PAINTING ROBOT FOR EXTERIOR WALLS OF HIGH RISE BUILDINGS

Masahiro Takeno, Engineer
Technical Development Dept.

Taisei Corporation
1-25-1 Nishishinjuku, Shinjuku-ku
Tokyo, Japan

Akira Matsumura, Manager, Shigeru Sakamoto, Section Manager,
Yoshihito Sakai, Engineer and Atsushi Shirato, Engineer
Technical Development Dept.

Taisei Corporation
1-25-1 Nishishinjuku, Shinjuku-ku
Tokyo, Japan

ABSTRACT

The robot described in this report has been developed for painting the wall surfaces of the Shinjuku Center Building located in Shinjuku, Tokyo, which was recently decided to be repainted. A comparison study was made on the difference in efficiency between robot and manual painting. It was found that using the robot would reduce the work schedule by four months, make painting safer, prevent drifting of paint mist, and result in better finish of the painted surfaces. The robot was therefore chosen to do the painting. The robot's first task is scheduled to start in August 1988, and it will complete painting within 4.5 months. The building to be painted is a 219.5 meter high-rise building constructed in 1979 which has 53 floors above ground and 5 floors below ground. A total area of 47,700 m^2, excluding window glass sections but including 7,800 m^2 of the inside of the guide-rails, will be painted and the robot will paint approximately 70% of the total area. The conditions under which the robot will paint are very severe as the exterior of this building has a complicated configuration. This study report is based on examples of performance during experiments.

1. INTRODUCTION

A large number of high-rise buildings have been built in Japan, and many have concrete or metal panels covering their exterior which require painting. Exterior painted walls generally require repainting at intervals of about eight years. Spray painting is ideal as it is efficient, allowing rapid application with a lower number of aberrations. However, spray painting causes drifting of the sprayed paint, and therefore painting by a roller or brush is still preferred despite the labor and time it requires.

Many of the high-rise buildings in Japan will soon need to be repainted. New mechanized technology is hence required, not only for painting but also for cleaning the walls, stripping off old paint, and for other work carried out at elevated locations.

In this report we introduce a painting robot for the exterior walls of high-rise buildings. After much trial and error, we finally succeeded in practically applying this device.

This practical robot greatly reduces the dangers involved in repainting tall buildings, improves work efficiency, and eliminates environmental problems for the surrounding area.

2. HISTORY OF DEVELOPMENT

We started developing robots to paint the exterior walls of high-rise buildings in 1985, first formulating a basic plan and then carrying out basic operating tests. In 1986, we performed confirmation tests, manufactured a prototype, and then field tested.

In 1987, we manufactured a second robot with the aim of upgrading the efficiency of the first robot by emphasizing a larger painting hood, lighter body weight, and speedier operation. The unit is now undergoing endurance tests prior to commercialization.

The robot was tested on the walls of the Shinjuku Center Building, one of the high-rise buildings located in the center of Tokyo's Shinjuku ward. Constructed in 1979, it is one of the tallest buildings in Japan; at 219.5 m high, with 53 floors above ground and 5 floors underground.

Its exterior walls are precast concrete panels covered with acrylic urethane paint. The total area to be painted excluding glass was 47,700 m^2 (including the inner surfaces of the guide-rails), and approximately 70%, or 37,200 m^2 can be painted using the robot.

The concrete panels form a very complicated pattern, as shown in Photos 1 and 2, which made it fairly difficult to plan painting using the robot.

