The Robot Intelligent Spraying Glazing System for Sanitary Ceramics Industry

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Abstract—Aiming at the current situation and existing problems of the sanitary ceramics industry, the paper presents the R&D of a set of multi-robot cooperation in the spraying glazing system. Firstly, the paper introduces the requirement of spraying glazing and puts forward the technics of spraying glazing robot. Then the paper introduces the system solution of spraying glazing robot, the working mode of the cooperative multi-robot, and the method of robot trajectory planning. Finally, according to the real experimentation of established spraying glazing robot system, the paper tested and verified the performance of the system. This system plays a positive demonstration role in the sanitary ceramics industry.

1. Introduction

As a major producer of sanitary ceramics, China has gathered relatively perfect industrial chains and production bases in Guangdong, Henan and Hebei provinces. Since 1993, production volume has been ranked as No.1 in the world stably. But compared with advanced countries, there is still a certain gap in production technical level [1]. In recent years, with the increase of labor cost, the sanitary ceramics enterprises moving towards the development policy of high-end and brand marketing, and some enterprises have begun to implement the automatic transformation [2].

Spraying Glazing is an important process in the production of sanitary ceramics, and it affects the quality of the final product directly. In foreign countries, the technology of spraying glazing robot is well developed, but in China, this technology is still at its starting stage, most of which are manual operation that could easily cause occupational diseases, heavy labor intensity, instable product quality and many other problems [3-4]. In order to solve the above-mentioned problems, it has become an inevitable requirement for the industry to develop and promote the spraying glazing robot production line, and it's also necessary to promote the transformation and upgrade the level of sanitary ceramics industry [5].

2. Production Technics Analysis of Spraying Glazing Robot

2.1 Quality Requirements of Sanitary Ceramic Spraying Glazing

Spraying glazing is an important part of sanitary ware production. The glaze thickness, surface smoothness and pinhole condition of glaze after spraying have a direct influence on the quality of the firing product. The quality requirements of the products after spraying glazing are as follows:
TABLE I. MAIN REQUIREMENTS FOR SPRAYING GLAZING

| Element                      | Index                              |
|------------------------------|-----------------------------------|
| Glaze thickness              | 0.8-1.0mm                         |
| Thickness after firing       | 0.6-0.8mm                         |
| Water content of body        | 4%-7%                             |
| Pinhole number               | The number of pinholes in 5cm² is not more than 3 |
| Whiteness after firing       | L:90.85±1                         |

2.2. Formulation a Robot Glazing Technics

According to quality requirements of sanitary ceramic spraying glazing, it’s necessary to make strict spraying glazing technics to ensure the final quality result [6]. If we use robot to glaze, it has lower flexibility and adaptability than manual work, but the running speed and positioning accuracy is much higher. We should formulate a special spraying glazing technic according to the feature of robot.

The formulation of robot glazing technics mainly takes account of glaze, body performance, parameters of spraying glazing system, the planning of robot motion path, site environment and so on.

- Glaze. Compared with artificial glazing, the robot has fast running speed, high accuracy but low adaptability. So in terms of glaze parameters, we should reduce glaze fluidity and increase specific gravity to suit the robot. Therefore, the glaze will not sagging easily after spraying.
- Body performance. Due to the automatic production, the body has to be transported on the transferring line or other equipment, so it is necessary to improve the strength of the body and prevent the body billet damaged.
- Parameters of spraying glazing system. The spraying glazing robot uses middle and high-pressure automatic spray gun, it requires precision and stable glaze supplying. Because of the difference of performance parameters between robot sprayed glaze and artificial glaze, the parameters of glaze system such as glaze pressure, atomizing and spraying fan should be adjusted properly, which is suitable for robot.
- Robot trajectory planning. The operating principle of the spraying glazing robot combines the characteristics of artificial spraying and robot is high speed with many times, which can improve the TAKT time of robots and the spraying glazing quality.
- Actual site environment. Because the glaze material, the body and the glazing effect will change with environment, and the trajectory of robot programming could be high repeatability, the stable working site environment is an important condition to guarantee the quality.

Based on the above analysis, the theoretical process parameters of spraying glazing robot are listed as follows:

TABLE II. THE PROCESS PARAMETERS OF SPRAYING GLAZING ROBOT

| Category                     | Parameters     | Index                  |
|------------------------------|----------------|------------------------|
| Glaze                        | Specific gravity | 1.74-1.75             |
|                              | Flow speed      | 130-150s               |
|                              | Sip up          | 15-18min               |
| Spraying glazing system      | Glaze pressure  | 0.2Mpa                 |
|                              | Atomization     | 0.6Mpa                 |
|                              | Spraying fan    | 220mm (400mm/gun distance) |
| Robot trajectory             | times           | 4                      |
|                              | Takt time       | 55s                    |
| Actual environment           | Temperature     | 28-32°C                |
|                              | Humidity        | 60%                    |
3. **THE OVERALL DESIGN OF SPRAYING GLAZING ROBOT SYSTEM**

The design of whole working line of spraying glazing robot takes the toilet close stool for example. In [7], the toilet close stool is the most complex products in the process of design for sanitary ceramics, the design line is also compatible with pots, pillars and other small products. The glazing process of toilet close stool includes pipeline glazing, water tank, water outlet, the inner and outer surface, nanometer glaze and other several steps, in which inside and outside surface of spraying glazing plays a predominant role. Based on the above-mentioned process, we prefer to finish spraying glazing with four times that is completed by four robots respectively. The overall line of spraying glazing robot system is designed as follows:

The whole line is designed as a belt conveyor mode, and the multi robot stations work cooperatively. The TAKT time of each station is basically the same, so as to improve the utilization ratio of robots.

