Development of A Fireproof Insulation Spray Robot System

Yukihiro Watanabe*,Hideo Tanijiri**,Muneyoshi Matuo*,Ryoji Yoshitake**,Masao Kato**

* Machine Development Section,Machinery Department,Civil Engineering Division, Fujita Corporation
1-15-6,Honda,Niiza-shi,Saitama Prefecture,352 JAPAN

** New Production System Development Section,Architectural Division,Fujita Corporation
Fujita NO.3 Bldg. 5-23-15,Sendagaya Shibuya-ku,Tokyo,151 JAPAN

ABSTRACT

This report describes the summary of the development of the fireproof insulation spray robot No.1 system in 1991, as an example of promoting the automation of architectural work by taking advantage of a wide-use type industrial robot. This was reported at the 9th International Construction Robot Symposium in 1992. The research and development activities have been continuing and the No.3 system was developed by making various improvements to the No.1 system and it is now being applied to the all-weather type building automatic construction system.The system is composed of two major devices, which are as follows:1)Fireproof insulation spray robot,and 2)Remote control type fully-automated plant.The aim of this thesis,is to describe the positioning of the above system in the all-weather type building automatic construction system,the details of the development from the NO.1 machine,through to the NO.2 machine and to the NO.3 machine.Also, the special features of the system,the details of each constituting device,the composition of the software and the results of the execution,will be described.In addition there is discussion of the possibility of applying the wide-use type industrial robot to the construction site.

1. INTRODUCTION

Fireproof insulation spray work executed by using the dry method for buildings of reinforced concrete construction, has to be performed under adverse environmental conditions accompanied by a great volume of dust arising from heavy labor which includes the throwing of materials, the dismantling of scaffolds, and the moving thereof. For this reason, the shortage of younger workers is presenting a problem. There have not been many improvements to address these problems and therefore, larger scale improvements by means of mechanization and the use of new materials have been under great demand.

This development, as an example of promoting the automation of architectural construction work takes advantage of a wide-use industrial robot. It aims to make great improvements addressing the problems of the conventional construction operation,reducing labor and upgrading the quality of the work by structuring a robot system subject to the in-situ mix dry spray method, which makes up the greater part of the fireproof insulation spray work.

2. PROGRESS OF DEVELOPMENT

The development commenced in 1989 by analyzing the conventional work and by examining applicable technologies not only of the construction industry, but also including other industries. The design of the basic system was carried out. The following shows problems raised as a result thereof:

· Because the dimensions and configuration of the girders and columns the subjects of the fireproof insulation spray are diversified. It becomes essential to input the bulky amount of data available to complete the automated construction.
· There are many obstacles to construction, such as wiring and piping for utilities, and consequently it will be necessary for human judgments to be made on the spot.
· Complete automation will be difficult to achieve for practical purposes in view of the time needed for development and the cost involved.

In consideration of these problems, the basic focus for this development was the labor saving system by means of "men + robot", and the actual development commenced in 1990. The development of No.1 system had proved applicable to the wide use of the industrial robot to a building construction site and the possibility of using it to fireproof insulation spray operation. The development of No.2 system following the No.1 system, included the development of peripheral technologies including improvements of the position measurement device and the self-control travel flatcar. These improvements were made aiming at realizing a practical system which meets the demands of an actual building construction site. Although the completion of this No.2 system had attained the initial target of development, to aim at further upgrading the construction efficiency by introducing it to an all-weather type building, the automatic construction system, No.3 system equipped with a rail travelling function was developed.

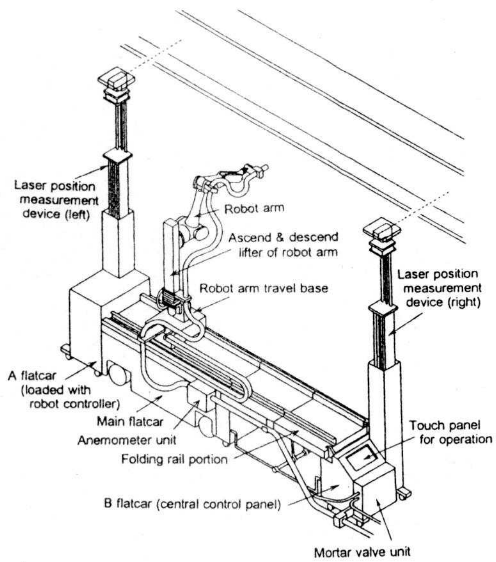
Table 1 shows the main examinations and implementation items which were performed up until the development of the No.3 system.

