IMPROVEMENT OF THE PAINTING ROBOT (FR-1) AND ITS APPLICATION TO THE SITE

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ABSTRACT

In June 1988, the first test model (FR-1) of the painting robot was developed. its painting robotization was subjected to a demonstration test which, in the Fukushima No.2 Nuclear Power Plant of the Tokyo Electric Power Company was conducted on the outer walls of the sea water heat exchanger building. Based upon the achievements in Fukushma, especially in order to assure the easiness of handling the robot on site, some improvement was made to develop a model of practical use (KFR-2).

Furthermore, in August 1988, this model was put into an actual painting work of a solid waste storage building, Tomari Power Plant, Hokkaido Electric Power Company and successfully completed with remarkable results such as shortening of working period, labor saving and enhancement of safety.

1. INTRODUCTION

Nowadays, the following reasons can be given for the advancement of robotization:

- A shortage of laborers, in particular, skilled workers.
- The major reason of the decline of safety and productivity with age.

We, as constructor, are actively struggling with these problems, and the owners on their side, thinking introduction of robots indispensable, display a strong inclination toward further introduction of robots.

We, from this type of background, have turned our attention to the finishing of large size structures, and have been grappling with automization and robotization since 1986. In 1988 the finishing robot test model (Finishing Robot - No. 1, hereafter referred to as FR-1) was produced, and was applied to the repair work of the outer wall of the Fukushima No.2 nuclear power plant of the Tokyo Electric Power Company. Further, in 1989, based on the operation results of the test model, aiming at improvement of operational capacity and a decrease in size and weight, we produced a practical model (Kumaigumi Finishing Robot No.2, hereafter referred to as KFR-2), applied it to the painting of the outer wall of the solid waste storage depot of the Hokkaido Electric Power Company Tomari power plant, and were able to obtain great results.

2. DEVELOPMENT OF THE KFR-2

2.1 Critical Problems and Their Countermeasures in the FR-1

Based on the demonstration test results at the Tokyo Electric Fukushima No. 2 nuclear power plant, critical problems and their countermeasures were investigated, in order to make the finishing robot even more practical, the objectives for the KFR-2 were established as below.

(1) Problems arisen

Table 1 shows the problems and their causes identified through the FR-1 demonstration test.

Table 1 Problems confirmed through the demonstration test and their countermeasures

Problems	Causes	Countermeasures
Many spots left unpainted	-Use of suspension hooks in connection with the auto-tensioning device -The traveling pattern (lateral movement) is not good. -The automatic painting unit is not well positioned on the carriage.	-Study of a solution accompanying no suspension hooks -The traveling pattern which may not influence painting in the upper section of the wall should be studied. -The automatic painting unit is shifted in position so as to perform painting of the upper section.
Moving the system takes much time	-The robot is large sized and weighs heavy. -The attachments are layouted at random.	-Making the robot main body compact in size and light in weight -They are grouped systematically.
Much time is needed for changement of programs	-The data to be inputted are too numerous.	-They should be reduced in number.

(2) Development objectives for the KFR-2

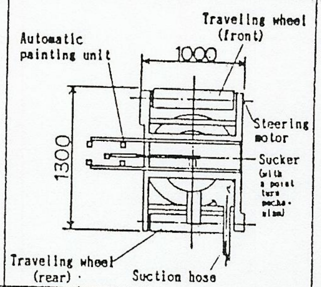
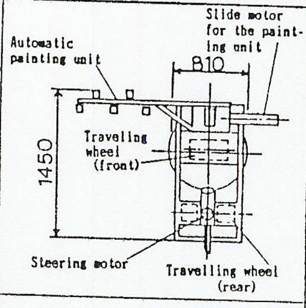
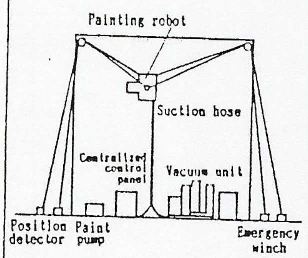
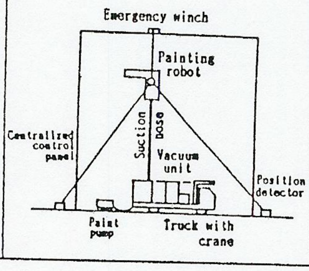
As a result of investigation concerning the measures in Table 1, the objectives below were established.

