The 5th International Symposium on Robotics in Construction June 6-8, 1988 Tokyo, Japan

PAINTING AND FINISHING ROBOT FOR WALL SURFACE

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ABSTRACT

The object of this development is to complete a robot system which is capable of executing a series of wall finishing works. The system can adhere to the wall surface and move freely there, and automatically perform shot-blasting and painting with a respective unit on it. As part of the study, in order to finish such works to perfection, a spray type painting mechanism and a shot-blasting mechanism to treat the wall surface uniformly are developed and installed on the robot.

In this paper, is reported the development of a wall-climbing robot, an automatic painting unit and a shot-blasting unit. At the end of this paper, we discuss the automatic painting robot.

1. Introduction

Actually, finishing works of the concrete structure wall surfaces, which are composed of surface treatment (removal of dust, laitance and various type deteriorations) and painting, are made by workers manually, using a scaffolding constructed along with the wall or a gondola suspended from above. Especially, in the case of large scale concrete builings such as a nuclear power plant, many of wall finishing works are made at elevated places. With a large area to be treated, so many workers are involved that the finish quality may vary along with their ability and experience. In this conventional process, there are some problems, that is, the scaffold should be assembled for painting only and be kept as such till the completion of works. To face these problems, we proceed to automating and robotizing the wall finishing works.

This system is composed of the following characteristic units:
- a carriage (wall-climbing robot with sucker), which may move in any direction freely on the wall surface,
- an automatic shot-blasting unit which evenly grinds and cleans the wall surface, and
- an automatic painting unit, which applies various kinds of paints by spraying.

With this system, it is possible to perform a series of finishing works, by mounting any of the above units to the carriage, according to need.

2. Development and Basic Conditions

In developing a robot which, with a shot-blasting unit or a painting unit on it, is capable of treating concrete wall surfaces, a procedure flow composed of 3 steps is prepared as follows:

Step I ;- Preliminary study on the conventional shot-blasing and painting methods, determination of robotization elements, their feasibility test.

Step II ;- Feasibility study of mechanization
- Determination of products and problems to be solved
- Fabrication of a prototype

Step III;- Confirmation experiments using simulation walls, modification and improvement for to ensure availability in construction

2.1 Development of a Wall-climbing Robot

2.1.1 Selection of Sucking and Automobile Units

The wall climbing robot with sucker is designed and developed so as to move freely on wall surfaces, holding a weight on it. For this development, a sucking unit and a climbing unit are chosen and studied as crucial items of the system, so that they may be incorporated successfully in the finishing robot. For this purpose, are listed up the features and the problems involved. They are studied taking account of the following requirements; smooth moving on irregular surfaces, continuous traveling and costs. Through studying these parameters as driving mode, it is selected a centralized type vacuum wheel-driving system. Table-1 gives a trade-off study results for three solutions.

2.1.2 Description of the Wall-climbing Robot with Sucker

A trial automobile robot is fabricated, based on a basic design which is established identifying conditions and requirements for walls, weights of a shot-blasting unit and a painting unit. It adheres to the wall by a suction force produced through the vacuum unit on the ground (or on the roof), and moves freely at 0 to 5 m /min. Its structure is designed to carry about 200 kg of weight. Its steering, when facing small curves, is performed by changing the direction of the front wheels, and through a turn table when turning a big curve. Photo.1 shows the robot climbing on the wall, being verified for traveling and loading.

2.2 Development of an Automatic Painting System and its Function

2.2.1 Paint Materials used and Spraying Test by woker

The paint chosen is an elastomeric material which is widely used for walls of newly constructed nuclear power plants as well as for repairing walls of existing nuclear power plants. For the purpose of mechanizing the painting process, a test painting by skilled worker, with several representative machines, was executed, first to know the conditions of the machines used, secondly to check the painting actions of the worker; paint is sprayed on to slates at about 5 kg/cm2, by a spray gun designed for elastomeric paint. Through this test, were obtained the data such as functions of spraying pumps, reference pressures, painting actions and speeds.