Table 1 Progress of system development.

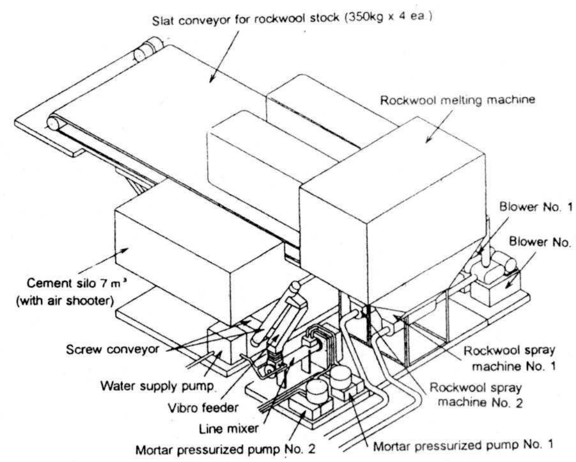
Item		Specification of No.1 system	Main points of improvement	Specification of No.2 system	Main points of improvement	Specification of No.3 system
Robot	Type	6 axes robot	⇨	6 axes robot	Selection of light weight machine with ascend and descend & sideway travel	7 axes robot + ascend and deacend + sideway travel
	Control Panel	Separated layout	Upgrading of maneuverability	Loaded with lifter	Light weight by splitting when moved	Traction type
	Splay length	Max.1,000 mm	Due to change in type of machine	Max.800 mm	Upgrading of construction speed	Max.3,000 mm
Flatcar	Ascend & Dscend mechanism	1 step scissors lifter	Miniaturizing of flatcar, securing of lift height	2-step scissors lifter	Relocated to robot arm portion	Not equipped
	Control for above	Ultra-sonic sencer measurement display	Automatic control of lifter	Automatic control of linear encoder measurement	Controlled by robot control panel	No control
	Steering mechanism	3 mode (2ws,4ws,90°)	Upgrading of operability	4-mode (2ws,4ws,90° ,spin)	⇨	4-mode (2ws,4ws,90° ,spin)
Central Control	CPU	Robot control panel takes place of it	Utilization of sequencer network	Sequencer for exclusive use	Speeding of computation speed up keep of data	Factory computer
	Input & output	Button input · Digital indicator	Upgrading of operability	Touch panel display	⇨	Touch panel display
Position mesurement	Sencer	Ultra-sonic sencer	Upgrading of measurement accuracy	Laser distance measurement sensor	⇨	Laser distance measurement sensor
	Measurement item	Away from girder	Upgrading of quality and operability	Distance from girder,posture angle,girder span length	⇨	Distance from girder,posture angle,girder span length
	Outfit	Smoke prevention shutter	Changed to enclosure type	Ascend & descend,turning, head swing	⇨	Ascend & descend,turning, head swing
Plant	Machinery	Conventional by relay	⇨	Conventional plant	Automation of supply of materials	Fully-automatic plant
	Control mode	Control by relay	Remote control of plant	Sequencer and inverter control	⇨	Sequencer and inverter control
	Control item	ON/OFF control	Upgrading of quality	No. of revolution and ON/OFF control	⇨	No. of revolution and ON/OFF control

3. SYSTEM COMPOSITION AND SUMMARY

As shown in Fig.1 this system is composed of a fireproof insulation spray robot and a fully-automatic semi-wet type fireproof insulation spray plant.



Fireproof insulation spray robot.



Fully-automatic semi-wet type fireproof insulation spray plant.

Fig.1 System composition.

3-1 Fire proof insulation spray robot

The fireproof insulation spray robot that moves in sequence from the floor of the construction site and sprays according to the construction schedule, is composed of 4parts as detailed below.

(1) 9 axes robot arm portion

Added to the robot arm portion that grips the nozzle and carries out the spray action in this system, were an ascend and descend lifter that moves the robot upward and downward and a sideways base that allows the robot to travel sideways to the wide-use vertical multi-joint type 7 axes robot.