- No occurrence of spots left unpainted (in particular, on the upper section of the building).
- Miniturazation of the robot, and approximately halving the weight.
- Approximately doubling the painting width each time.
- Having the mobility to place the attached equipment on a cart.
- Approximately halving the amount of necessary input data for automatic operation.

2.2 Development of the KFR-2

As a result of concretizing the countermeasures and objectives of 2.1, first of all, in the functions of the main body, in particular the reduction of weight and size, and the improvement of the capability of the automatic painting equipment, and further, improvement of the attached equipment, were carried out. Figure 1 shows a comparative chart of the FR-1 and the KFR-2.

Figure 1 Performance comparison between FR-1 and KFR-2

	FR - 1	KFR - 2	Merits of the practical model
Overview			In this renewed system, it is possible for the robot to approach to the upper section of the wall. The painting unit, because its location is shifted to the upper end of the carriage, is able to paint all over the uppermost section without leaving unpainted spots.
Specifications - Robot main body Traveling mode	Traveling on wheels (turning at small radius is made with the steering mechanism and that at large radius unit)	Traveling on wheels (turning at small and large radius is made by the steering mechanism)	The traveling speed is two times that of the test model.
Traveling speed	0 ~ 5 m/min	0 ~ 10 m/min	
Loading capacity	max. 180 kg	max. 130 kg	The overall system becomes compact in size, and the dead weight is halved approximately.
Outer dimensions	1000 x 1300 x 800 (mm)	810 x 1450 x 700 (mm)	
Weight	about 400 kg	about 250 kg	
- Painting unit Nozzle	5 (fixed nozzle: 4, swing nozzle: 1)	5 (fixed nozzle: 3, swing nozzle: 2)	
Effective painting width (primer coat)	500 mm	900 mm	Painting width is approximately doubled.
Layout			The equipment being placed on the truck, higher mobility on site is ensured.

2.3 Overview of the KFR-2

The KFR-2 is composed of automatic painting equipment equipped with numerous nozzles, on a carriage able to move freely about left and right, up and down, by means of two drive wheels front and back, which is attached to the wall surface by means of a sucker in the body of the robot.
Below we describe a comparison with the FR-1, concerning the points that have been changed.

(1) Concerning the function of the main body
- The type of movement was changed from point turn type to switch back type which utilizes a rear wheel steering capability.

- Movement speed was upped from a maximum of 5 m/min to 10 m/min.

- The front wheels were put inside the sucker, aiming for a reduction in size and weight.

(2) Concerning the automatic painting equipment

- Five painting nozzles were lined up, thereby increasing the effective painting width.

- The automatic painting unit attaching position was moved to the upper section of the robot, eliminating unpainted spots in the upper part of the wall surface.

- The robot was structured with painting devices also in its head, eliminating unpainted spots along the right edge of the wall.

2.4 Attachments

The attachments consist of the vacuum unit that creates negative pressure in the sucker on the main body of the robot, the auto tension devices for the prevention of falls, the central control room for the performing of operation, and the paint pump unit.

2.4.1 System Truck

For the test model, because the vacuum unit, control room, compressor, and the various types of equipment are stationed near the wall surface, it was anticipated that considerable time would be required to move and set them up. In order to aim at reduction of the transport and set up time, the vacuum unit, control room, compressor, and the various types of equipment were mounted on a 4t truck. The system truck is shown in Figure 2.

2.4.2 Auto Tension Devices

In the main equipment of the experimental machine, because two winches were positioned near the wall surface, and further, on the wall parapet a sheave for the wire was placed, in the upper section of the wall surface, spots left unpainted occurred. Moreover, because in transport and set up, heavy construction machines were necessary, and required considerable time, the improvements below were carried out.

- The number of winches was reduced to one which was positioned on the top of the roof, and the sheave for the wire was eliminated.

- The winch was mounted on a carriage that would enable movement on the roof top, and mobility was improved.

In Figure 3 the auto tension equipment is shown.

