Study on the Cleaning Device of Cement Silo Wall

Honghua Zhao*, Zhitong Hu, Jian Zhao, Xuyin Gong, Qifei Han and Yifei Lin
School of Mechanical Engineering, University of Jinan, Jinan 250022, China
*me_zhaohhi@ujn.edu.cn

Abstract. The traditional way of cleaning the cement storehouse wall is manual storage, which is very dangerous. The collapse of the accumulated material causes casualties. In view of the current needs of cleaning, this paper designs a kind of machine which is suitable for the cleaning of domestic cement warehouse. The machine has the advantages of light weight, assembling and being suitable for any diameter warehouse. In this paper, the design scheme and mechanical structure of the machine are studied, and the working principle of the device is introduced. Finally, the static analysis of the finite element software is used to check the key parts and verify the correctness of the design scheme.

1. Introduction
With the rapid development of industrialization, the output of cement is increasing day by day, which puts forward higher requirements for cement storage. The cement silo is poured with concrete, with cylindrical shape. Due to the obvious gap in the output of domestic cement plants, the diameter of cement silos on the market is different. Taking the cement plant of the 2500 ton production line as an example, the size of the cement warehouse is 10m, 12m and other diameter sizes; the size of the 6500 ton cement warehouse is 15m and the size of the 10000 ton cement warehouse is 20m, 22m and other sizes. In the process of cement storage, the cement will harden in the warehouse and block the cement warehouse, which will lead to the failure of normal use of the cement warehouse and affect the production of the enterprise [1,2]. Therefore it is very important to clean up the cement warehouse. The traditional manual warehouse cleaning method is very dangerous, and the collapse of accumulated materials causes casualties.

Therefore, it is of great research value and application value to replace workers with cement warehouse cleaning machines, but at present, there are not many researches on cleaning machines at home and abroad, especially at home. Gironet products produced by French standard industry company are widely used in large warehouse cleaning operations [3], which can clean 2-14m in diameter and 47m in depth. No need to enter the warehouse for cleaning, simple operation and effective cost saving. Zhan Feng [4] of Shandong University of science and technology and other researchers have developed the underground coal bunker cleaning robot, which can effectively solve the problems of underground manual cleaning coal bunker, such as high risk, time-consuming and laborious. Cao have been studying the granary cleaning robot for a long time [5]. Zhang designed a kind of arm type coal bunker cleaning device based on hydraulic drive [6]. Steel cat Technology Co., Ltd. has manufactured a machine for cleaning the wall of cement warehouse, which is hydraulically driven, with complex equipment and heavy operation. At present, the existing cleaning equipment in China has the limitations of large weight, large volume and large opening on the top of the warehouse, which can not meet the cleaning requirements of large-scale cement warehouse in China. Therefore, it is of great significance to study a set of equipment suitable for the cleaning of cement warehouse in that year.
2. Overall structure scheme design
According to the actual structure and size of the cement warehouse, as well as the current effective cleaning methods of the cement warehouse. The overall structure of the cleaning device of the cement silo designed in this paper is shown in Figure 1. The whole structure is composed of two parts: the upper mechanism on the top of the storehouse and the lower mechanism in the storehouse. The upper mechanism of the storehouse top is composed of a support frame, a fixed base, a worm gear mechanism, a manual winch and a hose winch. The mechanism in the storehouse is composed of a vertical arm, a guide wheel, a working arm and an end actuator. The upper mechanism of the storehouse top supports the whole clearing device and power source, and has the degree of freedom of rotation, so that the working arm rotates in the storehouse. The lower mechanism in the silo plays a role in locating the cleaning position of the cement silo. The air duct is responsible for transmitting the power output from the power source to the end actuator. The wire rope is responsible for transmitting the power output from the power source to the working arm, so that the working arm can swing up and down. The rotation and swing of the working arm can suspend the end actuator to any position of the warehouse wall for cleaning. The device has the advantages of light weight and self-assembly, which is very suitable for cleaning the cement warehouse and any diameter cement warehouse.

![Figure 1. Overall structure of cement silo cleaning device.](image)

3. Mechanism design of storehouse top
The storehouse top mechanism mainly includes the main support frame, rotary mechanism, fixed base, winch mechanism and manual winch.

The main support frame is as shown in Figure 2(a). The support frame is equipped with vertical arm, slewing mechanism, winch mechanism and winch. As shown in Figure 2(b), the vertical arm is installed on the vertical face of the support frame, which is fastened by the upper and lower connecting seats. The connecting seat and the fixing sleeve are welded together for easy installation and unloading. As shown in Figure 2(a) and Figure 2(d), the slewing mechanism is installed at the bottom of the main support frame and consists of slewing bearing, upper bearing seat, lower bearing seat, fastening fixture and other parts. There are two fastening clamps to tighten the braking of the slewing bearing. As shown in Figure 2(a) and Figure 2(c), the structure of manual winch is composed of winch and winch support. It is installed upside down under the main support to realize the function of manually rotating the steel wire rope, extending the handle and leading it out for easy operation.
4. Mechanism design in warehouse

The mechanism in the storehouse mainly includes vertical arm, working arm and end actuator.

