Research on grinding mechanism of wall-climbing grinding robot for large spherical tank

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***Abstract*—The structural integrity of spherical tanks is very important. Weld grinding is a significantly necessary preparation of the non-destructive testing. Due to the need for scaffolding, poor operating conditions and low grinding efficiency, manual grinding has become an undesirable method of weld grinding, and automated inspection techniques are preferred for using in weld grinding. In order to improve the grinding efficiency of welds, the present work introduced an automatic wall-climbing grinding robot technology according to the grinding process requirements of the spherical tank wall. The design requirements and device structure component of the grinding robot were analyzed. A visualized wall-climbing grinding robot adopting a swing-arm mechanism was designed and tested by comparing the grinding performance of different grinding head mechanisms. The weld grinding results shows that the designed wall-climbing grinding robot has good grinding performance, which effectively improves the automation level of the weld grinding.**

Keywords-wall-climbing robots; spherical tank; grinding; structural design.

I. INTRODUCTION

Magnetic particle testing is the main method for surface non-destructive testing on spherical tanks. Aiming at the requirements of magnetic particle testing, it is necessary to remove grease, rust, oxide or other adhering magnetic powder materials from the weld and heat-affected area [1].

At present, the non-destructive testing of large pressure vessels (such as large spherical tanks) in China still relies on manual testing in most cases, which often is needed to build scaffolding. Manual testing not only has low efficiency, long operation cycle, bad working environment and high cost, but also the testing quality depends on the operation skills and psychological factors of the inspectors, which is prone to result in personal safety accidents [2]. Thus, for replacing manual grinding, it is necessary to develop the wall-climbing grinding robots for large spherical tanks, which has high engineering application value. The grinding robot will enhance the working efficiency, reduce the labor intensity, improve the working environment and shorten the shutdown time to reduce the loss of enterprises.

II. PROCESS REQUIREMENTS OF SPHERICAL TANK SURFACE GRINDING

A. Grinding Application Environmentte

The wall-climbing grinding robot is used to remove rust on welds and heat-affected zone of spherical tank surface.

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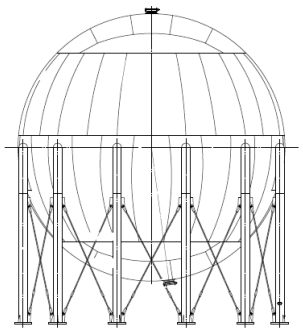

Figure 1. Shell structure of a spherical tank.

As shown in Fig.1, the spherical tank consists of several pre-pressed plates with longitudinal and transverse welds. The weld groove has two forms: single-side groove and double-side groove.

The wall grinding of spherical tank serves for the yoke method magnetic particle testing in the next process. The magnetic yoke pole distance is generally set at 75~200mm. Therefore, the width range of grinding robot is within 200mm on both sides of the weld.

B. Quality Requirements after Grinding

According to JB/T 4730.4-2005, no grease, rust, oxide or other adhering magnetic powder materials shall be allowed on the surface of examined workpieces. The surface roughness Ra of tank wall need to be less than 25μm and tank wall will present metallic luster. In addition, the base material of spherical tank wall and the solid material of weld seam should not be damaged in the grinding process. Since the damage of wall base material will cause shell wall thinning, thus reducing the safety of tank.

III. PROJECT DESIGN FOR GRINDING ROBOTS

A. Basic requirements for Grinding Robots

According to the special working environment and operation condition of grinding tanks, the basic requirements of the designed wall-climbing grinding robot are as follows [3],

(1) Weight. Since the robot needs to be manually carried in the spherical tank, the robot should be as light as possible.

(2) Size. The robot needs to be carried in the tank through the manhole, which diameter is greater than or equal to 500mm. Therefore, the robot structure needs to have at least one projection surface with diagonal dimension to be less than 500mm.

(3) Grinding and moving speed. The grinding speed of the robot is 0.6 m/min, and the moving speed is designed to be 2 m/min without grinding.