As well as aiming at reducing the weight of the whole system and in consideration of the swing caused due to the upward, downward and sideways movements of the robot arm,the type was selected was the one with the lightest robot arm among the movable weight 10kgf types that are on the market. It is one which allows the addition of 2 axes,upward and downward and sideways movements in the movement software.

Table 2 shows the main specifications of the robot arm portion and Fig.2 shows its scope of movement.

Table 2 Specification of robot arm portion.

Item		Specification
Robot arm	Type	7 degree of freedom, vertical multi-joint type
	Protective structure	Dust proof, dripproof(IP-53)
	Maximum composite speed	1.55 m/sec
	Position repetition accuracy	± 0.1 mm
	Weight capacity	10 kgf
	Driving mode	AC servo motor
	Body weight	32 kgf
Ascending descending device	Type	LM guide, ball screw type
	Maximum ascending & descending speed	250 mm/sec
	Ascending & deacending stroke	805 mm
	Driving mode	AC servo motor
	Body weight	81 kgf
Sideway travel device	Type	Rack & pinion type
	Maximum sideway travel speed	250 mm/sec
	Sideway travel stroke	3,000 mm
	Driving mode	AC servo motor
	Body weight	30 kgf
Robot control panel	Protective structure	Dripproof type(IP-43)
	Control mode	Each axis control, simultaneous 7 axes + OP 2 axes
	Playback function	PTP, CP
	Driving mode	Transistor PWM control
	Instruction mode	Each axis, position, posture, direct
	Program language	C language
	Interface	RS-232C, DI / O
	Power source	AC 200V / 220V
	Weight	30 kgf + OP

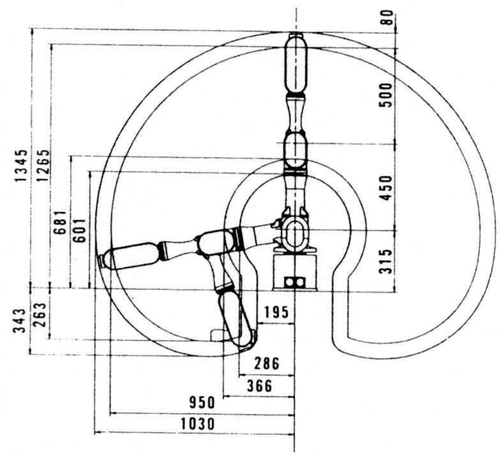


Fig.2 Robot arm scope of movement.

(2) Self-control travel flatcar

The self-control travel flatcar that forms the rail for the sideways travel base on which the robot arm is loaded and moves this rail to the girder to be sprayed, was newly developed. The main characteristics of this flatcar are described below.

① 3-divided mode and folding mechanisms were adopted to make moving in and out, as well as to and from the floor to be worked on, easier and to make it movable even on a narrow floor.

② To increase the travelling accuracy including ability to advance straight, and to make maneuverability better, a 4-mode steering method (4-wheel steering, 2-wheel steering, 90° sideway travel and spin turn) by means of a non-backlash hydraulic rotary actuator, was adopted.

③ In addition to manual operation the use of cable and radio remote control automatic operations from the central control panel was made possible.

Table 3 shows the main specifications of a self-control travel flatcar and Fig.3 its summary.

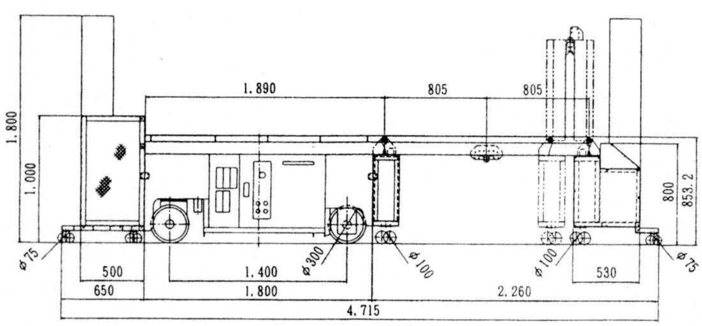


Fig.3 Self-control travel rail flatcar summary.

Table 3 Self-control traveling rail flatcar specification.