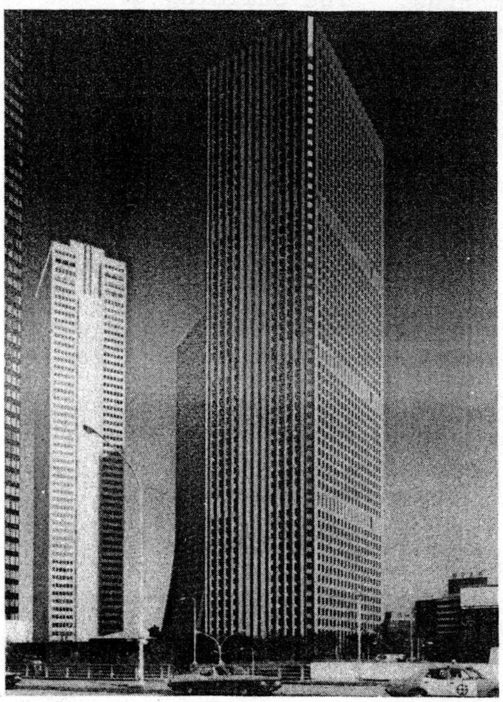


Photo 1 Side View of Building

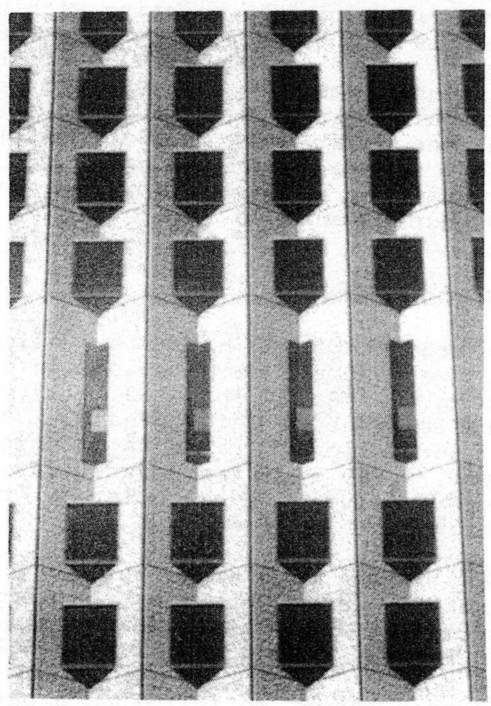


Photo 2 Wall Surface

3. SELECTION OF PAINTING SYSTEM

3.1 Painting Method

There are several methods of painting building surfaces including brush painting, roller painting, and spraying. Usually, the selection of the method is made according to the shape and area of the object to be painted, the required quantity and viscosity of the paint, the evaporating speed of the solvent, and the setting speed of the paint.

To automate the painting work, however, not only the method of painting but also the delivery of paint must be considered. We studied the advantages and disadvantages of different painting methods from the viewpoint of automation, and concluded that spraying was the most suitable method because it works well, coats easily in the required film thickness, paints quickly, and gives a beautiful finish.

3.2 Study of Painting Techniques

To automate spray painting by means of the robot, we analyzed how experienced painters do their work and carried out various tests based on the results. These included the moving speed of a spray gun over the wall surface, spraying angle, painting width, paint viscosity, delivery pressure, differences between air and airless guns, and other factors. Based on such study, we were able to obtain data on paint running on the coated surface, spots left unpainted, film thicknesses, drifting state of paint mist, and the paints used (Photo 3).

Photo 3 Study of Manual Painting

The following were deemed necessary from the study:

a. A device to keep paint mist from drifting.
b. Coating with spray guns which move back and forth.
c. Four pairs of spray guns, upper and lower, which spray at an angle.

4. OVERALL SYSTEM CONFIGURATION

4.1 Requirements for System Design

The following design conditions were set for the exterior-wall paint robot:

a. To provide protection against adhesion of paint to window glass, without using any manual protection.

b. To completely prevent paint mist from drifting during spraying.

c. To leave no unpainted spots on the wall surface, however complicated in structure.

d. To achieve an operating speed ten times faster than manual painting.

e. To secure a specified minimum paint film thickness which is necessary for protecting the wall surface.

4.2 System Configuration

The system has three major sections: a robot section to paint the wall surface with moving spray guns, a roof-car section which lowers the robot section by wire ropes and moves it up and down, and a paint supply section. The paint supply section, installed on the roof car, supplies paint through a high-pressure hose (Fig. 1 and Photo 4).