2.2.2 Basic Experiment for Mechanization

Analyzing the data thus collected about the hand movements of the painter and the painting machines used, a basic test was conducted to change the hand actions into mechanical ones. In this experiment which is intended to confirm the using conditions of the spraying pump and the nozzle, it was used a nozzle-shifting device which allows to move freely the gun to a given position on the plan X-Y. It was successfully obtained the mechanical reference values which should be required to have a uniform paint layer as specified, to optimize the position of the nozzles, and to determine their operation method, these being indispensable for mechanization and automatization of the sprayed painting. And the problems to be solved were well identified.

2.2.3 Description of the Automatic Painting Mechanism

Target values are determined as follows for painting condition, effective pattern widths, using the results through the above test. A pilot painting unit of automatic type is designed and fabricated, on the basis of these parameters. When designing, the target values being attained successfully, the painting unit itself was reduced in size and simplified in structure to be mounted on the wall climbing robot.

- o Nozzle diameter : 1 mm or more for primer, middle coat (urethane), top coat
- o Nozzle shifting speed : 4 m/min or less
- o Effective pattern width : 60 cm or more (minimum layer thickness: 800 μ) middle coat
- o Effective pattern width : 60 cm or more for primer and top coat

Note : Effective pattern width in spray painting ; width in which a specified thickness can be produced.

Fig. 1 outlines a pilot machine. As shown there, it is provided with 5 nozzles, A, B, C, A' and B'; when the painting unit is rising, the nozzles A, B, C are used, and when lowering, A', B' and C to form a uniform layer free from color irregularity.

Furthermore, our first consideration was to choose a clogging free nozzle, and the holding structure was designed with a possibility of adjusting a nozzle-wall distance freely, this in order to cope with a variety of viscosities in painting materials (middle coat; about 70,000 cps, primer and top coat; about 50 cps).

2.2.4 Performance Test of the Automatic Painting Mechanism

This experiment is intended to check:

- if the mechanism actions or functions as specified,
- if the painting layer produced is of a desired thickness,
- if the effective pattern is produced as specified.

For this test, slates were used as specimens and the painting unit was attached to the carriage which may move vertically on the wall. It was confirmed that most of the target values are attained successfully. In Tables 2, 3 and 4, are given test results of the primer, middle coat and top coat.

2.3 Development of the Automatic Shot-blasting Mechanism
2.3.1 Basic Experiment for Automatization

On the basis of the requirements imposed to our surface-treatment unit such as: removal of deteriorations, recovering of dusts and installation on the wall-climbing robot, it was selected the shot-blast method, because of its excellence in grinding and in dust recovery.

Actually, the shot-blasting unit is operated manually, but in our project, the process should be automatized and remote-controlled. For this purpose, an experiment was provided for collecting basic data and identifying the problems involved. In order to simulate the process, a shot-blasting unit was mounted on X-Y shifting device carriage which is defined in 2.2.2. See Photo 2 Basic Experiment for Automatization.

2.3.2 Mechanism of the Automatic Shot-blasting

In order that the unit could be incorporated into the wall-climbing robot, it should be light in weight and fulfil the related mechanical requirements; a pilot unit was designed and fabricated taking account of these factors, referring to the shot-blasting performace confirmed in the above test. The unit is incorporated into the suction mechanism which is situated in the center of the wall-climbing robot, structually capable of shot-blasting when both climbing and decending. Its performance test is on the way. Fig.2 is a diagram of the shot-blasting unit mounted on the wall-climbing robot.

3. Painting Robot
3.1 Description

The painting robot is a painting unit on the wall-climbing carriage, with a computer control mechanism separately provided. It is designed so as to be program-controlled through a control system in the centralized control panel, or manually remote-controlled. It was confirmed that formation of a uniform layer without irregularity is possible with this painting robot. The surface treatment performance through this system is expected to be 6 to 8 times higher than in manual spraying by worker. Fig.3 shows a diagram of the painting robot. Photo 3 shows the concrete wall under painting and in Table 5, are given the main specifications of the painting unit.