Item	Specification
Total length (when connected)	Unfolding : 4,727 mm Folding : 3,505 mm
Total length (when disassembled)	Maximum 1,940 mm
Total width	800 mm
Total height	1,800 mm
Weight (when connected)	1,050 kgf
Weight (when disassembed)	Maximum 615 kgf (including laser sensor)
Driving mode	Hydraulic motor 2 weel diagonal drive
Steering type	Hydraulic rotary actuator 4 weel independent steering
Steering mode	2ws, 4ws, 90°, spin
Operation method	Manual cable, manual radio, automatic
Wheel	φ300 urethane wheel
Power source	DC 24V/AC 200V switching type
Outfit	·Rack for robot travel ·Manual winch type folding mechanism ·Possible to be divided into 3 ·when moving in and carrying out

(3) Laser type automatic position measurement device

This device has the self-control travel flatcar installed parallel to the girder to be sprayed at an accurate distance apart from it. It is equipped with the automatic position measurement device which measures the length of the girder.

This measurement device allows the performance of an accurate position measurement at all times by ascending and descending, making a 90 ° turn and by shaking the head using a pair of laser measurement sensors placed in front and in rear of the flatcar by means of an air drive.

Fig. 4 shows the functions of the instruments and Photo 1 shows the external appearance thereof.

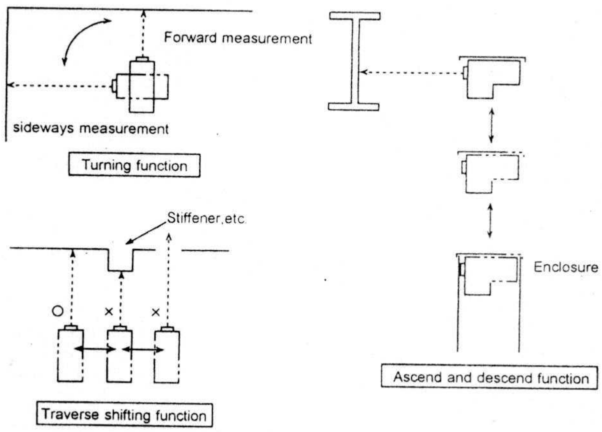


Fig.4 Functions of a laser position measurement instrument.

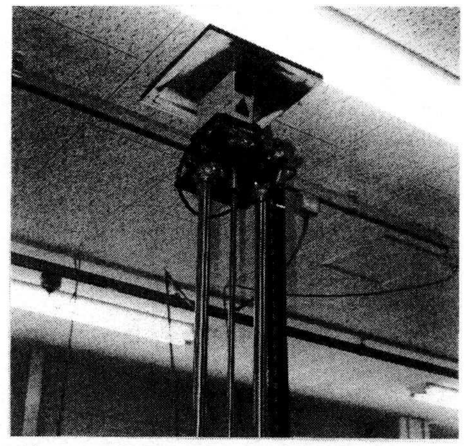


Photo 1 Exteral appearance of a laser position measurement instrument.

(4) Central control panel

The central control panel is loaded on a self-controlled travelling rail flatcar in rear and performs the general control of the computers of each device that constitutes this system.By using a touch panel display attached thereto, it is possible to readily perform the setting of the motion data of robot and plant. Fig.5 shows examples of the indications of the touch panel display and Photo 2 shows the circumstances of use by a worker.

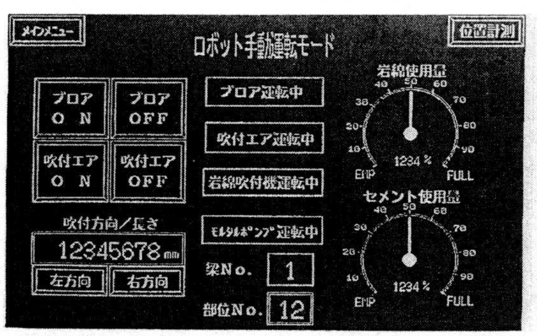


Fig.5 Example of an indication of a touch panel display.

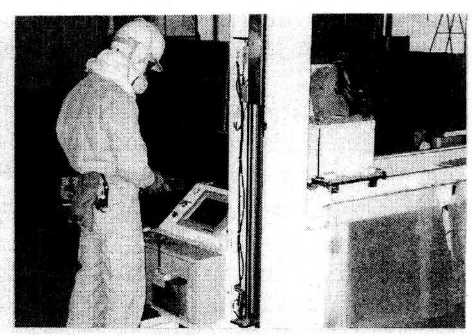


Photo 2 Circumstances of use by a worker.