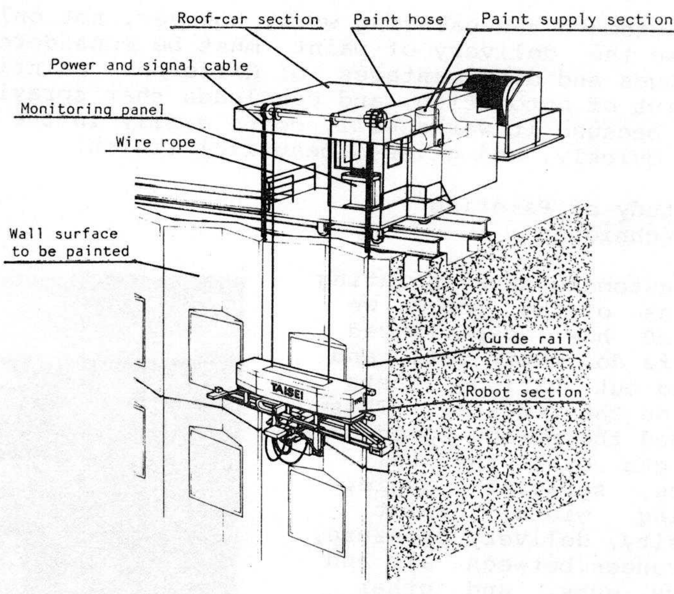


Fig. 1 System Configuration

a. Robot section

This section further consists of a carrier to mount devices with a hood fitted beneath it and moving right and left on a rail.

A control panel, a compressor to drive the spray guns and air actuator, and a tank for excess paint (collected by recovering paint mist adhering to the inside of the hood) are mounted in the carrier. Guide rollers are on the front of the carrier so that it can move along guide rails on the building, as well as a locking device which fixes the carrier onto the wall surface to stabilize the position of the robot during painting.

There are four types of drives on the operational part of this section: a motor to move the hood (in which the spray guns are mounted) right and left, another motor to move it forward and backward, a motor which moves the hood to keep it vertical to the wall surface, and a motor which moves the spray guns right and left.

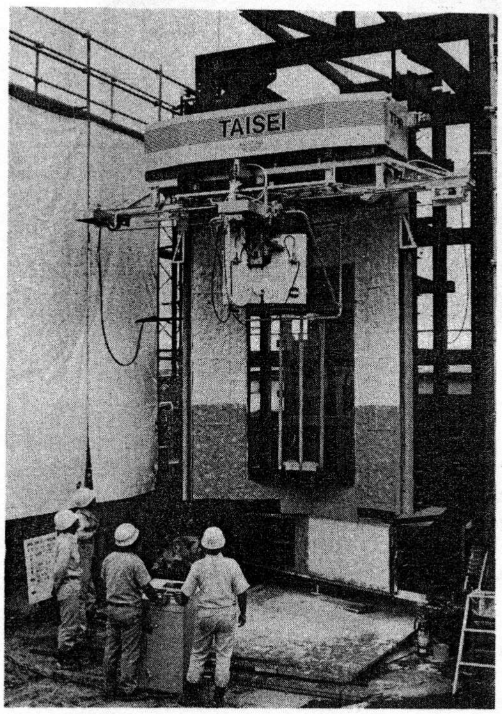
A total of eight spray guns are mounted inside the hood that keeps paint mist from drifting. The spray guns are grouped into pairs, and each pair is so adjusted that they can paint the same area from different angles, eliminating unpainted spots on even the most irregular textures (Figs. 2 and 3).

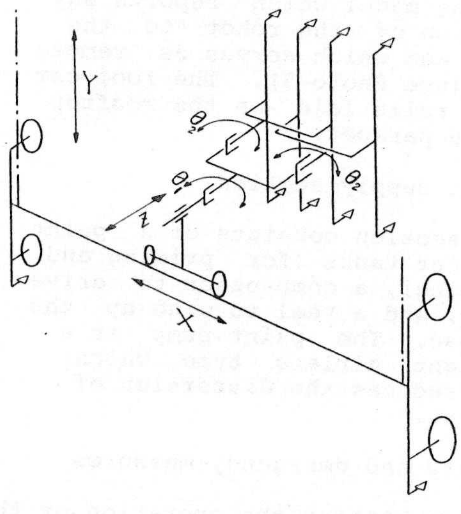
Since the hood comes in close contact with the wall surface during painting, a pad which can adjust to the irregularities of the wall is attached to the top end of the hood.