3.2 Operation and Control

The painting unit can be operated manually, automatically or in their combination. In the case of the automatic mode, an on-line teaching mode is used with a personal computer. The operation is performed, by inputting various requirements through a key board connected directly with the computer, and considering as well its posture in operation.

The control system is composed of:
1) Sensing system with measurements of absolute position, posture and steering which are provided to move the robot as instructed.

2) Monitor system; this function of the system is to display, in CRT, the movement of the robot in real time and its daily operational conditions-related data.

3) Emergency stop function with which the robot can detect abnormalities on the concrete walls and stops if needed, but as for the known obstacles and discontinuities on the wall, their data being previously input in the program, the robot may move detouring these parts.

For safety, that is, in order to prevent the robot from falling, it is suspended from above, through two tension winches on the ground which hoist the robot by cables.

3.3 Execution Planning and Procedure

When establishing an execution planning by the painting robot, it is necessary to investigate the peripheral environment, forms and dimensions of the building to determine the access route and the arrangement of the equipment. As joints of large size or differences in level may become restrictions to the works, some auxiliary measures (ex.: gondola) should be studied to deal successfully with such difficulties.

As an execution procedure, in Fig. 4, it is shown an example where the wall is devided into 4 portions which are completed one by one, lifting and descending the robot with a gondola.

According actual site conditions, the pump system is installed, on a gondola, on the roof or the ground.

4 Conclusion and discussion

The wall-climbing robot, with a load of about 200 kg, is capable of traveling past the joints and differences in levels which exist normally on the walls of the buildings. But, it is known that there are considerably large joints in the big buildings. To cope with these, the robot should be improved further, with an additional mecnanical device.

As for the painting robot, although it is found that it can form a uniform layer almost without irregularity (+/- about 150 μ in error/1000 μ of reference thickness), the following must be studied and solved; prevention of mist dispersion, on-site control of coating thickness and prevention of nozzle clogging. As part of function, the projected parts of the building also are needed to be painted successfully with the painting robot; for this purpose, the robot may be equipped with an arm to enhance degree of freeness in adaptability.

This robot, as being intended to be used experimentally on large structures, is large in dimensions, but required to be made smaller, in view of its transportability and manipulation (setting and resetting on the walls).

References

(1) Handbook of Coating for Buildings 1983: Painting Contractors Association
(2) Development of a wall-finishing robot, by S. Tokioka et al.; "Preliminary Papers for the 2nd Symposium of Construction Robots 1988": Architectural Institute of Japan

Table 1 Trade-off Study

Type	Availability on irregular surface	Continuous running	Applicability to the painted surface	Driving	Traveling on curved surface	Adaptability in dusty environment	Maintenance	Cost	Assessment
Centralized type vacuum wheel-driving system	○	◎	○	◎	○	◎	◎	○	◎
Non centralized vacuum wheel drawler type driving system	◎	◎	△	△	◎	△	○	◎	○
Non centralized vacuum walking system	△	△	◎	○	△	△	△	△	△

◎ Very excellent ○ Excellent △ Less excellent

Table 2 Performance Test (example) of the Middle Coat

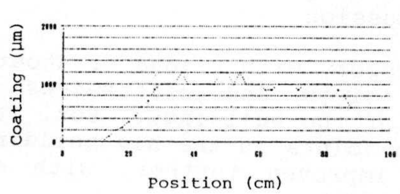
Condition	Coating thickness distribution
Pump discharge pres. (kg/cm2) 25 Spraying air pres. (kg/cm2) 4.5 Spraying distance (cm) 35 Pitch between guns (cm) 35	

