Experimental Design and Spray Technology Research of Ship Paint Spraying Robot

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Abstract. A wall climbing robot for ship painting is designed. The robot is the separation of the paint output device and the main machine of the painting equipment to realize the painting operation of the wall climbing robot. The test environment and test method design of the robot are introduced in detail, and the painting process of the robot is verified. On this basis, the thickness of paint film and the related aspects of spraying process are studied, so as to eliminate the random error caused by experience and technical techniques, and to achieve the established film thickness and the stability of paint film coating. Improve automatic spraying process and labor productivity.

1. Introduction

In the large-scale open magnetic working face, such as the outside surface of the ship, because the working range is usually large, it is necessary to set up a scaffolding temporarily in the painting operation, and then the construction personnel cling to the scaffolding to carry out the painting operation. This spray painting method has the feature of low automation, high environmental pollution and low safety factor, which will cause serious harm to the health of the constructors. As a wall-climbing robot used for painting and pretreatment of hull, it is similar to other wall-climbing robots. Firstly, it should have the ability to adsorb on the surface of steel hull. Secondly, the developed robot needs to paint and pre-process the hull, so the robot needs to be integrated with the related process equipment, in order to reduce the load of the wall-climbing robot. The robot body is separated from the main machine of the process equipment. In order to finish painting and pretreatment task well, robot must have better control performance. In addition, in order to reduce the workload of manual operation and ensure the stability of painting effect and the uniform thickness of coating film, the off-line task planning of painting combined with wireless positioning of robot is considered to realize the automation of painting.

Figure. 1 is the structure diagram of the working system of the ship painting robot. The working system of the ship painting robot includes a wall climbing robot, a protective lifting unit, a control unit, a painting process equipment unit, a spray gun and a display setting terminal wall climbing robot adsorbed on the outer surface of the ship, and the spray gun is loaded on the wall climbing robot. The control unit is used to control the wall climbing robot forward, backward, turn and spray gun attitude adjustment. The painting process equipment unit and the spray gun are connected through the air circuit and the paint output line. It is used to transfer liquid coating through high pressure to gun protection
lifting unit through flexible protection rope connecting climbing robot display setting terminal for working system status display, fault alarm and parameter setting.

1. Outer surface of ship. 2. Protective lifting unit. 3. for device. 4. Wall climbing robot. 5. Spray painting process equipment unit. 6. The control unit. 7. Display setup terminal. 8. Paint delivery line.

Figure 1. Structure of ship spray painting robot working system.

2. Control system
Figure 2 is the block diagram of the control system of the ship painting robot. As the core of the whole electronic control system, the control system of the ship painting robot is mainly composed of a controller, a display and an associated sensor, and is used for acquiring the peripheral attitude information of the robot, the logic operation, the driver control, the state display and the parameter modification. The system adopts industrial radio remote controller. The industrial radio remote controller is used for converting a button signal, and a switch signal into an electromagnetic wave after being modulated by a transmitter, and the receiver amplifies the received electromagnetic wave signal to be decoded and identified, and sends the signal to the control system through a communication bus to perform a logical operation, so as to realize the control function. When the robot is crawling and turning on the ship wall, the robot is realized by the left and right servo motors, the left and right turns are realized by the differential of the two driving wheels, and the driving wheels are driven by a servo motor matched with the speed reducer. When the two motors are rotating, the robot will start to advance; instead, when the two motors are rotated in a reverse direction, the robot returns.

Figure 2. Marine spray paint robot control system frame.
3. Experiment design

3.1. Design of test environment and test method

The system verification environment is mainly used to test the spraying process of spray-painting robot, including process test platform, safety protection device, testing equipment of paint film mechanism, communication tools and so on. The whole process test platform is constructed by steel structure. In order to simulate the practical application environment of paint spraying robot on the outer wall of ship, the outer surface of the process test platform in this scheme is composed of arc of 5mm and straight steel plate respectively. The safety protection device is mainly composed of a magnetic crane and an anti-falling device. The anti-falling device is fixed by the magnetic crane attached to the upper part of the platform, and can be extended and expanded according to the distance between the robot and the wall-climbing robot. When the falling speed of the robot exceeds the 0.5m/s, the anti-fall device will automatically tighten to prevent the robot from falling further, thus acting as a safety guard. The testing equipment for coating mechanism is used to detect the dry film formed in the spraying process, including the thickness and hardness of the coating.