B. Function design for Grinding Robot

Firstly, the robot must be able to reliably adsorb on the spherical tank wall, and the adsorptive force is not too large [4]. Due to its wide working range, the robot needs to be able to move freely on the wall surface. For weld cleaning and grinding, the robot is required to have grinding function.

Through the above analysis, the developed robot needs several first-level functions, such as adsorption function, moving function, grinding function and video function [5].

IV. STRUCTURE DESIGN FOR GRINDING ROBOT

A. Adsorption Function Design

Magnetic adsorption is one of the most common adsorption methods used in wall-climbing robots, including permanent magnet adsorption and electric magnetic adsorption [6]. The magnetic adsorption unit often is located on the surface, and keeps a relatively close distance from the adsorbed surface (<5 mm), which only generates a huge adsorption force in a small area. Rare-earth permanent magnet can create energy-free adhesion and maintain stability during operation. As the spherical tank is a magnetic material, permanent magnet adsorption is selected.

B. Moving Function Design

The contact force between the robot and the wall surface is complex during grinding, which requires a rigid moving chassis. In order to the great friction produced by the adsorption force of tracked moving mode, the indentation will be generated on the wall surface and damage the wall surface of the pressure vessel. Therefore, it is reasonable to choose wheeled type as the movement mode of wall-climbing grinding robot. The wheeled moving mode adopted in this paper has the advantages of simple structure and small forward resistance, and adopts deceleration motor to provide driving force. There are many steering modes for wheeled moving robot, among which the differential steering mode is the most commonly used and reliable one. The steering mode of robot designed in this paper adopts the differential steering mode.

C. Grinding Function Design

The wall-climbing grinding robot grinds in the designated weld zone. The grinding space range can be achieved by the cooperation of the motion of the robot and the grinding mechanism. The grinding wheel driven by motor is used to grind the surface of spherical tank.

According to the different operation states of the wall-climbing grinding robot, the grinding head should have the lifting function.

The grinding head during grinding is pressed against the wall with preset positive pressure to perform grinding operation. When the robot is crawling, the grinding head needs to be raised again to avoid touching the wall weld and other protrusions.

D. Vedio Function Design

One or more high-definition video monitoring devices t of the robot system should be equipped, so that operators can observe the grinding condition, walking status and surrounding image information of the robot. This improved the working condition of operators to large extend. If the grinding and walking status of the robot can only be monitored in the tank instead of outside the spherical tank, it will not be of much help to improve the working conditions of the operator.

V. Comparison of Grinding Mechanisms

Among the four functions of grinding robot mentioned above, the research on the adsorption function, moving function and video function are relatively mature, while the research on weld grinding devices for the spherical tank is less. Therefore, the paper focuses on the grinding devices. The common grinding methods are as follows,

(1) Swing arm grinding

As shown in Fig.2, the swing arm drive motor 7 drives the driving gear 6, which is meshed with the driven gear 5. The roller 4 installed on the driven gear 5 moves along the guide rail 3, thus driving the grinding wheel 1 installed in the front of the swing arm 2 to swing around the center 8 of the reference component of the swing arm.

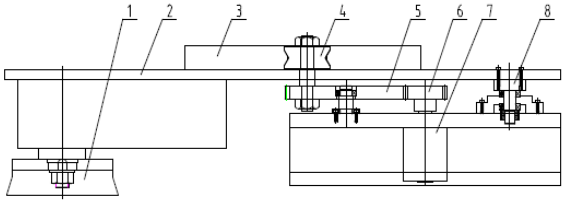

Figure 2. Swing arm grinding mechanism.

When swing arm grinding is conducted from left to right, the grinding wheel rotates clockwise, while when grinding from right to left, the grinding wheel should be counterclockwise. Otherwise, if the rotation direction of the grinding wheel remains unchanged, there will always be one side of the angle between the weld and the spherical tank wall surface that is not grinded cleanly.