Table 3 Performance Test of the Top Coat

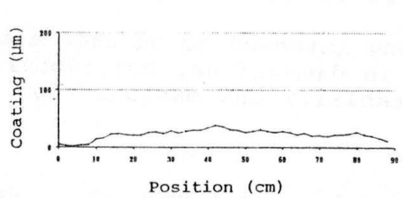
Condition	Coating thickness distribution
Pump discharge pres. (kg/cm2) 0.4 Spraying air pres. (kg/cm2) 4 Spraying distance (cm) 37	

Table 4 Performance Test of the Primer Coat

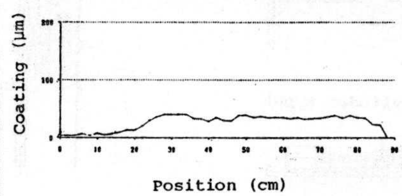
Condition	Coating thickness distribution
Pump discharge pres. (kg/cm2) 0.5 Spraying air pres. (kg/cm2) 3 Spraying distance (cm) 37	

Table 5 Specifications of the Painting Robot

Item	Specifications
Painting features	Painting method : spraying Nozzles : 5 Painting capacity: 60 m3/H about
Main body	Suction mode : centralized type Moving media : wheels Moving speed : 5 m/min. maximum Outer dimensions : 1.5 x 1.3
Attachments	
-Vacuum unit	Power : 45 kW (200V) Outer dimensions : 1700 x 4550 x 2000 (mm)
-Air compressor	15 HP
-Material feeding pump	Material feeding
-Emergency winch	1.5 kW (200V) x 2 Auto tension type