4. **Trajectory planning of spraying glazing robot**

4.1. **The multi-robot cooperative glazing method**

In order to reach the thickness of the glaze, the toilet close stool needs to be continuously deposited by spraying glazing repeatedly. For the purpose of improving the deposition rate and promote the glaze absorption, it's better to finish the drying process after glazing.

The mathematical model of glazing is established as follows:

\[
A = \frac{(L-F) \times n}{v} \times \eta
\]  

Where A is the deposition, L is spraying quantity, F is wastage, v is gun speed, and n is spraying times.

The mathematical model of wastage is established as follows:

\[
F = \lambda \times P \times D \times (1 - X\%)
\]  

Where P is atomization pressure, D is gun distance, X is glaze absorptivity. F can be considered as a fixed value when the robot trajectory and glaze parameters is steady.

By (1), (2), when P is a certain value, A is only related to v and n. The experimental data for the deposition at different speeds (v) is shown as follows:

![Glaze deposition and Velocity](image-url)
It indicates that if we want to get the glaze deposition thickness of 0.8-1.0mm, we can choose the gun speed of 600-800mm/s and n=4.

According to the relationship between glaze thickness A and v and n, we use the four robot stations cooperation model. With the aim of balanced TAKT time when robot sprays with glaze, a drying station is arranged between each robot, so as to improve the glaze absorptivity to the body.

4.2. Robot Trajectory

4.2.1. Glaze material distribution model and trajectory of spray gun:
The glaze material distribution model can be expressed by a variety of distribution functions. Some people proposes to use β or Gauss curve to fit the spatial distribution of glaze material, but the effect is not satisfactory. Therefore, we can analyze the spraying pattern of actual gun [8-9], and the picture below shows the spraying pattern result and glaze material distribution which is measured by experiment (The spray fan is set to 270mm).

![Figure 3 Spraying pattern and glaze material distribution](image)

From the glaze material distribution curve, it shows that the glaze material distribution in the middle section is uniform distributed, and there are uneven ends and peripheral transition zones. So, when we plan the trajectory of spray gun, it is necessary to adopt partial overlap to improve the glaze material even distribution. In [10], the spray gun running path is shown as follows: (Where 1-4 are spray gun running paths, v is speed, w is effective spraying area, d is superimposed area, and s is the central point of the two paths.)

![Figure 4 The spray gun running path](image)

4.2.2. Glaze material distribution model and trajectory of spray gun:
Toilet closetool surface is 3D complex cured surface. In order to achieve a even spraying glazing on inner and outer surfaces, we can divide it into three parts according to cured surface characteristics: water tank surface, side surface and inner surface, and make trajectory planning respectively. The surface of the water tank is approximately square. The side surface is a semicircular curve, and the gun distance is changed according to the side surface; The inner surface is approximately elliptical curve. Three part of the robot trajectory is shown as follows:
5. The system test of spraying glazing robot

In summary, when the environmental condition is as followed: temperature with 28-32°C, humidity with 50%-70%; The spraying glazing system parameter is set as: glaze pressure 0.2MPa, atomization pressure 0.6MPa, spray fan 270mm. Taking the robot trajectory plan into consideration, we can test the system of spraying glazing robot. The results of different glaze material parameters are shown as follows.

| Flow rate (s) | Specific gravity | Sip up (min) | Test result                                      |
|--------------|------------------|--------------|--------------------------------------------------|
| 80           | 1.721            | 26’          | Glaze thickness is thin, black                   |
| 90           | 1.734            | 23’          | Spray sagging                                    |
| 100          | 1.764            | 22’          | Flowing glaze locally                            |
| 110          | 1.765            | 20’          | Glaze thickness is thin, flowing glaze locally   |
| 120          | 1.765            | 18’          | Qualified                                        |
| 130          | 1.759            | 17’          | Qualified                                        |
| 140          | 1.762            | 17’          | Qualified                                        |
| 150          | 1.758            | 16’          | Many pinholes locally                            |
| 160          | 1.765            | 15’          | Glaze thickness is thicker, many pinholes locally|
| 170          | 1.756            | 13’          | Glaze thickness is thicker, dehiscence           |

According to the test result, we can know that when glaze flow rate is 120-140s, specific gravity is 1.76, and sip up is 17-18 minutes, good glaze effect is achieved. The test result is basically matched with the theoretical analysis.

6. Conclusion

In this paper, we take the requirements of glaze surface into consideration at first and give quality requirements of spraying glazing, and then the spraying glazing technics of robot are made by comparing with manual work. Secondly, we analyze the cooperative trajectory planning of multi robot, and test the correspondent system. As a result, the final testing achievement is in good match with the theoretical analysis.

The spraying glazing robot system has been officially put into production in local enterprises, and the quality of glaze and its TAKT time are in the leading position in China. The system has great application and promotion value in sanitary ceramics industry. The actual production picture is shown as follows:
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