3.1.1. Design of the process test platform. The overall figure of the process test platform is shown in figure 3.

![Figure 3. Overall appearance of process test platform.](image-url)

As shown in the figure above, the spraying process test area is mainly used for the wall climbing robot equipped with spraying equipment to achieve automatic spraying, and then the wall climbing robot equipped with paint film detection equipment to achieve the detection of dry film quality and dotting record of unqualified dry film. In order to ensure the convenience of transportation and installation of the process test platform, the upper test is divided into four component units, and the base is divided into three component units. Forklift holes are left at the bottom of each component unit. Figure 4 is the composition of process test platform.
(1) The upper part of the test area constitutes the unit. (2) The lower part of the test area constitutes the unit. (3) The base.

**Figure 4.** Process test platform composition.

Mounting holes are left in both the base component unit and the bottom component unit of the test area. During assembly, positioning and fixation are carried out through screws, as shown in figure 5.

**Figure 5.** Base and lower test component unit installation.

During the assembly of the upper and lower component units in the test area, in order to effectively butt the two parts and ensure the flatness of the panel in the test area without displacement or dislocation, a positioning mechanism is designed for the lower component unit in the test area, and the through screws are also installed between the two parts, as shown in figure 6.

**Figure 6.** The upper and lower component units of the test area are installed.
3.1.2. System verification method. The dry film formed by spraying robot with airless spray gun needs to be tested mechanically, mainly including film thickness test, impact resistance test, hardness test and so on, aiming at different process parameters. Under different robot walking speed, the dry film is detected to meet the standard, and the testing results are counted and the spraying process database is obtained.

After painting operation, it is necessary to detect the thickness of paint film on the paint surface and mark out the unqualified area, so it is necessary to design the mechanism of measuring the thickness of paint film. Figure. 7 is the structure of the paint film thickness measuring and hitting point mechanism. 2 is the block diagram of the control system of the ship painting robot. The paint film thickness measuring and hitting mechanism mainly consists of two modules, one is the paint film thickness measuring function module and the other is the paint film thickness measuring function module is composed of the linear reciprocating motion mechanism and the lacquer film thickness measuring equipment, and the film thickness measuring mechanism is composed of a linear reciprocating motion mechanism and a paint film thickness measuring device. The function module is composed of a linear reciprocating motion mechanism and a marking device, both of which are independent of each other, and the film thickness measuring device and the polishing device should be as close as possible to each other.

![Figure 7. Film thickness measurement dot mechanism structure.](image)

In this scheme, the thickness of dry film is measured by magnetic thickness meter. When the spraying effective area is greater than 1 m², any 1dm² area is taken as the base surface and the dry film thickness at 10 points is measured, and the arithmetic average value of 10 values is taken as the local average thickness value of the datum level. The number of reference surfaces shall be determined by the spraying effective area and shall be not less than three reference surfaces for every 10 kgs on the flat outer surface of the ship. When the spraying effective area is less than 1°, the five-point coating thickness is measured with any area as the 1cm²datum, and the arithmetic average of the five values is taken as the local thickness of the base surface.

In order to obtain more accurate thickness of paint film, a reference surface is selected to measure the thickness of paint film. The average thickness measurement point obtained should not be less than or higher than 90% of the specified dry film thickness, otherwise the count will be recorded. The number of measuring points which do not reach the required dry film thickness should not exceed 10% of the total measured point, otherwise, the spraying dry film does not meet the requirements.

In this scheme, the hardness of paint film is tested by pencil. Firstly, the lead core is cylindrical exposed about 3 mm, and then ground on sand paper until the edge of pencil tip is sharp. The hand-held pencil is about 45°and moves at the speed of 1cm/s at the speed of 1 cm on the dry film of the process test platform with the strength of the pencil core not breaking. Each scratch on a dry film requires re-grinding of the tip of the pencil core and repeated scratching of the pencil with the same hardness mark. In the case of five scratches, if two or more of them have not been scratched to the bottom or bottom of the paint film, replace the pencil of the previous hardness mark with the above test until two or more pencils have been scratched / injured, until the paint film has been scratched / injured, and two or more
pencils have been scratched / injured, until two or more pencils have been scratched / injured. Write down the pencilundefineds hardness label, which is the hardness of the paint film.

