bearing parts include Z-axis bracket, lead screw, mechanical gripper, etc., all of which are made of 45 steel with a yield limit of 350 MPa.

The key bearing parts of Z axis are analyzed by finite element method.



a) Velocity curve

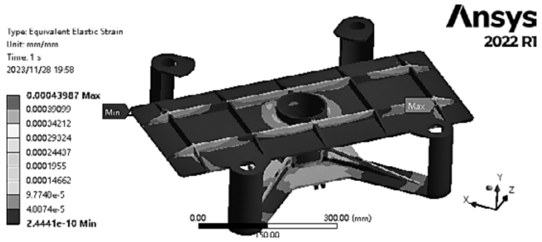


b) Acceleration curve

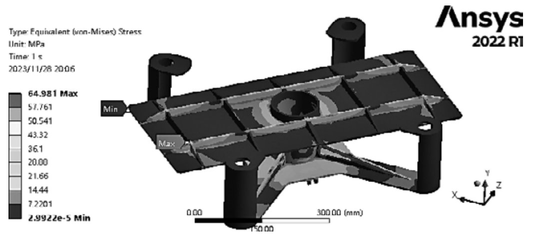
Figure 5 Velocity and acceleration curves of Z-axis mechanism

Static analysis of Z-axis pallet

The Z-axis bracket is connected to the Z-axis lifting mechanism, and the bolt is fixed to tighten the shaft and the mechanical gripper. The load is the total weight of the entire Z-axis assembly and the grinding cap, and the force exerted by the mechanical gripper on the Z-axis bracket when it grabs the grinding cap. The load of the bracket is 1 225 N, the reaction force of the cylinder to the bracket is 1 355 N, and the equivalent elastic strain and stress of the Z-axis bracket are obtained by applying the corresponding load analysis, as shown in Figure 6.



a) Equivalent elastic strain

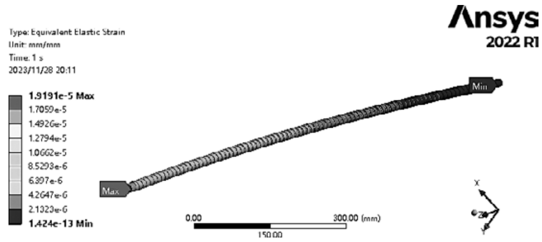


b) Equivalent stress

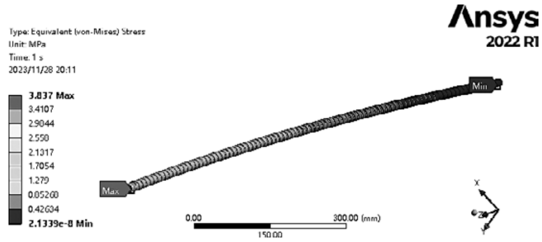
Figure 6 FEA of Z-axis plate

Static analysis of Z axis lead screw

The Z-axis lead screw drives the Z-axis bracket, manipulator assembly and grinding cover to move, and the maximum load is 152kg. The equivalent stress-strain cloud diagram obtained from the analysis is shown in Figure 7.



a) Equivalent elastic strain

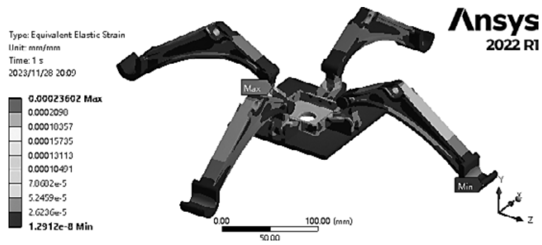


b) Equivalent stress

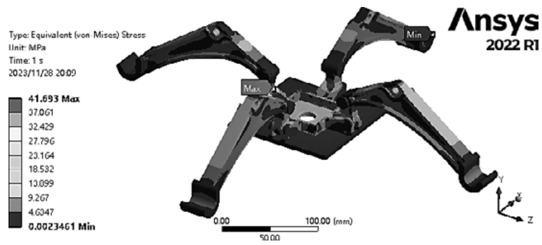
Figure 7 FEA of Z axis lead screw

Statics analysis of manipulator

The manipulator exerts a force of 1355N through the gripper cylinder. The force analysis of the gripper rocker determines that the grinding cap applies a resistance of 931N. Figure 8 illustrates the nephogram depicting the analyzed equivalent strain and equivalent stress of the gripper.



a) Equivalent elastic strain



b) Equivalent stress

Figure 8 FEA of manipulator

Statistics of FEA data of several bearing parts are shown in Table 2.

Table 2 **Result of finite element analysis**

unit	Maximum stress /μm	Maximum deformation /MPa
Z-axis pallet	0,43987	64,981
Z axis lead screw	0,019191	3,837
manipulator	0,23602	41,693

CONCLUSION

In order to enhance the efficiency and reduce the risk associated with manual opening and closing of the grinding cap of a steel slag ball mill, an automated manipulator capable of performing these tasks has been designed. The key findings are as follows:

The two-degree-of-freedom Cartesian manipulator achieves precise positioning and transportation of the grinding cover. The end actuator of the manipulator has been designed and calculated based on bolt tightening requirements.

Simulation tests have been conducted to validate automatic positioning, release nut tightening, grabbing and moving/resetting of the grinding cover, ensuring that all motion characteristics meet specified criteria.

Static analysis has been performed on bearing components of the manipulator, resulting in an equivalent stress-strain cloud map. Although maximum equivalent stress, total strain, and total deformation occur at the Z-axis bracket, they remain well below allowable limits. This confirms that all critical components are adequately strong and appropriately designed.

The manipulator features a simple yet practical structure with reasonable positioning capabilities and a large gripping capacity. It can be easily expanded for multi-station operations while providing valuable insights for further enterprise development.

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Note: The responsible translator for English language is T.X. Zhang - NCST.