The Development and Practice Test of the "MARK" II" Mobile Robot for Concrete Floor Slab Finishing

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ABSTRACT

Since 1984, the Mark I mobile robot for finishing concrete floor slabs has been used at construction sites. This operation has confirmed the robot's constant finishing accuracy, high efficiency, and savings in night-shift manpower through its use. The previous report discussed the robot's effectiveness as a replacement for plasterers. Since then, the operation results of the Mark I have been analyzed and used to develop an improved version, the Mark II, in 1986.

This report describes the Mark II and describes the results of its use. The Mark II is a compact robot with excellent operability, and is well-suited to construction-site work. It has met our development objectives. The Mark II robot is now technically completed and has gone into use by plasterers. So far its operation results are promising, and it is likely to come into widespread practical use.

INTRODUCTION

A careful analysis of the operation results of the Mark I, reported from construction sites, has revealed two ways in which it could be improved: making the controls simpler and lighter in weight, and making robot operation easier. With these objectives, and by making the robot better suited to construction sites, we incorporated a number of improvements and new ideas into the next version, the Mark II. Since then, the Mark II has been used at more than ten work sites, during which further fine improvements were made. This has brought the Mark II to completion in terms of its technological implementation.

This report discusses the measures taken to improve the applicability of the Mark II to construction sites, and their results. The Mark II is a guideless mobile robot like the Mark I, which eliminates the need for an auxiliary guide system. The robot has a self-navigation system that uses a gyrocompass, measuring rollers, and a microcomputer. It does finishing work while travilling automatically. An automatic obstacle-avoidance system has been developed and incorporated into the Mark II to make it more useful and increase its work efficiency.

In addition, a concrete-surface-roughness-measuring system and an analysis program have been developed to check the surface finishing accuracy after using the robot. The measuring system and program are also described in this paper.

1. CONFIGURATION OF THE CONCRETE FLOOR SLAB FINISHING ROBOT (MARK II)

The Mark II consists of a travel device, double trowels as end effectors, and a bumper as shown in Photo 1 and Fig. 1. The Mark II needs no peripheral equipment as did the Mark I. Further, the Mark II can be taken apart into three units to make transporting or moving it at a construction sites easier, and for cleaning it after use. The three units are separated and put together by a one-touch mechanism and screws so that preparation and rearrangement work is easy and delays are minimized.

2. SYSTEM CONFIGURATION AND SPECIFICATIONS

The specifications of the robot are as shown in Table 1. The Mark II weighs 185 kg altogether, which is the lightest of any work robots of this type. Our robot's power supply is 200 VAC (three-phase) motor. As the result, there is no noise such as that produced by engine driven robots. This allows night-time operation, even on a crowded street.

2.1 Travel device

The travel device consists of a power supply unit, a control unit, a travelling unit, a data input panel, and a safety device. The travel device weighs 105 kg.

Robot control is based on a self-navigation system that uses a gyrocompass, measuring rollers, and an 8-bit microcomputer (similar to the Mark I). The travelling unit uses a two-wheel roller system and is driven by an AC servo-motor. The travelling mechanism allows the robot to travel forward and turn itself at the same spot (spin turn) so as to widen the robot finishing area.

The Mark I needed complicated data entry from the operation panel that was one piece of peripheral equipment; data had to be entered by an engineer. The Mark II, on the other hand, needs only simplified data input so that even a plasterer can enter data; the panel for entering data is incorporated into the travel device. Data entry is described in Section 3.1.

The travel device is provided with several safety devices, which are shown in Table 1.

2.2 Trowel section

The trowel section consists of double trowels, a drive unit, a trowel-angle adjuster, and a guard. The trowel section weighs 75 kg.

Each trowel has three steel blades that are flexible enough to follow the concrete surface smoothly. The driving force is transmitted from electric motors through a trowel-driving mechanism to rotate the pair of trowels in opposite directions. This arrangement offsets the reaction forces caused by rotation against each other and helps the robot to travel straight. The trowel section can be easily fixed to the travel device by one-touch fasteners.

2.3 Bumper

The bumper is a safety device that detects obstacles and sends a signal to the microcomputer to control the robot accordingly. The bumper is one of the elements of the automatic obstacle avoidance system, which enables the robot to avoid obstacles automatically. The bumper weighs 5 kg.