3.2. Experimental verification
The actual environment has been tested and verified in a certain unit of ships. The main system indexes are as follows:

1) The coating effect can achieve uniform film thickness without any phenomena such as flow, bubble or leakage coating;
2) Moving ability, continuous working ability and bending ability can meet the actual use needs.

3.2.1. Test verification method. The schematic diagram of the test system is shown in figure 8.

![Test system principle frame.](image)

3.2.2. Test steps. The test steps of coating robot system are as follows:

1) put the robot on a unit ship test section;
2) Power on the robot system;
3) open the ball valve of the high-pressure airless sprayer, and the high-pressure pump starts to work;
4) Make the robot walk to the test area through the remote control, adjust the robot posture, make the direction of robot travel parallel to the ground, and adjust the pendulum rod perpendicular to the robot body;
5) start the paint conveying, and the robot carries out the painting work;
6) When the transverse walk to the edge of the test area position, stop paint delivery, robot turn to test area under a starting position, spray gun rotated 180 ° at the same time;
7) Carry out the next spraying, and at the same time, control the robot's walking through the remote control to ensure that the current spraying track and the last spraying track can achieve the superposition of 50%.

After the paint is atomized and ejected through the compressed air, except for the invalid area on the edge of the sprayed workpiece, a layer of film is finally formed in the effective area, as shown in figure. 9.

![Example of paint film section.](image)

After spraying in the test area, the test results are filled in the spray test record table by visual inspection to see if there is any wet film hanging, and checking the edge pressing of any two paint films.
After the wet film was completely dried, the thickness of paint film was measured by the thickness meter of paint film and the thickness value was recorded in the spraying test record table.

3.2.3. *Test verification result.* The relationship between the thickness of paint film and the flux of spray paint is measured by experiment, as shown in table 1.

| Traffic/(ml min⁻¹) | Film thickness/um |
|-------------------|-------------------|
| 50                | 30                |
| 70                | 40                |
| 80                | 50                |
| 120               | 70                |
| 200               | 110               |
| 250               | 120               |
| 300               | 140               |
| 350               | 150               |
| 400               | 170               |

All the data obtained above are fitted by cubic power with matlab tool, and the fitting curve between the flux and the thickness of paint film is obtained. It can be seen from the diagram that there is a linear relationship between the flux of spray paint and the thickness of paint film, which is basically a linear relationship between the flux of paint and the thickness of paint film. Figure 10 is a fitting curve between the flow rate and the thickness of the paint film.

![Figure 10. Fitting curve of flow rate and film thickness.](image)

The relationship between coating pressure and film thickness is shown in table 2 below. It is observed from the data in table 2 that there is an approximate linear relationship between the paint pressure and the film thickness, so the linear equation is used to fit it here. The curve is fitted numerically by mat lab as shown in figure 11.
Table 2. Relationship between spray pressure and film thickness.

| Pressure/MPa | Film thickness |
|--------------|----------------|
| 0.05         | 120            |
| 0.10         | 110            |
| 0.15         | 105            |
| 0.20         | 100            |
| 0.25         | 90             |
| 0.30         | 80             |
| 0.35         | 75             |
| 0.40         | 70             |
| 0.45         | 65             |
| 0.50         | 60             |
| 0.55         | 50             |

Figure 11. Fitting curve of film thickness and spray pressure.

4. Conclusion
Based on the experimental results, it is concluded that the factors affecting the film thickness are the paint flow rate and paint pressure. Therefore, the spray paint test is carried out, and all the data obtained from the experiment are fitted by curve. The relationship between the film thickness and the above-mentioned technological parameters is obtained: under the same conditions as other factors affecting the film thickness, the film thickness is basically linear with the spray pressure, and the paint flow rate is basically linear. Therefore, in the actual coating process, it is necessary to set relevant parameters according to the actual situation and combined with the test data to ensure that the film thickness is controllable and adjustable.

Acknowledgments
Nothing.

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