The vertical arm is a structural steel pipe with a diameter of 89mm and a wall thickness of 6mm. There are three guide wheels installed in the middle, as shown in Figure 3. The guide wheels are divided into cable guide wheel and hose guide wheel. The cable guide wheel is installed in the center, and there are two hose guide wheels, which are respectively installed on both sides of the cable guide wheel, symmetrically installed. The air guide pipe only passes through one guide wheel, which is determined according to the site conditions. The end of the guide wheel shaft is equipped with retaining ring, gasket and other axial fixings. A stop arm is designed on the guide wheel seat to prevent the air pipe from falling off the guide wheel.

The working arm can be installed with multiple sections according to the actual needs. Three working arms, the clearance radius is about 10 meters; four working arms, the clearance radius is about 12 meters. As shown in Figure 4(a), three or four working arms are successively pin connected to achieve the suspension of horizontal distance. The pin shaft shall be installed with anti-falling structure to avoid looseness during operation. In this paper, three working arms are introduced as an example. The first working arm is a large arm close to the vertical arm, which is 100*100mm aluminum alloy square tube with a wall thickness of 5mm. As shown in Figure 4(b), there are fixed points at the end of the boom to lead out the wire rope and connect it to the winch. The second section is the middle arm in the middle position, which is 90*90mm aluminum alloy square tube with a wall thickness of 5mm. As shown in Figure 4(c), a fixing hole is installed at both sides of the end, and two wire ropes are used for traction to ensure stability. The third working arm is a small arm, 80*80mm, 5mm thick aluminum alloy square tube. A number of pin holes are designed on the jib to realize fixation at different positions, so as to deal with the cleaning of the cement warehouse wall in a small radius range. As shown in Figure 4 (d), an end guide wheel is installed at the end of the working arm to guide the air pipe.
The end actuator is a pneumatic rotary actuator, which is fixed on the air hose. The structure is as shown in Figure 5. High strength steel chain or thermoplastic whip can be used. When the working arm reaches the designated position, rotate the actuator at high speed and hit the cement hanging on the wall of the warehouse. The whip chain of different materials can be selected according to the hardness and softness of the cement warehouse.

5. How to use the cleaning device

By using the vertical arm, the horizontal working arm and the steel wire rope together, the cleaning cutter head can be suspended to any cleaning position, and the pneumatic motor is used to drive the cleaning cutter head to remove the cement warehouse wall binder. The specific cleaning steps and precautions are as follows:

(1) Firstly, the warehouse wall cleaning machine shall be transported to the top of the warehouse for assembly. In the factory with lifting conditions, the fixed base, winch mechanism, support, etc. can be lifted as a whole. (2) The corresponding hole on the top of the warehouse is used as the cleaning operation hole of the cleaning machine. If there is no suitable operation hole, the hole can be opened on site (consult the design drawing in advance when opening on site to avoid the position of steel beam). The minimum hole diameter of the working hole is required to be Φ500. (3) Assemble the cleaning machine on the upper part of the selected hole, and select the corresponding working arm combination according to the diameter of the cement silo. Pay special attention to the wire rope and the air supply pipeline, and do not intertwine. (4) The installation and debugging of the cleaning machine can adjust the left and right rotation of the horizontal working arm and the up and down pitching angle swing respectively by driving the horizontal rotating mechanism and the lifting mechanism, so as to adjust the position of the working cutter head. After the commissioning, the distance between the location of the cutter head and the storage wall shall be less than 200mm, and a certain working stroke propulsion space shall be reserved. (5) In order to improve the cleaning efficiency, the accumulated materials on the wall of the warehouse should be cleaned from the bottom to the top under the premise of safety. During the cleaning process, the position of the working head should be adjusted at any time according to the residual materials, until all the accumulated materials are cleaned up. (6) For the super large warehouse, if the length of the horizontal working arm is not long enough, eccentric opening can be added at the top of the warehouse to realize the cleaning. In order to improve the cleaning efficiency, two machines can be arranged at the symmetrical position on the top of the warehouse to work at the same time, and the anti-collision measures of two machines should be considered during the operation.
6. Experimental verification

Before the finite element analysis, according to the working condition of the working arm, the static balance equation is established.

As shown in Figure 6, given the gravity $F_T = 500N$ of the end actuator and the tension $F_T' = F_T$ of the wire rope, it can be concluded that:

$$\begin{align*}
F_{AY} &= (1 - \sin \alpha)F_T \\
F_{AX} &= F_T' \cos \alpha
\end{align*}$$

Get result: $F_{AY} = 417.8N$, $F_{AX} = 493.2N$, $F_D = 4150.0N$, $F_{BX} = 4593.9N$, $F_{BY} = 186.9N$.

According to the established three-dimensional solid model, import ANSYS finite element analysis software for strength calculation, and get the deformation diagram and stress diagram of the vertical arm and horizontal working arm of the cleaning robot, as shown in Figure 7 and 8.

![Figure 6. Stress analysis diagram of working arm.](image)

![Figure 7. Calculation results of vertical arm.](image)
Material safety evaluation: As shown in Figure 7(b) and 8(b), it is concluded that the maximum stress of the robot is 113MPa, which occurs on the vertical arm support guide frame. The material of the vertical arm is Q235 steel, and its allowable stress is 235Mpa, which is greater than the maximum stress of the robot 113MPa, so the material meets the safety requirements.

7. Conclusion
Based on the current domestic cleaning demand, this paper designs a kind of machine which is suitable for cleaning the domestic cement warehouse, studies the overall design scheme of the machine and the mechanical structure of the key parts, uses the static analysis of the finite element software to check the key parts, and verifies the correctness of the design scheme. It lays a foundation for the following prototype construction and intelligent control research.

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