Cleaning Device for Inner Wall of Vertical Cement Tank Based on Electromagnetic Principle

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Abstract. In the process of cement storage in cement tanks, the cement on the inner wall is affected by various factors, which will cause hardening. Cement hardening will cause a series of problems such as the decrease of effective storage capacity of cement wall. Therefore, in the mortar production process, the cement tank needs to be cleaned regularly. In order to solve the above problems, the device is designed. The device adopts intelligent design and cleans the inner wall of cement silo by spiral cruise cleaning method to realize the effective cleaning of cement silo.

Keywords: Cement tank, inner wall, mortar.

1. Project background and research significance

1.1. Project background
In engineering construction, concrete and mortar are essential raw materials. In recent years, China's demand for cement is increasing day by day.

Figure 1. The trend chart of cement demand from 2000 to 2016

At present, ready-mixed concrete and mortar are mostly used in construction. In order to promote the popularization and application of ready-mixed concrete and mortar and ensure the engineering quality, local governments have formulated the Measures for the Administration of Local Ready-mixed Concrete and Ready-mixed Mortar in accordance with the Construction Law of the People's Republic of China and the Circular Economy Promotion Law of the People's Republic of China.
However, in the process of cement storage in cement tanks, the cement on the inner wall is affected by storage temperature, storage time, exhaust capacity of cement tanks, moisture and other factors, which will cause hardening. The cement agglomerates have large shape and high strength. The existing treatment methods are mainly manual high-pressure water gun cleaning or using simple mechanical devices such as iron pick and electric pick. If the drying is incomplete after cleaning with water, the problem of sand agglomeration will be caused again. In the process of artificial cleaning, there will be risks such as falling and crushing by materials and poisoning by harmful gases.

1.2. Research significance

In view of the above problems, the project team designed a cleaning device for the inner wall structure of the vertical cement tank, which can automatically clean the inner wall of the cement tank, and improve the cleaning efficiency while ensuring the cleaning quality. Compared with the traditional arch breaking device, the device has the following advantages:

(1) It adopts the cleaning mode of spiral cruise and works from top to bottom. It effectively solves the problem that the mechanical extension mechanism cannot completely clean cement on the arc surface in the sand tank due to limited space, and reduces the volume of the device.

(2) Intelligent working mode can clean the caking in the cement tank regularly, and feedback the humidity inside the cement tank in real time during the cleaning process. According to the cleaning time of different parts, the data of caking distribution are analysed, which is beneficial for cement tank managers to implement corresponding improvement measures.

2. The implementation plan of the project research and the research method and technical route to be adopted

2.1. Overall plan

As shown in the figure, the main structure is divided into internal and external modules which can operate independently. The movement mode of the device mainly utilizes the electromagnetic principle,
and the device can move slowly along the guide rail on the outer wall of the cement tank through the cooperation of the electromagnetic block at the bottom of the device and the power provided by the driving motor in the running guide rail. When the external module works, the vibrator is triggered by the electromagnetic coil, and the scale on the inner wall of the cement tank is shaken by vibration. The inner wall cleaning module consists of a vibration crushing module and a hobbing cutting module. If the movement of the device is blocked during the back-and-forth lamination cleaning of the device, a signal will be returned to start vibrating and crushing. The broken inner wall or the inner wall which does not need to be broken can be hobbed directly, and then the debris can be thrown away to clean the inner wall of the cement tank.

**Figure 4.** Overall device diagram

### 2.2. Research methods and technical routes

#### 2.2.1. Motion module

Considering that the working object of the device is a vertical cement tank with a diameter of 3-6M, there are two schemes for the motion mode: (1) the inner wall support rotary type; (2) the electromagnetic adsorption type.