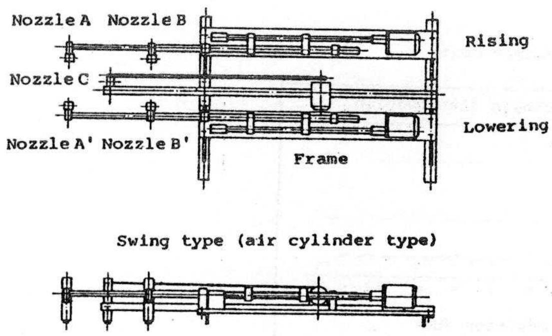


Fig. 1 Schematic Drawing of a Pilot Automatic Painting Machine

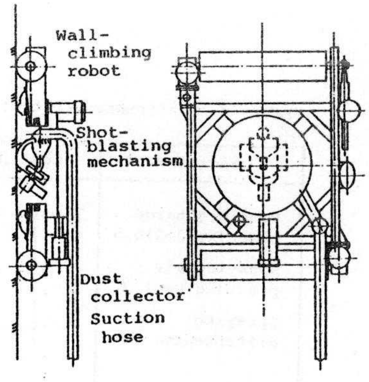


Fig. 2 Diagram of the Shot-blasting Robot

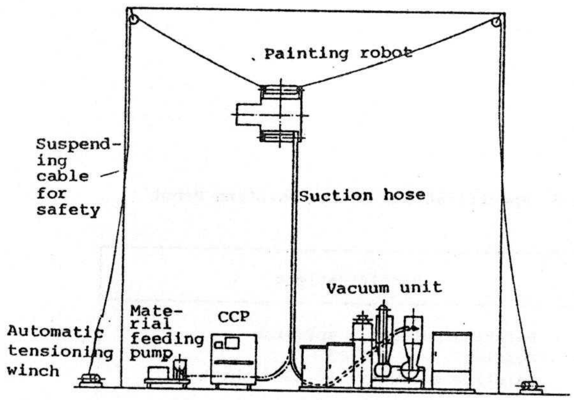


Fig. 3 Schematic Drawing of the Painting Robot System

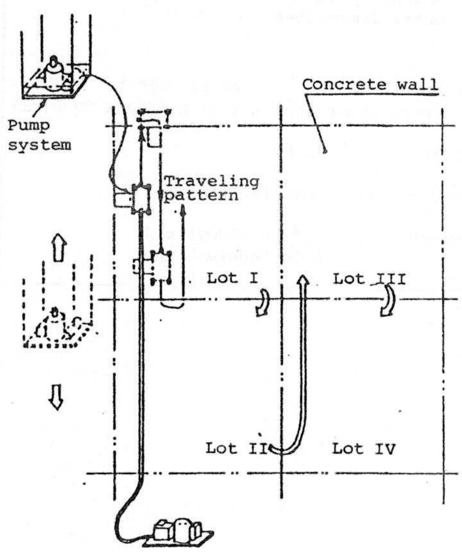


Fig. 4 Example of the Execution Procedure

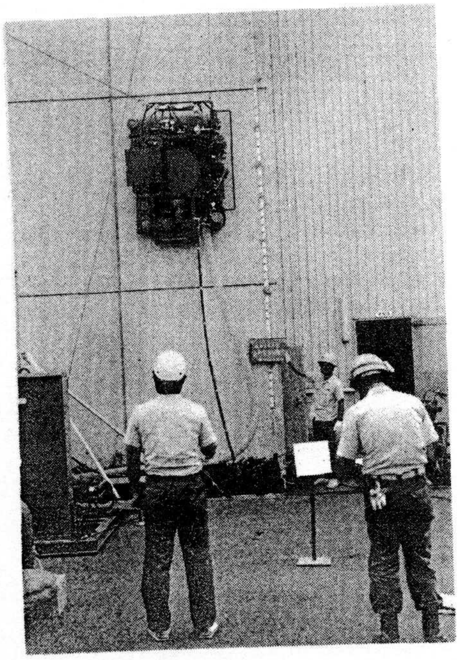
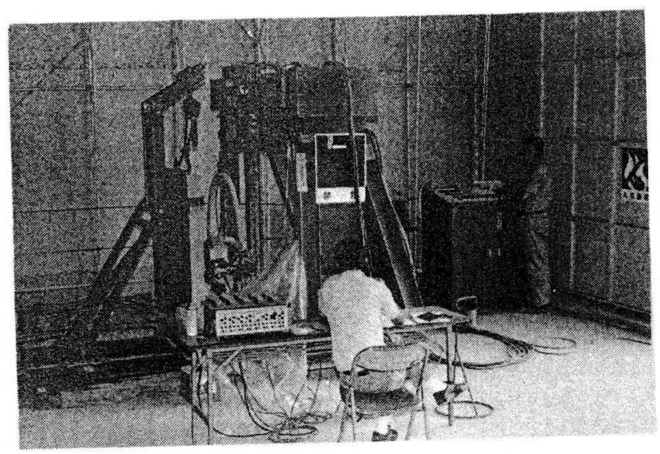


Photo 1　Wall Climbing Robot

Photo 2　Basic Experiment by Shot-Blast Unit for Automatization



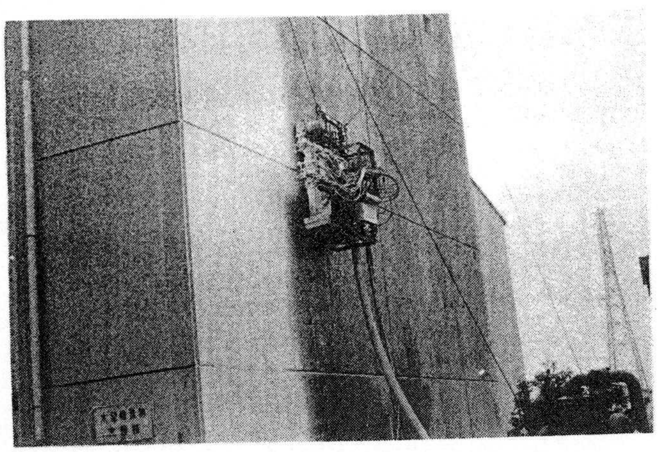


Photo 3　Painting of the Structural Concrete Wall by the Painting Robot