The closed hood prevents paint mist from drifting. The spray guns inside the hood move back and forth, painting a rectangular area of 75cm x

60 cm during each single run. The robot completely paints a 60 cm wide rectangular strip and then descends by 60 cm and repeats the operation in a series until the entire job is finished.

The vertical position is detected in two steps: the robot detects the joint between concrete panels and then senses the distance below the joint. Another sensor detects windows and instructs the robot to use a painting pattern different from when there are no windows.





	Working range (permissible tolerances)	Drive
θ1	25° to right and left (±0.5°)	Air actuator
θ2	50° to right and left (±1.0°)	Servo motor
X	2.0 m (±1.5 mm)	Servo motor, chain
Y	200 m	Winch
Z	0.7 m (±2.0 mm)	Servo motor

Photo 4 Experiments on the Ground

Fig. 2 Robot Working Range and Driving System

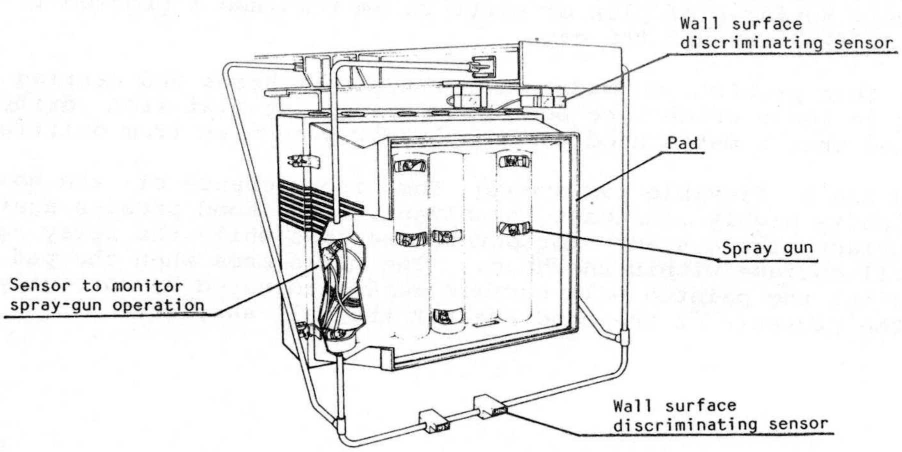


Fig. 3 Paint hood

b. Roof-car section

A roof-car on top of the building lowers the robot section by two wire ropes and moves it up and down. The roof car has winches for winding up the wire ropes, a reel to take up the cable for electric power, and a monitoring panel which reports any malfunction of the robot to the operator and which serves as remote control (see Photo 5). The roof-car moves on rails laid on the rooftop along the parapet.

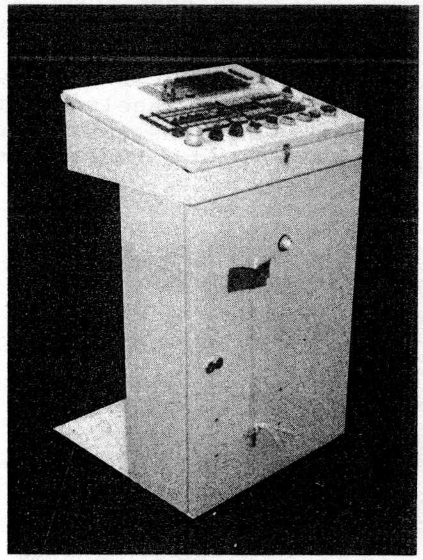


Photo 5 Monitoring Panel

c. Paint supply section

This section consists of a paint pump, paint tanks (for priming and overcoating), a compressor to drive the pump, and a reel to wind up the paint hose. The paint pump is a lightweight airless type which greatly reduces the dispersion of paint mist.

d. Safety and emergency measures

Sensors monitor the operation of the spray guns to prevent accidents caused by spray gun malfunctions. A load cell prevents breakage of the wire ropes or cables due to overloading when the robot moves up and down. Furthermore, should the paint supply hose break, changes in the pump's internal pressure and discharge are immediately detected and the supply of paint stopped (see Fig. 4).