3. ROBOT OPERATION

3.1 Automatic operation

The robot is automatically operated by setting digital switches on the data entry panel mentioned in Section 2.1. The travelling pattern of the robot is set automatically as follows: (1) specify the work area, giving the width and length of the floor in the scheduled area; (2) enter the operating conditions (such as the robot travel speed, lapping width (the distance the travels overlaps) and the direction of the robot movement towards the building); (3) set the first turn direction of the robot enable (in this case, the location of the robot when the data are entered will be the origin). Press the START button on the handy controller to start the robot operating automatically. If the robot encounters an obstacle in the work area during automatic operation, the bumper is struck and sends a signal to the microcomputer so the robot can avoid the obstacle automatically and continue operation without interruption. Because data input is simple and the travel route is set automatically, the Mark II can be used in buildings under a variety of conditions, and the robot can be "taught" in a short time. These user-friendly features enable any plasterer to operate the Mark II.

3.2 Remote control

Remote control is used to move the robot to the start position at a site or to a safe place in an emergency. The remote control instructions are unit operations such as "forward," "backward", and "turn." Each operation is implemented by the microcomputer, which uses feedback from the gyrocompass to ensure that the robot moves straight forward and turns at right angles (the same way as for automatic operation).

3.3 Measures in case of trouble

The Mark II robot is provided with self-diagnostic that display alarm codes as required on 7-segment LEDs on the top of the travel device. An alarm code may be displayed because of a failure or an incorrect operation. The twenty or so diagnostic codes help the operator to pin point the trouble when anything goes wrong so that prompt measures can be taken.

4. APPLICATIONS

The Mark II had been used for a total of 30 times at 14 construction sites by December 1987. During this time, concrete finishing was done under various work conditions (different building constructions, purposes of use, seasons of the year, floor levels, types of concrete, differences of the slump, floor slab thicknesses, and types of form).

During the test period, we accumulated much information on the robot's operability, applicability, finishing timing, work efficiency, and finishing accuracy, as well as basic knowledge for the practical use of a robot in this type of work.

We also examined application of the Mark II for general-purpose work (in which the robot is used in the final stage of the concrete finishing) and also systematic work for which the robot was combined with a screeder for such processes as leveling and screeding. It was evident that the systematic execution improved the work efficiency of the robot.

5. APPLICATION RESULTS

5.1 Work efficiency

The robot travels three times to do the finishing work shown in Fig. 3. The travel time varies considerably with the work conditions as described in Chapter 4. The work efficiency is determined by the robot's travel speed, time required per turn, and lapping width. However, it also depends on the concrete placing route, the placing speed, the hardness of the concrete, and the distance of each forward movement.

Table 2 shows one example of the actual measurement. If the robot travel speed is 12 m per minute, the finishing area is 450 m^2/h for a lapping width of 50 cm and 700 m^2/h for a lapping is 20 cm. Comparing these values with the traveling speed of an experienced plasterer, 120 m^2/h, we see that the robot has a productivity 4 to 6 times than that of a human plasterer.

5.2 Finishing accuracy

The finishing quality is shown in Table 2, and quality requirements are shown in Table 3. The flatness is expressed as specified by the Architectural Institute of Japan (the AIJ), while the surface roughness and other quality requirements are set by us because there are no applicable standards.

To efficiently measure the finishing accuracy of plasterers and of the robot, we developed a concrete surface roughness measuring device (shown in Photo 2 and Fig. 4). This device is capable of measuring a distance of 3 m in compliance with the AIJ standard, and data obtained is recorded by a pen recorder and stored in a floppy disk.

Data stored on the floppy disk was processed by a personal computer, which output the computed flatness and surface roughness. The surface roughness was recorded by a pen recorder on chart paper. However, we have newly developed a surface roughness analysis program that will give us a much more accurate and reliable analysis of data. The program eliminates undulation from the roughness component and normalizes it, producing an easily read concrete floor surface roughness diagram, like that shown in Fig. 6. Examples of the measured flatness and surface roughness are as shown in Figs. 5 and 7.

The flatness of the plasterer-finished surface and that of the robot-finished surface are shown in Fig. 5; both are within the AIJ tolerance and their average value ($\overline{x}$) and standard deviation ($\sqrt{v}$) are almost the same. The process capabilities (Cp) are also much better than 1.3, which means that both finished surfaces are well within tolerance.

