Design and Experiment of Dross Scooping Robot for Slag Scouring of Aluminum Ingot

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Abstract. In the metallurgical casting industry, the dross removing process is the most critical process that affects the casting quality of aluminum ingots. At present, the dross removing operation is mainly done manually. In order to reduce the labor intensity of workers, researchers at home and abroad have designed a variety of dross-removing robots to replace manual labor to realize automated dross-removing operations. However, the dross removing robots currently on the market all have problems such as unsatisfactory dross removing effect, poor working stability, and unclean slag removal. In order to solve the above problems, this article starts from practical applications, based on functional design and safety design, through the structural design of the slag scraper, the experimental analysis of applied materials and the optimal design of the robot trajectory, a set of The dross picking shovel is required by industrial applications. Finally, the practicality of the dross removing robot verifies the practicality of the designed dross shovel, which is an important step for the intelligent development of the entire metallurgical casting industry.

Keywords: Aluminum ingot slag, robot, metallurgical casting.

1. Introduction

Aluminum ingot casting is composed of a series of processes such as casting, dross slagging, condensation, demolding, stacking, and bundling. Among them, online dross scraping by mold is a key process for removing scum on the surface of aluminum liquid in the mold. At present, the slag picking operation is mainly carried out by workers. The operating environment has high temperature, strong heat radiation, and high labor intensity. At the same time, there is a hidden safety risk of high temperature molten aluminum splashing and hurting people. This harsh working environment seriously affects the physical and mental health of workers and the company's civilized production image. The realization of automated and intelligent slag removal operations has become an urgent problem to be solved by foundry metallurgy enterprises.

With the introduction of "German Industry 4.0" and "Made in China 2025", the development and application of industrial robot technology is becoming more and more popular. A slag shovel is installed at the end of the industrial robot, and a certain trajectory is designed for the robot to realize automatic slag picking and slag removal operations. For the casting slag casting process of aluminum ingots,
domestic and foreign scholars and enterprises have also conducted a lot of experimental research. Although the "aluminum ingot dross robot" designed by Lanzhou University of Technology and the dross picking robot designed by Zhengzhou Research Institute can all realize automatic dross picking operations, there are still many problems. For example, the area of slag cleaning is not as good as that of manpower, and the robot is easy to collide with the casting mold during the slag cleaning process.

In order to promote the development of the entire foundry metallurgy industry, improve the level of automation and intelligent production of aluminum ingot casting process, and solve the problems in the slag stripping process. According to the shortcomings of the current manual slag slag, this article designs a slag shovel shoveling robot. Combining the dross shovel with robotic automatic control technology, the actual dross drossing robot's dross scouring effect meets the requirements of industrial applications, and finally realizes the automatic and intelligent dross slagging operation of metallurgical casting.

2. The working principle of the robot system

The overall structure of the robot control system is shown in Figure 1. When the casting machine is running, the synchronous detection system of the casting machine detects the movement parameters of the casting machine, and at the same time transfers the detected data to the robot control system. The robot receives the signal of the synchronous detection system and triggers the robot to start the slag picking operation. It can be seen from the figure that the dross picking shovel is installed on the end effector of the robot, and the aluminum dross removal operation is realized by setting the trajectory of the end effector of the robot. The slag stick is used to clean the aluminum slag adhering to the slag scraper, and the aluminum slag falls into the hopper for secondary recovery.

3. Design of dross shovel robot

3.1. Structural design

Figure 2 shows the manual dross shovel used by the dross extraction workers to remove aluminum slag during the aluminum ingot casting process. In the actual working process, the slag picker holds two pieces of manual slag picker. One shovel scrapes the slag along the surface of the molten aluminum from the distal end to the proximal end of the mold. The other shovel combines with the previous shovel to remove the collected aluminum slag and shake it down into the hopper for centralized recovery. As shown in Figure 3.
Through the analysis of the actual application, the structural design of the slag scraper consists of functional design and safety design.

The functional design is mainly based on the following aspects: (1) how to closely cooperate with the robot; (2) how to match the size of the casting mold; (3) the robot slag fishing method.

The safety design mainly considers how the robot protects itself when it collides with the casting tool during slag removal. The primary task of the design is to ensure the safety of on-site workers, and secondly, to protect the equipment from major damage and ensure that the on-site work is carried out normally.

The slag scoop structure designed in this paper is shown in Figure 4. The robot slag scooping mechanism is mainly composed of several parts: connecting flange, heat insulation ring, stop ring, connecting frame, connecting slot, connecting shaft, torsion spring and slag scraping blade. The dross scraping blade is the main mechanism for collecting aluminum dross. The torsion spring and the connection slot are the safety protection mechanism of the slag shovel. The specific functions of each module are as follows:

1. Insulation ring  2. Torsion spring  3. Bolt set  4. Slag blade  5. Flange  6. Stop ring  7. Connecting shaft  8. Connect the card slot  9. Connect the bracket

The connection flange serves as a connection between the slag scoop and the end effector of the industrial robot. The clamping groove on the flange is used to cooperate with the clamping groove at the end of the robot to realize the fixed connection between the slag scraper and the robot.
The stop ring prevents the slag shovel from being axially displaced by excessive inertia during the movement.