(2) Roller grinding

As shown in Fig.3, the grinding driving motor 1 drives the driving gear 2, and the grinding roller 5 on the driven gear 4 is driven by the synchronous belt 3 for grinding operation.

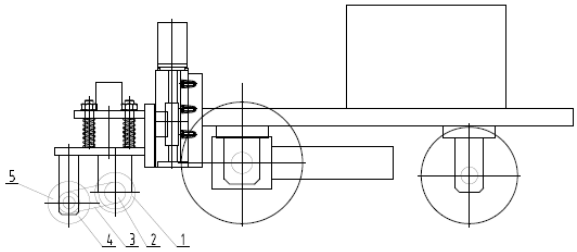

Figure 3. Roller grinding mechanism.

When this grinding method is applied to grind regular plane, it has high grinding efficiency and should be a good choice. However, when the maximum weld reinforcement is 5 mm, and there are some Misalignment defects on both sides of the weld, this kind of grinding method needs to be cleaned at one time, which is quite difficult.

(3) Linear grinding

As shown in Fig.4, the grinding head 4 is installed on the slider 2 of linear motion module 1 and carried out linear grinding back and forth along the screw rod 3.

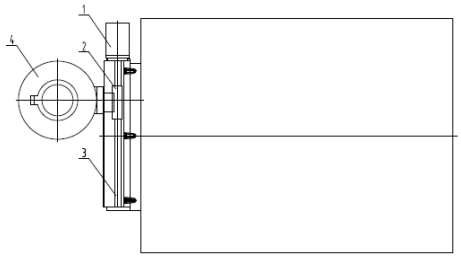

Figure 4. Linear grinding mechanism.

When this grinding method is used, the grinding head needs a certain angle to the grinding wall. The grinding method is similar to swing arm grinding, when grinding from left to right, the grinding wheel rotates clockwise, while when grinding from right to left, the grinding wheel should be counterclockwise.

(4) Propulsive grinding

As shown in Fig.5, three grinding motors respectively drive grinding head to grind along the weld direction, and the middle grinding head grinds the weld itself and the surrounding area. Three grinding heads cover the direction of the grinding width, and there is 10% overlap between the adjacent grinding heads to ensure that there is no blind zone in the grinding direction of the width grinding head. The two grinding heads on both sides have opposite grinding rotation direction, which can counteract each other's reaction force.

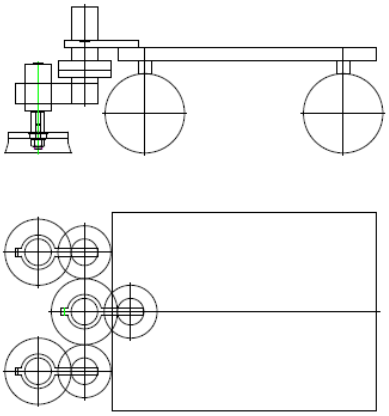

Figure 5. Propulsive grinding mechanism.

This grinding method requires three grinding drive motors and reducing vibration mechanism for lifting and damping of grinding head. The mechanism is relatively complex and heavy. Moreover, the angle between the weld and the wall of the spherical tank is difficult to be grinded cleanly.

In summary, a wall-climbing grinding robot was developed in this paper by using swing arm grinding mechanism. Several field grinding tests were carried out on a spherical tank. The grinding effect is shown in Fig.6, which shows that the grinding robot developed in the paper basically meets the grinding requirements.

Figure 6. Grinding effect diagram.

VI. CONCLUSION

In this paper, the wall-climbing grinding robot for spherical tank was studied. Through analyzing the design requirements of the robot, the function design of the robot was carried out by using the functional principle design method. And the grinding mechanism was mainly studied. The structure of the wall-climbing grinding robot was designed by selecting a relatively reasonable design scheme. The field grinding testing is conducted on a spherical tank. The result shows that the surface of the spherical tank wall exhibits mirror effect where the roughness Ra of less than 25μm meets the design requirements.

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