The surface roughness is also almost the same for the plasterer and for the robot, as shown in Fig. 7. The acceptance rate of the surface roughness tolerance 0.1 mm is 81.3% for the plasterer and 84.5% for the robot. The probability of exceeding 0.1 mm is within $1\sqrt{v}$ and all the roughnesses are 0.2 mm or less. The process capabilities calculated on the basis of the above tolerances are about 1.2 for both the plasterer and the robot, which shows that both jobs are within tolerance.

CONCLUSIONS

The Mark II robot involved much information during its development that was obtained from operation results of the Mark I. The Mark II is, technologically, fully developed to the current state of the art. We are also collecting software utilization technologies for applying the robot. The Mark II is so well designed that it can be operated by workmen instead of engineers, and is expected to find wide use.

In the future, we hope to systematize and develop the robot which can apply from casting concrete to final finishing by utilizing what we learn from the development of the Mark II.

REFERENCES

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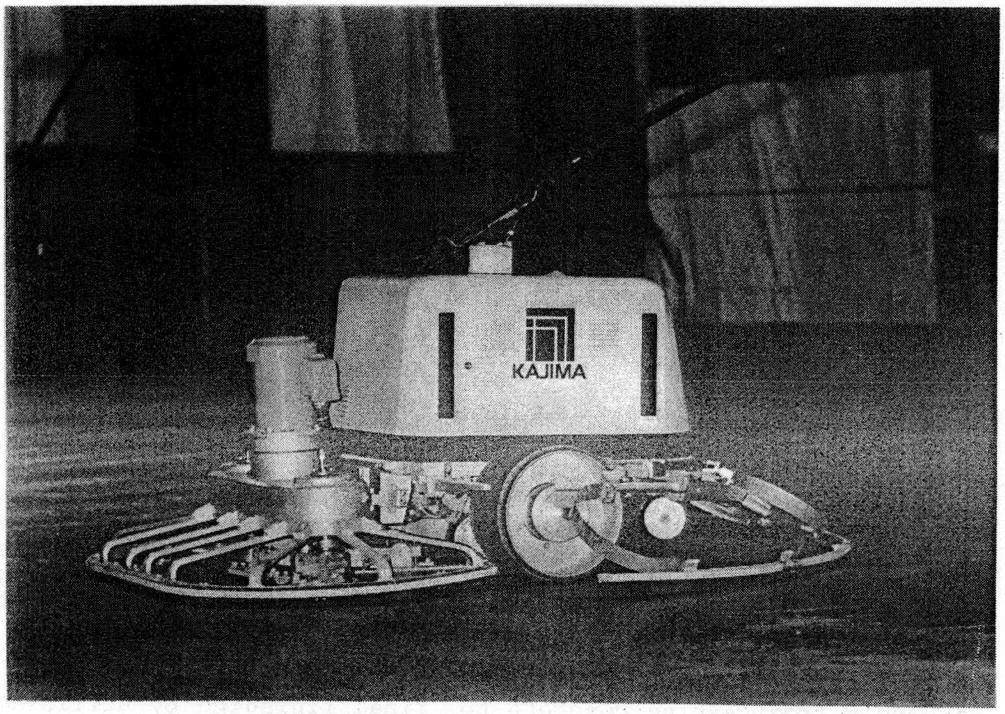