3-2 Fully-automatic semi-wet type fireproof insulation spray plant

In this system, with the objective of stabilizing the construction quality and the upgrading of the maneuverability by means of a stabilized supply of materials, a fully-automatic plant that can perform a series of operations was newly developed and adopted. These operations included the supplying of rock wool, cement and water, the mixing and stirring of slurry based on instructions from control panel installed on the floor of construction site and the performance of an ON/OFF control and the control of number of revolution of rock wool spray machines, a blower and a mortar pump. This plant is composed roughly of two parts, a rock wool plant and a mortar plant. Figs.6 and 7 shows the operation flow of each plant.

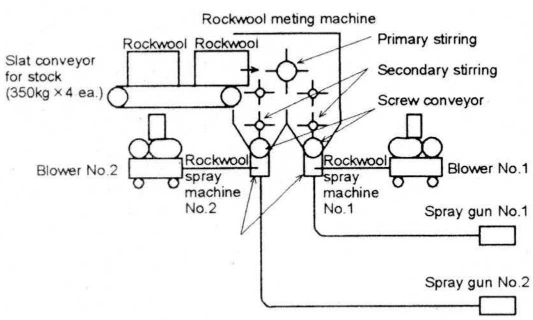


Fig.6 Rockwool supply flow chart.

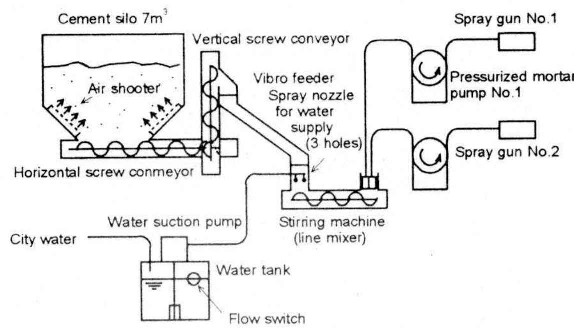


Fig.7 Mortar supply flow chart.

4. SYSYTEM CONTROL AND SUMMARY OF OPERATION

4-1 System control

The system control was arranged so that with the central control panel loaded on the self-control travelling rail flatcar in rear acted as a host computer. Based on input data from the touch panel display, 9 axes robot arm, self-control travelling rail flatcar and each respective control panel of entire automatic plant can be controlled. The following describes main control items:

① By means of the input construction conditions from the touch panel, display robot armmovement data are computed and transmitted to the robot arm control panel.

② While performing ascending and descending operations and 90 ° turns the head swing of the laser automatic position measurement device in front and in rear, measures the present position of the self-control travelling rail flatcar and guides the flatcar to the designated position.

③ On the basis of the above results of the position measurement, an error in the positioning that is caused when guiding the flatcar can be revised by correcting movement data of the robot arm.

④ Input data from the touch panel display is transmitted to the plant control panel and creates a monitor display of the operation situation of the plant on a touch panel display.

⑤ In the case of the semi-wet spray method, since there will be a time lag between the rock wool throwing to the discharge of the rock wool from tip of the spray gun nozzle (due to passage). A time chart taking into consideration such time lag is prepared and an ON/OFF movement timing is transmitted to each control panel.

⑥ At the plant control panel, the supply of cement and water at a designated mix ratio is made depending on the working conditions of the mortar plant and the number of revolutions by means of an inverter control.

Fig.8 shows the time chart of 1 cycle and Fig.9 shows the composition of the control equipment.

D0: Time lag (Passage time from throwing of rockwool to spray gun top ~ rockwool passage detection sensor (=T)

D1: Time of movement from spray home position to spray start position ~ computed value or measured value

D2: Spray time

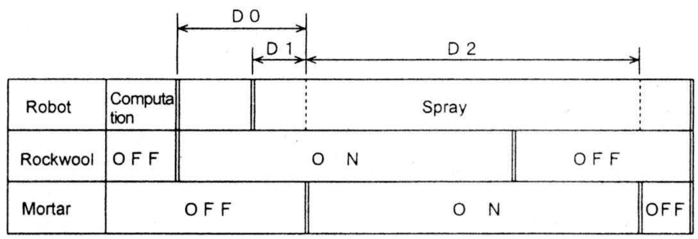


Fig.8 Spray time chart.