4.3 Measure to Keep Paint Mist from Drifting

The adoption of spray painting meant solving the very important problem of preventing mist from drifting.

We employed a box-shaped hood which covers the sprayers. The open end faces the wall during painting. Yet small gaps between the hood and irregular wall surfaces of plus or minus 25 mm remained a problem in that paint mist drifted through the gaps.

To solve this problem, we made several types of hoods and carried out experiments to learn which type best prevented paint mist from drifting. We determined that a metal hood can completely keep mist from drifting.

The hood has a flexible pad around the circumference of the hood opening which is highly resistant to solvent. The hood presses against the wall surface like a stamp for several seconds while the spray guns coat the wall surface within the hood. The marks made when the pad is pressed against the painted wall surface were eliminated by correctly adjusting the pressure of the hood against the wall surface.

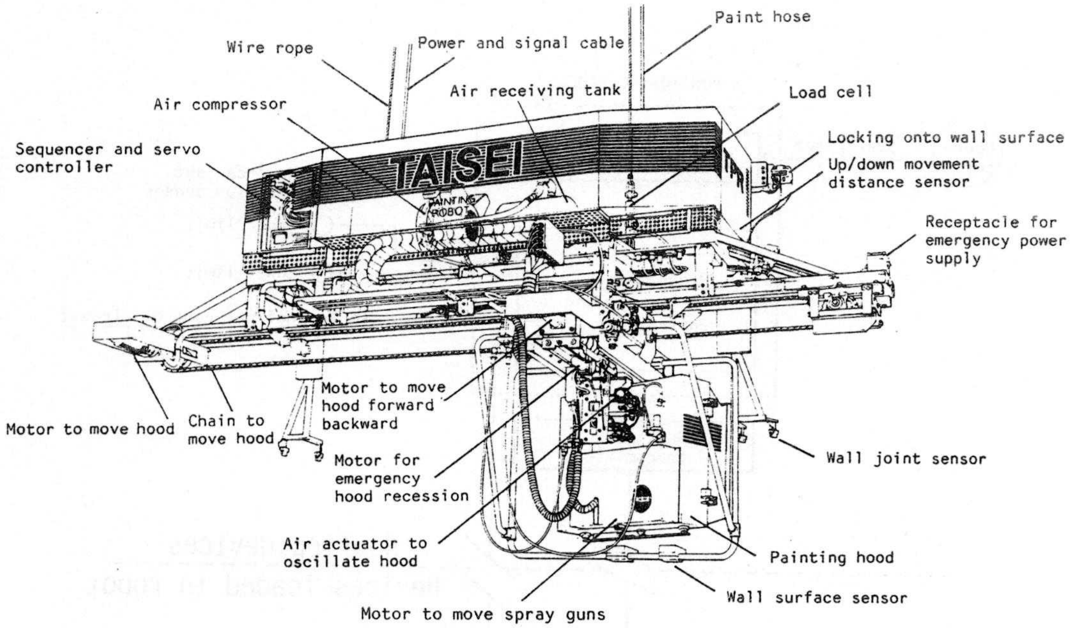


Fig. 4 Detail of Robot Section

5. OUTLINE OF CONTROL SYSTEM

This robot is controlled by two programmable controllers, one provided in the robot section and the other installed inside the rooftop monitoring panel.

The controller in the robot section processes signals from the sensors and controls the servo system, while the rooftop monitoring panel controls the entire system. A multiplex transmission between these two controllers reduces wiring. Signals from the load cells, however, are transmitted through another line to shorten response time. (See Fig. 5.)