Photo 1. The Mark II

Table 1. Specificatons

<table>
<tr><th colspan="2">Items</th><th colspan="2">Discription</th></tr>
<tr><td colspan="2">Size (mm, excluding bumper)</td><td colspan="2">1,400 (L) x 1,200 (W) x 670 (H)</td></tr>
<tr><td rowspan="3">Weight (kg)</td><td>Travel device</td><td>105</td><td rowspan="3">Total: 185
(Dividable into three units by one touch of a button)</td></tr>
<tr><td>Trowel</td><td>75</td></tr>
<tr><td>Bumper</td><td>5</td></tr>
<tr><td colspan="2">Travel Speed</td><td colspan="2">0 - 250 mm/sec.</td></tr>
<tr><td colspan="2">Finishing Capacity</td><td colspan="2">500 m^2/hour x 3 times finishing (depends on concrete spec. weather)</td></tr>
<tr><td rowspan="2">Drive System</td><td>Automatic</td><td colspan="2">After predetermining the working area, merely touching a button will be enough to start</td></tr>
<tr><td>Remote Control</td><td colspan="2">Start and stop, forward and backward movement rotation can be radio controlled</td></tr>
<tr><td colspan="2">Control System</td><td colspan="2">Independent automation control system with microcomputer gyrocompass, and travel distance sensor</td></tr>
<tr><td colspan="2">Power Suppry</td><td colspan="2">200 VAC, 3 phase, 1.5 kVA</td></tr>
<tr><td rowspan="4">Safety Devices</td><td>Obstacle avoidance</td><td colspan="2">Touch sensor (avoiding adrive bumper, travel device stops)</td></tr>
<tr><td>Opening detector</td><td colspan="2">Laser sensor (stop)</td></tr>
<tr><td>Infilling detector</td><td colspan="2">Touch sensor (stop when concrete is flabby)</td></tr>
<tr><td>Alarm device</td><td colspan="2">Flashing light (white while moving, red in an emergency)</td></tr>
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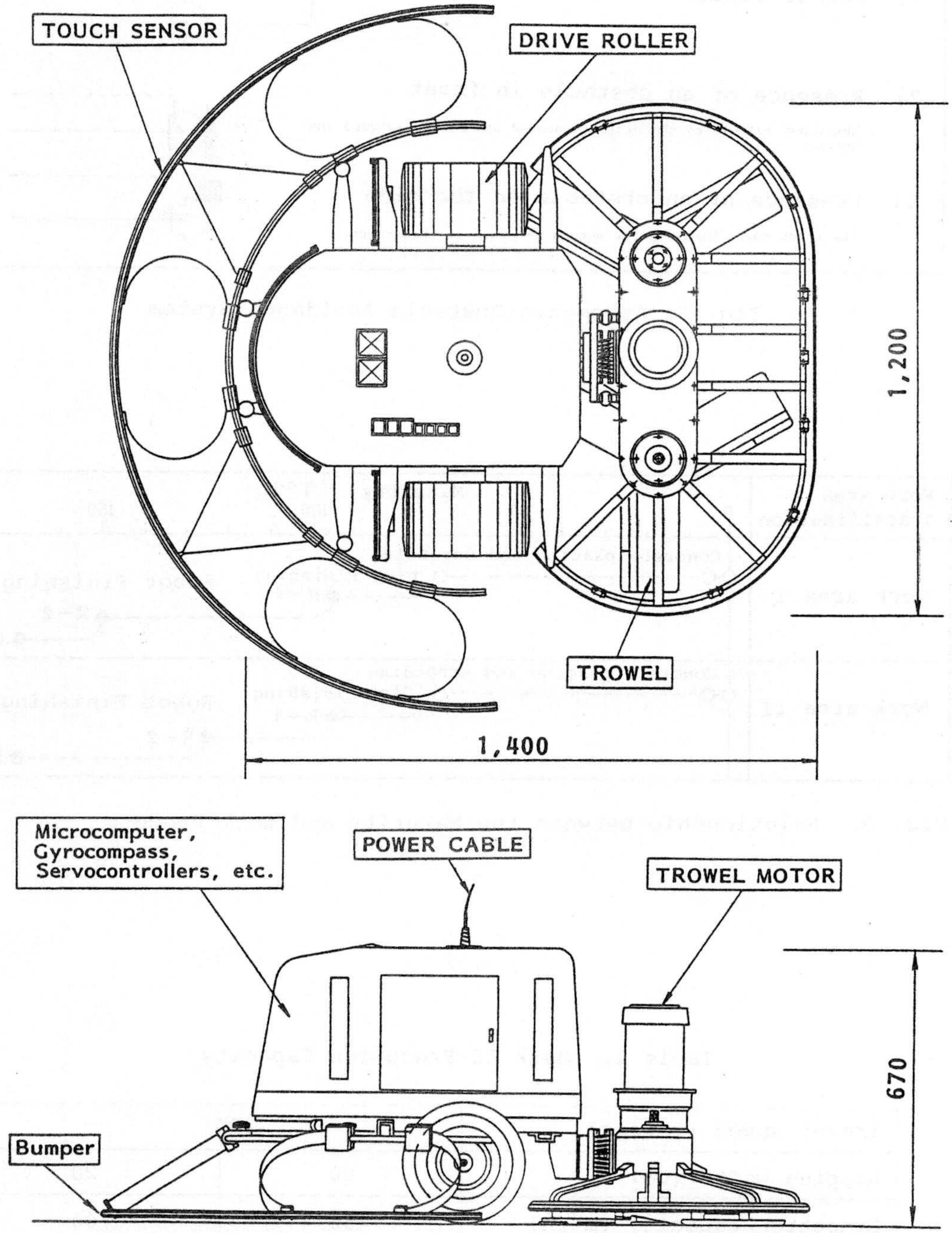