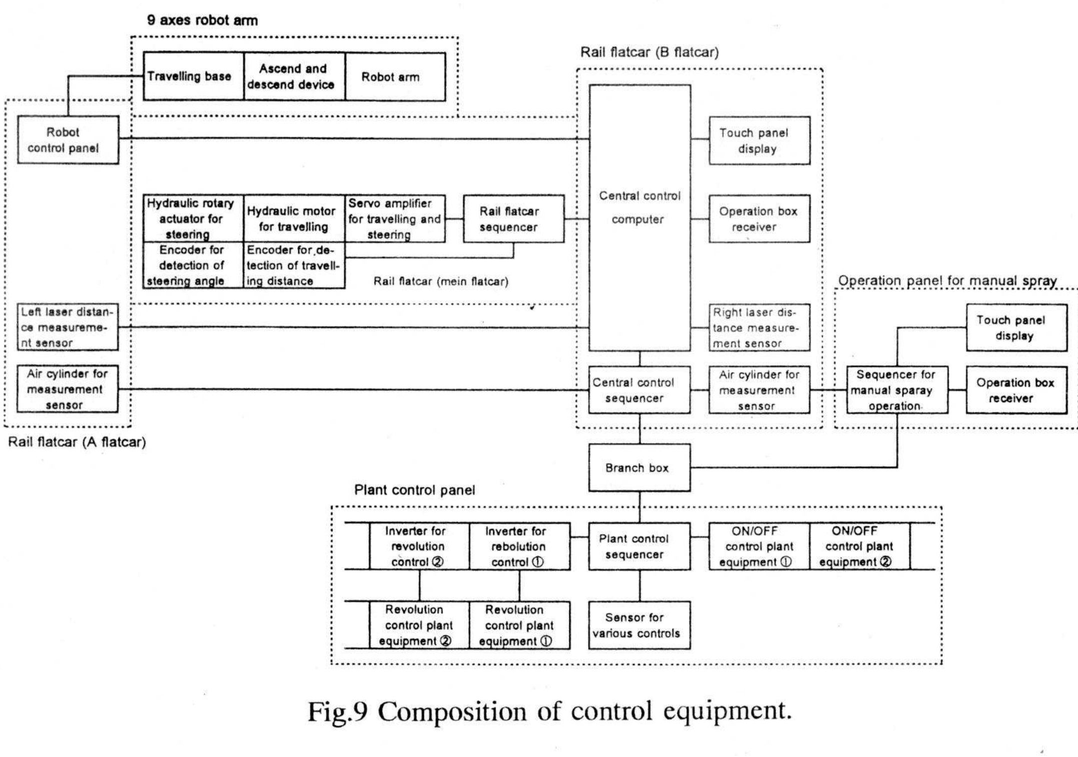


Fig.9 Composition of control equipment.

4-2 Operation procedure of system

Fig.10 shows the operation procedure and Fig.11 shows the construction procedure.The method of operation includes a manual mode in which the guiding to the spray start position and the input of the spray length are carried out directly by a worker and the automatic mode in which these procedures are carried out automatically. The selection of which procedure is to be used is optional according to the working conditions.

