Application Research of Slag-removing Robot for Zinc pot on Hot-dip Galvanizing Line

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Abstract. Metallurgical industry mostly works in high temperature, high pressure, dusty and other harsh environment, where applied research Metallurgy robots started late. In recent years, the application research of metallurgical robots has gradually gained the attention of everyone. The hot dip galvanizing pot slag is usually operated manually, the working environment of the workers is bad, there is with a large safety hazard, and the process of controlling the slag is difficult. The use of slag-removing robot instead of labor is applied to the hot-dip galvanizing line, which is the trend of intelligent and automated development of the coating industry.

1. Introduction
Galvanized sheet is a high value-added metallurgical product with good protection performance and beautiful surface. It is widely used in construction, home appliances, automobiles, containers, transportation and other fields. World consumption of galvanized sheet steel production of is 11.9%, a higher proportion of developed countries such as the United States could reach 15%, while China is only less than 5%. Most of the galvanized sheets in China can only be used in the construction industry, and the high-quality galvanized sheets used in home appliances and automobiles need to rely on imports. Although the overall production capacity of metallurgical products is excessive, for high value-added galvanized sheets, the production capacity is not enough, especially high-quality galvanized steel sheets, which are urgent for us. To increase production capacity, we need to increase the production efficiency of galvanizing production lines and improve the level of automation. While improving the quality of galvanized steel sheets, there are many factors that affect the quality of galvanized steel sheets. One of the most important factors is the influence of zinc slag on the quality of galvanized sheets.

The level of automation of China's hot-dip galvanizing line needs to be improved. In particular, some work related to harsh working conditions, high risk, labor intensity, and health hazards are urgently needed to be replaced by automated equipment. According to the survey, the work of domestic zinc slag removal is mainly done manually. Workers wear helmets, and heavy overalls, working in high temperature with low efficiency. If the cleaning of slag is not timely enough, it will seriously affect the quality of galvanized steel. Therefore, the use of robots instead of manual slag removal work can not only greatly reduce the labor intensity of employees, improve safety, but also reduce plating loss and reduce enterprise costs.

2. Application research of online slag-removing robot
2.1. Application field of online slag-removing robot
The online slag-removing robot can realize the online slag removal on hot-dip galvanizing line, and can be applied to the production of GI, Galfan, hot-dip galvanized Zn-Al-Mg, Zn-Ti, Zn-20% Al-Re steel sheet and so on.

2.2. Core equipment of online slag-removing robot

2.2.1. Slag-removing robot body. 6-axis 6-degree industrial robot performs slag removal. As shown in Figure 1.

![Figure 1. Schematic diagram of online slag-removing robot body.](image)

2.2.2. IRC5 controller. The IRC5 controller contains all the necessary functions for moving and controlling the robot. The controller consists of two modules, a control module and a drive module. The control module contains all the electronic controls, such as the main unit, I/O board and flash memory, and runs all the software needed to operate the robot. The drive module contains all the power electronics that power the robot motor.

2.2.3. Slag-removing tool. It includes a pusher plate and a slag shovel for direct contact with zinc and zinc slag during the slag removal process. The tool is a series of replaceable tools with reasonable design and convenient disassembly and assembly. The contact with zinc liquid is designed in the form of mesh and adheres to high temperature resistant coating, so it does not stick to zinc liquid. The schematic diagram of the slag-removing tool is shown in Figure 2.

![Figure 2. Schematic diagram of the slag-removing tool.](image)

2.2.4. Demonstrator. It is a hand-held operating device for performing tasks related to operating a robot system: running a program, jogging a manipulator, modifying a robot program, and the like. It can be continuously transported in harsh industrial environments, and its touch screen is easy to clean, waterproof and oil resistant.

2.2.5. Process control system. According to different steel grades, plating liquids and standard quality requirements, the slag removal process is set, and the frequency of slag removal process is issued to be set.
2.2.6. **Visual servo system.** The surface image of the zinc liquid is obtained by an industrial camera, and the surface slag amount and distribution of the zinc liquid are obtained through image processing, and the slag removal command is outputted to control the slag-removing robot.

2.2.7. **Safety protection system.** Realize emergency stop and other functions, consisting of the following parts.
- **Emergency stop button:** the device has an emergency stop when it encounters a problem.
- **Collision sensor:** set the collision sensor in the robot servo motor to stop the device when a collision occurs.

2.3. **Online slag-removing process**

According to the coating type, combined with the experience of artificial slag, the following fixed slag removal process is customized for the plating composition, substrate, coating surface quality and slag volume requirements.

The robot is placed on the right side of the zinc plating boiler rear refilling liquid area. The robot first pushes the scum at the rear of the furnace nose to the slag-removing robot working area (action 1), and then replaces the tool for the slag shovel (Action 2~6). As shown in Figure 3.

3. **Application research of offline slag-removing robot**

3.1. **Application field of offline slag-removing robot**
The offline slag robot is mainly used in the offline zinc pot of the GL coated slab production line.

3.2. **Core equipment of offline slag-removing robot**
The offline slag-removing robot consists of robot of 2 degrees of freedom, slag-removing tool, gantry self-positioning lifting device, process control system, pneumatic insulation system, and safety protection system, as shown in Figure 4.
3.2.1. **Robot of 2 degrees of freedom.** Execution of slag and slag-removing g action.

3.2.2. **Slag-removing tool.** It includes a pusher plate and a slag shovel for direct contact with zinc and zinc slag during the slag removal process. The tool is a series of replaceable tools with reasonable design and convenient disassembly and assembly. The contact with zinc liquid is designed in the form of mesh and adheres to high temperature resistant coating, so it does not stick to zinc liquid.

3.2.3. **Gantry self-positioning lifting device.** It is used to carry the machine gripper and drive the machine grip to cover all areas of the offline zinc pot.

3.2.4. **Process control system.** According to different steel grades, plating liquids and standard quality requirements, the slag removal process is set, and the frequency of slag removal process is issued to be set.

3.2.5. **Pneumatic insulation system.** Used for thermal protection of equipment.

3.2.6. **Safety protection system.** Realize emergency stop and other functions, consisting of the following parts.
- Emergency stop button: the device has an emergency stop when it encounters a problem.
- Collision sensor: set the collision sensor in the robot servo motor to stop the device when a collision occurs.

3.3. **Offline slag-removing process**
The machine gripper is installed on the gantry-type self-positioning lifting device, which is located above the offline zinc pot to carry out the slag removal operation on the entire offline zinc pot area. The offline zinc pot is divided into 12 areas, and the machine gripper traverses 12 areas (Figure 5) in the figure to perform the slag-crushing operation driven by the gantry-type self-positioning lifting device.

![Figure 5. Schematic diagram of the offline slag-removing process area.](image)

4. **Conclusion**
Introducing industrial robot technology into continuous hot-dip galvanizing production line, and replacing artificial slag by robot is the most optimized way to solve the problem of slag-removing. Therefore, the use of robots instead of manual slag removal work can not only greatly reduce the labor intensity of employees, improve safety, but also reduce plating loss and reduce enterprise costs. The industrial upgrading of the steel industry should be oriented towards the intelligentization of robots. The galvanizing line slag-removing robot will have a broad space for development in the future.

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