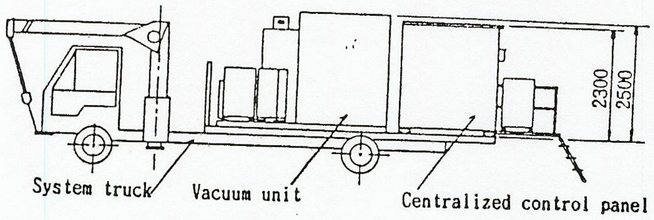


Figure 2 System truck

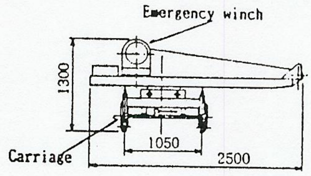


Figure 3 Auto tension device

3. APPLICATION TO THE PAINTING OF THE OUTER WALL OF THE TOMARI POWER PLANT

3.1 Overview of the Work

Work title: Painting of the outer wall of the solid waste storage of the Tomari Power Plant, The Hokkaido Electric Company Inc.
Execution of the robotized work was done in the period: August 7 to October 18 of 1989.
Building: The form of the building is shown in Figure 4.
Wall surface to be painted: approx. 2000 sq. m, (fair faced concrete with joints of width 30 mm and depth 20 mm in horizontal and vertical directions.)
Painting material used: acrylic elastomer paint; (Paint specifications are shown in Table 2.)

Table 2 Painting specification

Process \ Item	Paint amount consumed (kg/sq m)
Primer coat	0.30
Base spray	1.70
Pattern spray	0.50
Top coat (first layer)	0.15
Top coat (second layer)	0.15

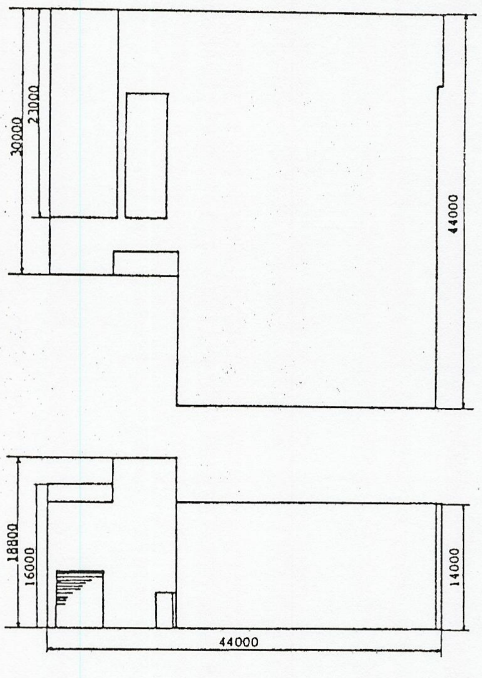


Figure 4 Building form

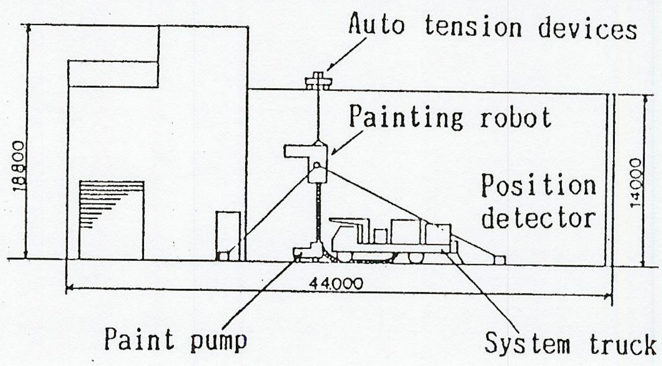


Figure 5 Layout of equipment

3.2 Method of Operation

3.2.1 Operation Preparation

In the implementation of a robotized painting operation, first of all was an investigation of the specifications and a survey of the site, then a study of the method of operation, and implementation of a preliminary spraying experiment were conducted. From the results of the survey of the site, the equipment was set up as shown in Figure 5.

Painting was begun after the preparation procedures (1) and (2).
(1) Transport and setting up of the painting robot
(2) Determination of the course pattern (a trial run of the robot after the planned course pattern)

3.2.2 Painting Method

In order to make sure of the paint specifications, immediately prior to painting the wall surface, first a trial spraying of a vinyl board was conducted. After confirming paint thickness distribution with a wet thickness gauge, and that there was no unevenness by a sight check, the primer coat, the main coat, and the finishing coat were applied. Photo 1 shows the robot applying the main coat.