6. QUALITY ASSURANCE OF PAINTED SURFACE

This robot will paint any irregular wall surface which would have needed triple coating to eliminate any unpainted spots if painted manually. To allow the robot to paint such a wall surface, our goals were to minimize the quantity and number of operations of the spray guns, to secure the prescribed paint coating thickness, to eliminate unpainted spots, and to reduce paint consumption as much as possible. To achieve these goals, we carried out experiments which combined several conditions including the position of the spray gun relative to the hood opening, spraying angle, range of horizontal spray gun movement and speed, paint delivery pressure, paint viscosity, and the type of spray gun tip. These tests enabled us to obtain the most suitable parameters for the painting devices of the robot section.

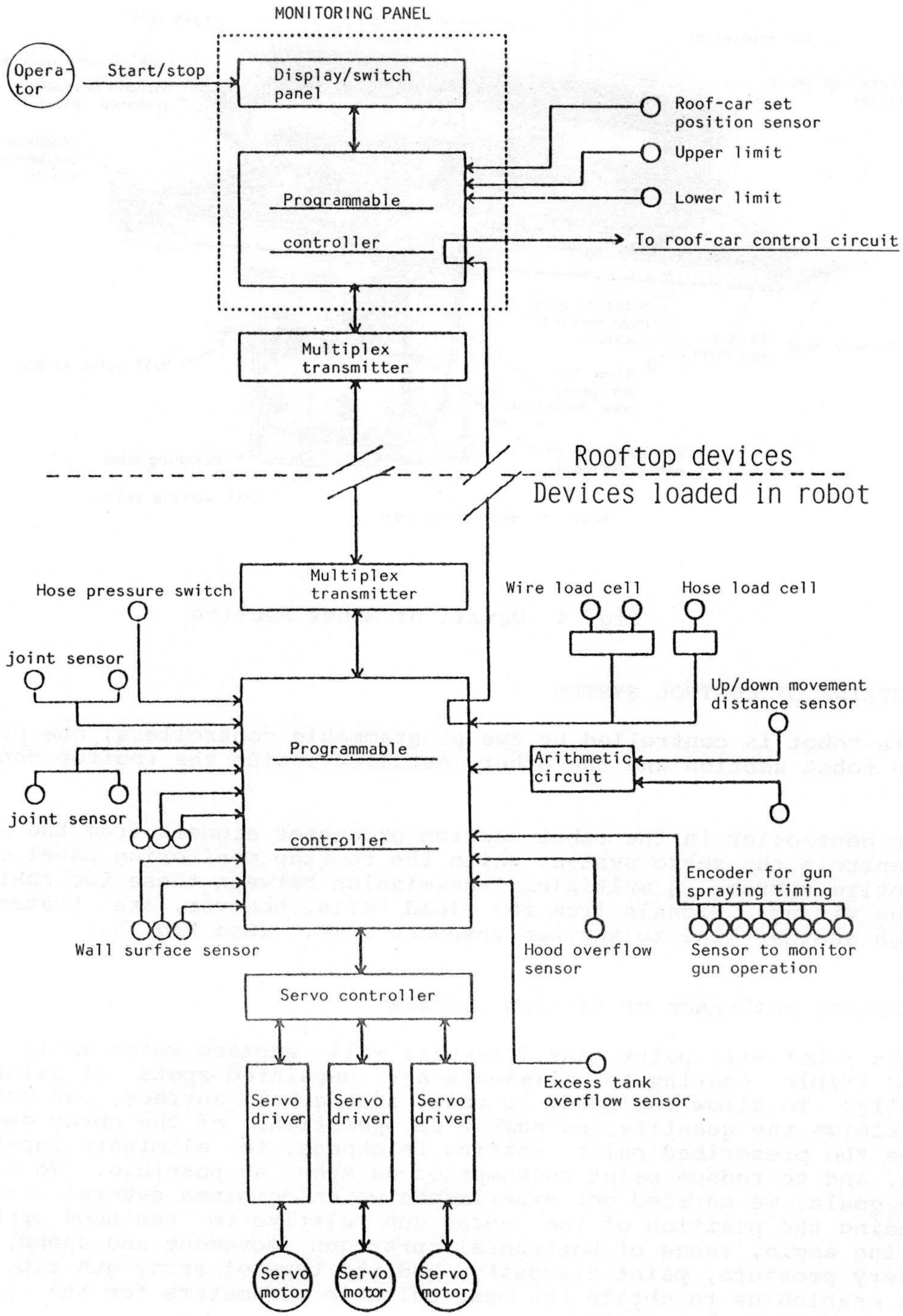


Fig. 5 Schematic Diagram of Control System

We came to the conclusion that painting with this robot requires only two coats --- one for priming and the other for overcoating (Table 1).