The connecting bracket is the main structure of the entire slag scoop, and all auxiliary mechanisms are connected to the connecting bracket to achieve various functions.

The dross scraping blade is used to directly contact the molten casting aluminum liquid to retrieve the aluminum slag floating on the surface of the aluminum liquid in the casting mold. A diversion groove at the bottom of the shovel is used to filter the aluminum liquid carried in the fishing process, so that the aluminum liquid is dripped into the casting mold again to prevent the aluminum liquid from being wasted, and at the same time, it is convenient for the aluminum slag to slide off the slag blade during the slag cleaning process.

The torsion spring is used as a safety protection device for slag scooping. It is integrally installed on the connecting shaft, one fulcrum is fixed on the connecting frame, and the other fulcrum is fixed on the connecting card slot, which can play a fixed role on the connecting card slot. When the connection card slot is subjected to radial force, a rotation displacement will occur. Due to the reaction force generated by the torsion spring on the connection card slot, when the blade is radially loaded, the reaction force of the torsion spring causes the connection card slot to return to the original position.

The connecting slot is mainly used to connect the slag blade and the connecting shaft. A groove is designed on one side of the connecting slot to prevent interference between the torsion spring and the connecting slot during the movement.

The connecting shaft is used for fixing the slag picking blade, the connecting card slot and the torsion spring on the connecting frame, and the slag picking blade, the connecting card slot and the torsion spring can generate a rotational movement around the connecting shaft. When the robot malfunctions during the work, the robot stops in the slag scraping process, and the slag scraping blade stays in the casting mold. Because of the action of the torsion spring, the slag picking blade can rotate sideways and will not get stuck in the casting mold, thereby protecting the entire robot, casting equipment and field staff.

3.2. The experiment of dross removing robot

Slag shovel material experiment. In order to enable the dross shovel to operate continuously at a high temperature of 750 °C aluminum liquid, and at the same time to meet the use conditions of the dross shovel with non-stick aluminum slag, materials such as Q235 carbon steel, 310S stainless steel, boron nitride paint were carried out one by one experiment. Figure 5 is a record of the continuous working time of various materials. From the figure, it can be seen that the slag scraper of 310S stainless steel combined with boron nitride coating has the longest continuous working time, which can meet the practical conditions of a class.

![Figure 5. Experimental record of the continuous working time of the robot slag shovel material](image-url)
The final structure of 310S stainless steel combined with boron nitride coating robotic slag scoop is shown in Figure 6.

![Robot slag shovel](image)

**Figure 6. Robot slag shovel**

*Experiment of trajectory of slag shovel.* Expressed by the Cartesian three-axis coordinates of the robot, the movement trajectory of the robot's dross picking movement is mainly synthesized by the movements of the robot end effector in the X-axis, Y-axis, and Z-axis. The X-axis motion trajectory is a motion trajectory along the negative direction of the X-axis from the robot shoveling point. The Y axis is the trajectory of the synchronous movement of the casting machine along the movement direction of the casting machine. The Z-axis motion trajectory is divided into three parts. The first part is to move from the robot's undetermined position in the negative direction of the Z-axis to a certain depth in the mold. The second part keeps the Z-axis coordinates unchanged during the robot's movement along the X-axis. The last part The robot raises a height along the positive direction of the Z axis, which is higher than the surface of the casting machine mold. The three trajectories of the robot's X-axis, Y-axis and Z-axis constitute the robot's slag trajectory. The final slag removal effect is shown in Figure 7.

![Artificial slag removal effect](image) ![Robot slag effect](image)

**Figure 7. Comparison of the results of manual and robotic slag**
4. Summary
This article takes dross picking robot as the research object, and designs a set of dross picking mechanism with functional design and safety design as the design criteria. This set of slag picking mechanism is used to retrieve aluminum slag floating on the surface of the casting mold during the casting process. In order to cope with the high temperature environment of molten aluminum, various experiments were carried out on the material of the slag scraper, and a new slag scraper material with 310S stainless steel combined with boron nitride paint was obtained. Finally, through the optimized design of the trajectory of the end effector of the robot, the work effect of the dross removing robot can reach the effect of manual dross removing, meeting the product quality requirements of the factory.

The slag scooping mechanism designed in this paper is very important for the research of the robot control system for slag scavenging. The combination of dross shoveling mechanism and robot can replace manual labor for real automation and intelligent dross removal. The perfection of the dross removing robot improves the efficiency of the dross removing station, reduces the safety hazards of the workers on site, and finally enables the enterprise to achieve cost reduction and efficiency production.

Acknowledgments
This work was financially supported by Guiyang Zhenxing Aluminum Magnesium Technology Industry Development Co., Ltd. fund.

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