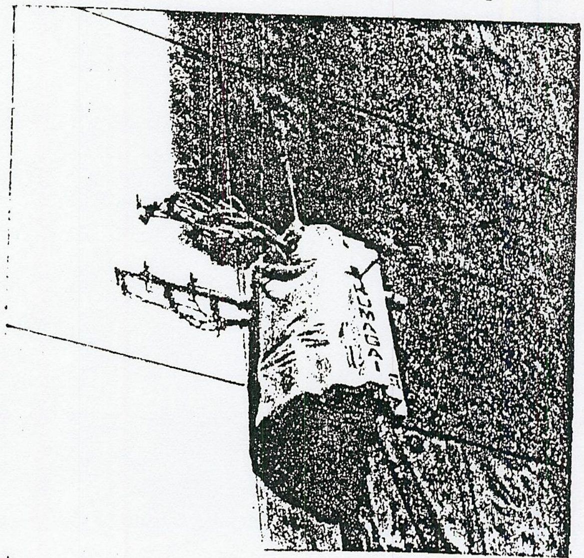


Photo 1 Robot applying the main coat

4. OPERATION RESULTS

(1) Concerning Painting Achievement

The painting results achieved for each of the processes in this work were as shown in Table 3.
From these results, comparing with the standard painting rate of 9 - 10 sq m/man-day (5 processes) in the case using a gondola, The robot achieved painting of 231 sq m/day (1 process), and since there were three workers (operator, paint controller, and overall supervisor), 231/3 = 77 sq m/man-day (1 process), for five processes this becomes 77/5 = 15.4 sq m/man-day, attaining a result of approximately 1.6 times the manual rate.

Table 3 Painting results by the painting robot

	Primer coat	Base spraying	Pattern spraying	Finish coat	Remarks
Working days	76 days (of 76 days, rain and holidays are 33 days)				
Actual working days	43 days				
Robot running ratio	running hours: 143.8 h (about 18 days) 18/43≒0.42 (about 42%)				
Max. painting speed	175.2 sq m/h	72.6 sq m/h	110.3 sq m/h	111.1 sq m/h	These are indicated as real speeds excluding preparation and troubles.
Aver. painting speed	147.7 sq m/h	68.0 sq m/h	99.8 sq m/h	96.1 sq m/h	
Performance (speed)	291.4 sq m/d	194.6 sq m/d	177.5 sq m/d	245.6 sq m/d	The figures given in this column are those confirmed on site, including the time of transport and set up on site.

(2) Concerning quality

The results of measurements with a wet thickness gauge of the coat thickness of the main coat base spraying are shown in Table 4. The result was that it could be seen that the paint coat irregularities in the painting thickness by a robot and manually were few but that the robot attained the achievement equivalent to the manual painting.
Furthermore, concerning the primer coat, the main coat pattern spray, and the finishing coat, these fulfilled the paint specifications.

Table 4 Measurement result of films

	Number of measurements n	Average x (μm)	Standard deviation σ (μm)	Target lower limit (μm)	Remarks
Robot spray	93	1455	28	1420	The lower standard values is 80% of the target lower limit
Manual spray	41	1448	24	1420	

(3) Safety

Because robotized painting, except the measurement of the coat thickness, was controlled at a location away from the wall, manual work performed high above the ground is almost eliminated, a work of a high degree of safety is able to be performed.

5. CONCLUSION

The achievements that were obtained from the operation results this time, the problems that remain in on-site application in the future, as well as future development are summarized below.

(1) Achievements obtained

As a result of attaching automatic painting devices to the upper section of the robot, and further making a structure in which it was possible for the load to be shifted to the head section, the unpainted spots in the upper sections of the wall surface and along the right edge were eliminated.

Beyond that, concerning the capability of the robot, most of the objectives set forth in 2.1 were achieved, including the reduction in size and weight.
Furthermore, concerning the operational achievements, in addition to the major success of painting an entire building (about 2000 sq m), the painting capacity was approximately doubled when compared with the FR-1.

(2) Problems remaining in on-site application

The building to be painted this time was 17 m high but in the future, application to even taller buildings is required. From this, a strategy for the method of control of the paint discharge volume is necessary.

Next, concerning operation control, compared with the FR-1, the related program changes and data input were considerably abbreviated. Concerning operation, because currently operation is impossible unless an expert operator is present, further simplification of operations is required, so that even a construction specialist (laborer) could be able to handle it.

(3) Future development

Concerning the future of this robot, we are considering first of all giving it multiple functions, and then expanding its applicable scope.

It is thought that the robot at this time with relation to painting and finishing, has the hidden potential to raise its capacity to a level of approximately two to three times when compared with conventional manual spraying. However, looking at it from the overall process of wall finishing work, the painting process is about 1/3, so that a large reduction in the work time cannot be anticipated. In the future, through attaching the automatic diagnostic system currently being developed, and an automatic cleaning system, the robot can be given multiple functions. We think that we would like to enable a reduction in the overall process.

REFERENCES

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4) Tokioka et al., Robotized Painting by the Wall Surface-Finish Robot (FR-1); The 6th International Symposium on Robotics in Construction, 1989