Table 1 Specifications of Component Devices

	Item	Specifications
Rooftop Section	Roof car	Lifting load: 1.5 tons Descending speed: 8 m/min Ascending speed: 16 m/min Power consumption: 7.5 kW (400V) (Winch)
	Painting devices Paint tanks Paint pump Compressor	Power consumption: 7.5 kW (200V) 80-liter x 2 13 liters/min max. 10 HP
Robot Section	Overall dimensions	5m x 1.6m x 2.0m (LxWxH) Power consumption: 5 kW (200V)
	Weight	1.5 tons
	Devices Compressor Control devices	 2.2 kW (200V) Programmable controller (for NC control) Up/down movement distance sensor Wall joint sensor Wall surface sensor
	Safety devices	Automatic release of carrier lock Receptacle for emergency power supply
	Hood Painting capability Spray guns	750mm x 600 mm (WxH) 100 m^2/H 8 airless-type guns

7. PAINTING OF GUIDE-RAILS

On the exterior wall surfaces of the building, slits are provided vertically from the top end of the parapet to the ground at horizontal intervals of 3 m. They serve as guide-rails for the stable up/down motion of a car gondola used for cleaning the walls and windows, checking the wall surfaces, and for other wall maintenance. When painting the building's exterior, the inside of these slits, i.e., the guide-rails, must also be painted.

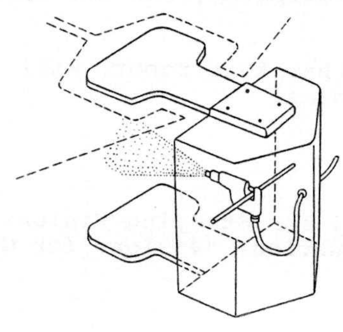


Fig. 6 Conceptual Drawing of Guide-rail Painting Unit

These guide-rails have a total area of 7,800 m^2, which accounts for 16% of the entire wall surface. To paint these areas we attached spraying units as shown in Fig. 6 to the lower part of the guide rollers located at both ends of the robot. As the robot starts upward after descending and painting, these units continuously coat the inside of the guide-rails with one spray gun while the guide rollers pass these sections.

8. DEVELOPMENT IN THE FUTURE

An increasing number of buildings will soon need repainting. An estimated 11.3% of fund budgeted for building work will go towards repainting in 1990, or roughly 3,500 billion yen. Most companies in this industry therefore established a specialized department or a new company to take positive and systematic action to provide repainting services.

Taisei's painting robot for the exterior walls of high-rise buildings was developed with future demand in mind. It is a basic technology for repainting exterior walls, and we would like to further improve the system and bring it to perfection.

Our next goal is to apply this technology to repainting the exterior walls of normal medium- and low-height buildings which have neither roof cars nor preinstalled guide-rails on their exterior wall surfaces.

9. CONCLUSION

In our attempt to develop a robot for painting the exterior walls of high-rise buildings, one of the most important problems was how to enable the robot to mechanically carry out the ideal spray gun motions of experienced painters and how to apply it to actual painting work by solving such unknown technical problems as the prevention of drifting paint mist, securing the prescribed paint coat thickness on complicated wall surface textures, and the method of supplying paint.

We have solved most of these problems and are now further improving the painting capability of the robot, the paint supply system and other peripheral equipment, and the operation, maintenance, and inspection of the robot.

We hope that this report will be of some help to others engaged in similar studies.

REFERENCE

(1) Society for Studying Visions for Building Industry, Ministry of Construction: "Visions for Construction Industry in 21st Century" 1986.