Compared with the two schemes, the inner wall support mode requires high torque of radial drive motor, and the whole annular device is large, which makes it difficult to manufacture and install the device. At the same time, due to the irregular inner wall shape, the movement mode of the inner wall annular support device is inflexible. Electromagnetic adsorption scheme, the device is small in size, which is conducive to flexible movement. To sum up, the project team chose electromagnetic adsorption scheme as the movement mode of the device.

| Fixing mode                  | Energy consumption | Motion flexibility | Installation difficulty | Cost of manufacture |
|------------------------------|--------------------|--------------------|------------------------|---------------------|
| Inner wall supporting type   | Medium             | Low                | High                   | High                |
| Electromagnetic adsorption   | Medium             | High               | Low                    | Medium              |

The investigation found that the existing vertical cement tank body materials are mainly divided into two categories: 1) Q235 structural steel; 2) 304 stainless steel. Among them, the cement tank made of Q235 structural steel is more widely used. In this project, an electromagnetic movement mechanism is designed to realize the movement of the device by electromagnetic adsorption.
Figure 5. Q235 cement tank

The electromagnetic motion mechanism is designed to meet the requirements of fixed attachment and relative motion of the device on the wall of vertical cement tank. Ensure that the device will not fall from the cement tank under the action of radial strong electromagnetic force.

The following calculation is verified.

According to the collected data, the super electromagnet can provide the maximum attractive force of about 12N/cm² within 16Kg of its own weight, and the working depth can reach 16mm. The project team plans to design a device with a dead weight of 80kg and a volume, of which the volume of electromagnet accounts for 1/8 of the total bottom area of the device.

| Specifications | Magnetic force (N/cm²) | Size W(mm) | L(mm) | H (mm) | Magnetic pole size (mm) | Weight (kg) |
|----------------|------------------------|------------|-------|--------|-------------------------|-------------|
| DYD 300×300    | 8                      | 300        | 300   |        | 70×70                   | 12          |
| DYD 300×300    | 12                     | 300        | 300   |        | 50×50                   | 16          |
| DYD 300×400    | 17                     | 300        | 400   | 51     | 50×50                   | 20          |
| DYD 300×500    | 20                     | 300        | 500   |        | 70×70                   | 28          |

The minimum friction required to ensure the static fixation of the device is:

\[
80 \times 9.78N/kg = 785N \tag{1}
\]

It can meet the fixing requirements of the device on the inner and outer walls of the cement tank, and the calculation and verification pass.

The friction coefficient of Q235 structural steel after plastic processing and painting is 0.6. According to comprehensive calculation, the maximum static adsorption force of outer wall provided by electromagnetic adsorption is:

\[
1/8 \times 110cm \times 70cm \times 12N/cm^2 \times 0.6 = 6930N \tag{2}
\]

At the same time, it is found that the friction coefficient of cement after solidification is between 0.88 and 1.41, and the wall thickness of cement tank is between 3 and 6 mm. According to comprehensive calculation, the maximum static adsorption force of inner wall provided by electromagnetic adsorption is:

\[
1/8 \times 110cm \times 70cm \times 12N/cm^2 \times 0.88 = 11300N \tag{3}
\]
2.2.2. Outer wall vibration module. The module is designed for electromagnetic motion of Q235 cement tank.

![Figure 6. Model of outer wall adsorption mechanism](image)

The module is designed with two curved electromagnet outer plates and running guide rails. Four electromagnets are distributed on the outer plate of each curved electromagnet at a distance of 20cm, and the base is designed as an arc, which can be well attached to the outer wall of the cement tank.

![Figure 7. Side view of curved base](image)

Running guide rails are located on both sides of the curved electromagnetic plate, and the two running guide rails are connected by a line wrapping mechanism. A driving motor is designed on each running guide rail. Through tooth chain transmission, the sliding block on the running guide rail can slide correspondingly, thus driving the outer wall vibration module base to move. After reaching the working position, the outer wall adsorption mechanism adsorbs the outer wall and fastens the machine body, and the electromagnetic vibration mechanism designed at the end of the module is started to vibrate the outer wall of the cement tank to achieve the cleaning goal.

2.2.3. Design of running guide rail. The module realizes the whole movement of the module through the cooperation of the electromagnetic adsorption mechanism on the outer wall and the wrapping mechanism on the running guide rail.

![Figure 8. Schematic diagram of running rail](image)

A driving motor is designed on each running guide rail, which can make the sliding block on the running guide rail slide correspondingly through the transmission of tooth chain. Before moving, the device is in a fixed state, and the electromagnetic adsorption mechanism adsorbs the outer wall. When moving, the electromagnetic adsorption mechanism at the last position releases the adsorption, and the
wrapping mechanism opens. The line feed mechanism locks the slider on the front running guide rail, starts the driving motor on the rear running guide rail to drive the tooth chain to move, and the rear base moves above the front running guide rail through the slide rail.