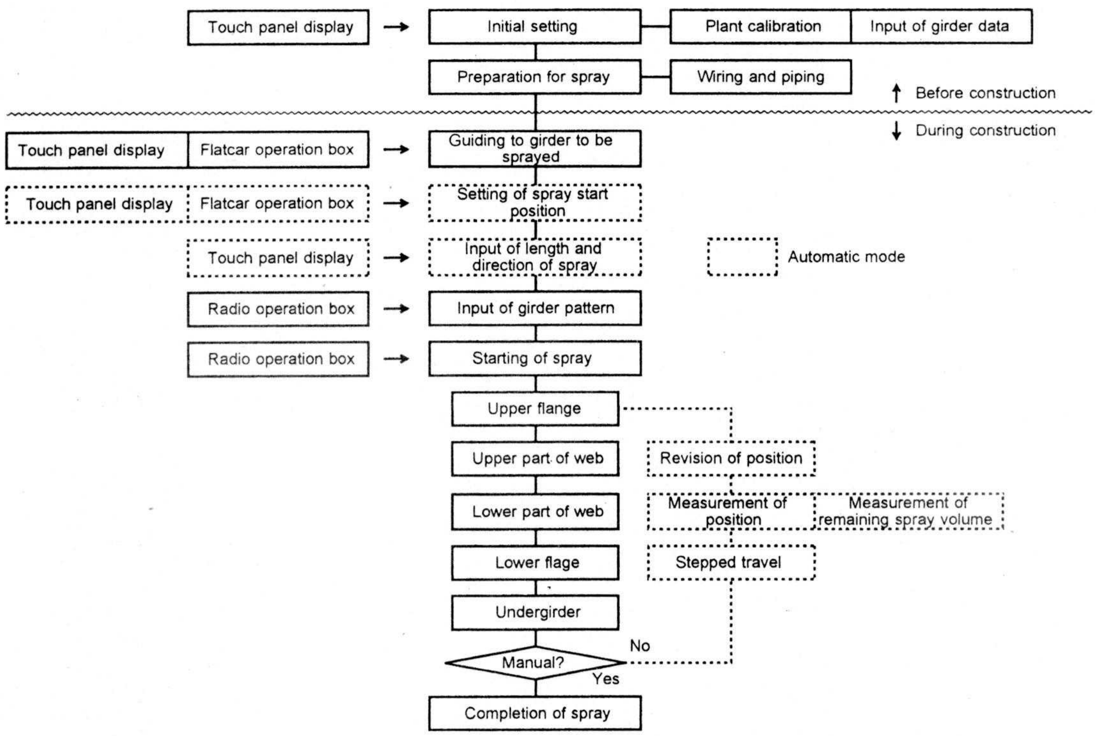


Fig.10 System operation procedure.

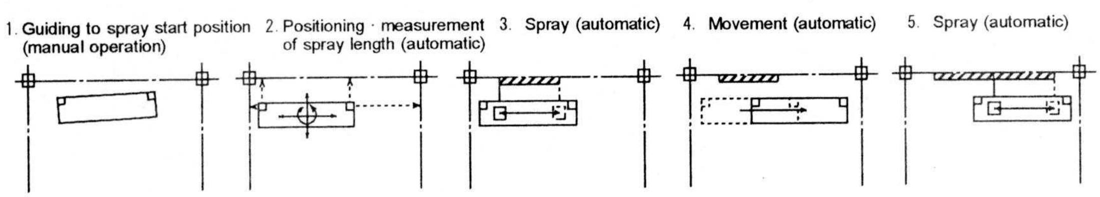


Fig.11 Robot-spray by automatic mode.

4-3 Sequence of spray movement

The sequence of spray movement was determined to be a side spray in which rock wool is sprayed with a spray gun swinging in a transverse direction. Fig.12 shows the spray sequence on a girder and Photo 3 and 4 shows the rock wool being sprayed.

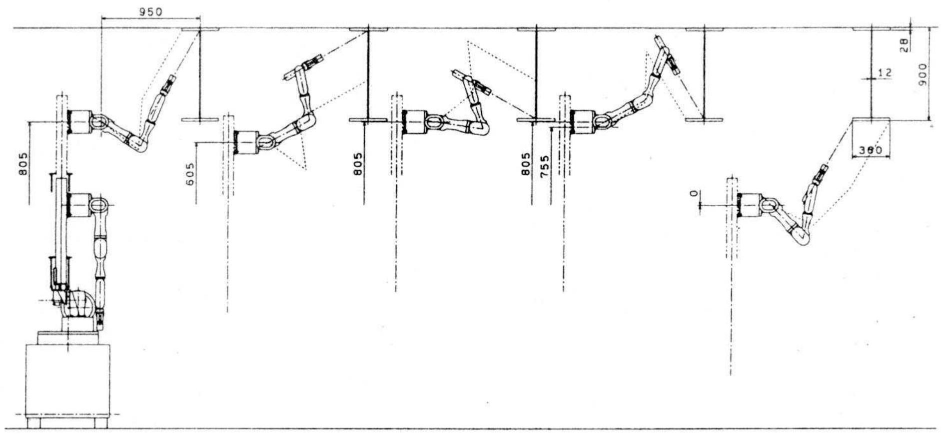


Fig.12 Spray procedure on girder.