![Figure 9. Diagram of the outer wall module in the transition position](image)

Finally, the lower left electromagnetic adsorption mechanism adsorbs the outer wall, the upper electromagnetic adsorption mechanism releases the adsorption, and the wrapping mechanism opens. The line feed mechanism locks the slider on the lower left running guide rail, and starts the driving motor on the upper running guide rail to drive the tooth chain to move. The upper base moves to the rear end of the front running guide rail through the slide rail, and the device returns to the initial state for the next work.

2.2.4. Electromagnetic vibration device. Electromagnetic vibration device adopts electromagnetic emission principle and is triggered by electromagnetic coil. When working, it is triggered instantly by the strong magnetism of the electromagnetic coil, so that the striking part generates strong beating force, and the electromagnetic coil enters the next charging again, thus generating periodic beating on the cement tank wall. Periodic rapping can make the material out of contact with the cement tank wall and eliminate the friction between the material and the tank wall. At the same time, due to the influence of alternating speed and acceleration, the material is in an unstable state, which can effectively overcome the internal friction and gathering force of the material, and is more conducive to the scale falling and discharging from the tank mouth.

![Figure 10. Schematic diagram of electromagnetic vibration device](image)

2.2.5. Gear hobbing and cutting module. Through the work of the vibration crushing module, large lumps of agglomerated cement are crushed. At this time, the caking cement thin layer attached to the inner wall is a concave-convex irregular surface, which is designed to be cleaned by hobbing and removing module. The module is located at the bottom of the device, the bottom cleaning baffle is 2mm away from the inner wall of the vertical cement tank, and the entrance slot of 2mm sinks at the entrance
of the baffle, which can cut the raised cement blocks on the inner wall of the cement tank without damaging the inner wall of the cement tank. There are many rows of rotary hobbing in the baffle, and the central axis of the rotary hobbing is made of GCr18 steel, which can well bear radial stress. The surface of hobbing is made of diamond, and the radial thickness of closely spaced hobbing is 3mm, which can reduce the wear of hobbing better. The hobbing is driven by a rotating motor. During cleaning, the cement tank has been cleaned, and the cement ash layer and scale cleaned by the device can directly fall to the bottom and be discharged from the bottom of the tank.

Figure 11. Rotary hobbing model

Figure 12. Hobbing stress analysis

2.2.6. Power supply and control module. The project team adopts external power supply to provide power. Two wires are pulled out at the top of the cement tower to supply high-voltage electricity to the device, accompanied by two sets of safety ropes, which can solve the problems of damage to the cement tank and the device itself caused by the device falling into the cement tank under unexpected circumstances and the recovery of the device.

The control module is built with AM380S, an intelligent chip for real-time positioning and map building. The chip feedback part can timely feedback that height position of the device itself. In order to prevent the equipment from impacting and damaging the original stairway, pipeline and other facilities of the cement tank, the cleaning operation mode is as follows: reciprocating stacking and descending. When moving, the direction is controlled by the guide wheel, and the target can be achieved only by providing the motor through the radial drive motor.

3. Research basis and feasibility analysis of the project

3.1. Basic research
Based on the current research on cleaning scale on the inner wall of cement silo, it can be seen that the efficiency of cleaning only by mechanical device is too low. According to the field investigation, the cleaning cycle of scaling on the inner wall of cement silo is long and it is difficult to clean. Generally,
cement silo is only equipped with arch breaking device. Based on the data of related papers, the experiment is carried out, and some data are obtained by controlling variables and analogy, and then follow-up research and improvement are carried out.

3.2. Feasibility analysis
The device operates according to the preset trajectory and fixed workflow, and has a high degree of automation. The equipment can be used for a long time after timely maintenance, and can be directly used in cement plants, which can greatly reduce the consumption of manpower and material resources. The device is mainly mechanical structure, supplemented by related circuit control system. Mechanical part of the processing method using welding, riveting, bolt connection, etc., the overall structure is firm, can achieve stable working effect. Through the simple experiment, we can get the correct principle and achieve the expected effect.

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