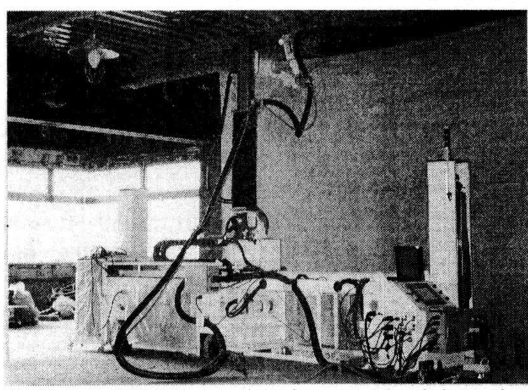


Photo 3 Rockwool being sprayed.(No.1)

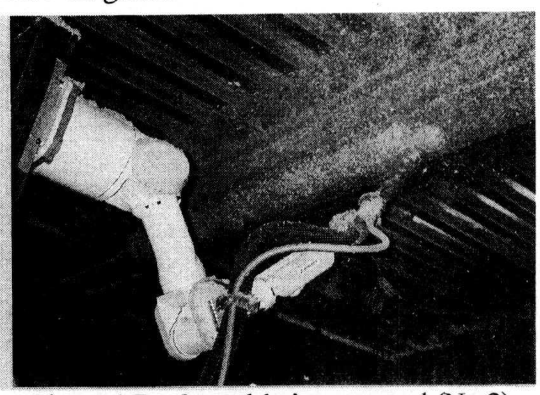


Photo 4 Rockwool being sprayed.(No.2)

5. CONSTRUCTION

Basic experiment and test construction were conducted on the 6th floor of a medium-rise office building which was to be constructed using the all-weather type building automatic construction system and subsequently actual construction was carried out on a part of the 7th floor to the 11th floor. The results obtained from such a basic experiment and actual construction are described below.

5-1 Summary of construction

The outline of the building constructed using this system is shown below.

Structural scale: S + SRC construction 1F underground 16F aboveground 1F PH
Floor area of construction: 13,098m²
Eaves height: SGL + 70.8m
Floor height of typical floor: 3.9m
Main structural steel members: BH-900*360*12*25 BH-900*240*12*19
H-346*174*6*9 H-396*199*7*11

5-2 Results of construction

① Method of quality control and results

Construction was carried out with test spray results of the basic experiment as the basic data and after completion of spray driving of the pins and a cutting test were implemented in a conventional way. As a result, the specification of the rock wool company for a 2-hour fire resistance was able to be satisfied.

The characteristics peculiar to construction using robots, which are different from those of a manual spray are, an excellent completed quality with a relatively small amount of dust since the spray gun was able to be kept at a fixed distance and angle.

② Construction speed

An excellent result, the average construction speed of 17.8 m^2/h for 2 hour fire resistance using this system was obtained.

As workers can perform trowel finish, driving of pins, and cleaning, on completed portion of spray even during construction using robots, the completed amount per day increased considerably.

6. CONCLUSIONS

The results of the basic experiment and actual construction verified that spray robot can be moved and construction was able to be performed by 1 spray worker of fireproof insulation only, and by using it together with a fully-automatic plant, a stable supply of materials becomes possible and a high quality construction was confirmed. By selecting, a robot arm with a light weight and an excellent capability to cope with environment. It was also confirmed that the overall system could miniaturized and be made to be light weight and have the capability to move between floors of construction.

As a result of the continued trial application of the wide-use industrial robot arm to actual building construction sites from the No. 1 system to the No. 3 system the following advantages and disadvantages have been confirmed:

[Advantages]

- By using a wide use product, cost reduction of the system can be made.
- Shortening of the development time can be achieved.
- Maintenance parts can be made available readily.
- Preparation of movement program can be readily made by means of the software attached.

[Disadvantages]

- There are many machines designed to be suitable for use on the floor of factory and a dead load is heavy.
- There are restrictions on the dimensions, and configuration, for design because it is a wide-use product.

Taking into account the above points, the application of a wide-use industrial robot arm to a building construction site can be made possible by developing peripheral equipment that can be used in combination with it. It is considered an effective labor saving method and upgrading of the quality for fireproof insulation spray work is not necessary and can be used for other types of building construction work as well. In the future, to make this system more practical, we will endeavor to proceed with improvements while using the system in actual construction and will examine the method of application of the wide-use industrial robot arm to other types of operations taking advantage of peripheral technologies obtained through its development.