Fig. 1 Diagram of the Mark II (mm)

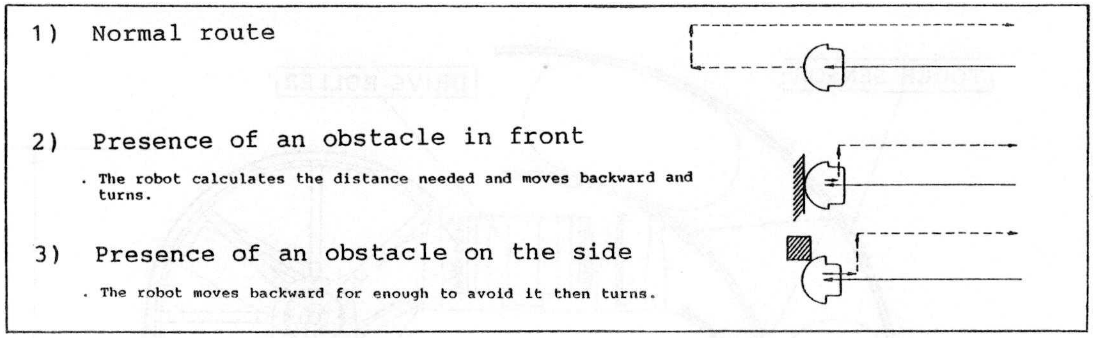

Fig. 2 Automatic Obstacle Avoidance System

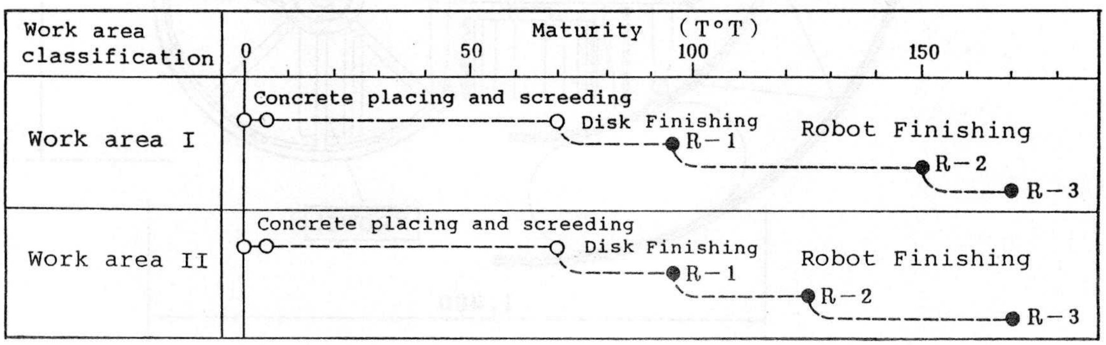

Fig. 3. Relationship between the Maturity and Work Process

Table 2. Mark II Execution Capacity

Travel speed (mm/sec)	200	
Lapping width (cm)	50	20
Execution capacity (m^2/h)	450	700
Comparison with a plasterer*	About 4 times	About 6 times

Note: *Provided that the trowel finishing capacity of a plasterer is 120 m^2/h.

Table 3. Finishing Quality Definition

Item	Definition (Section)	
Flatness (Undulation)	3 m (Ra)	Difference between uppermost convex and lowermost concave
Surface roughness (Roughness)	30 cm (Sa)	Difference between uppermost convex and lowermost concave
Floor level difference (Uneven trowelling)	Δ	

Table 4. Concrete Floor Slab Finishing Quality Requirements

Quality item	Tolerance
Flatness (Ra)	7 mm or less when checked with JASS 5 3m rule
Suface roughness (Sa)	0.1 mm or less
Floor level difference Partial convex Partial concave	0.3 mm or less

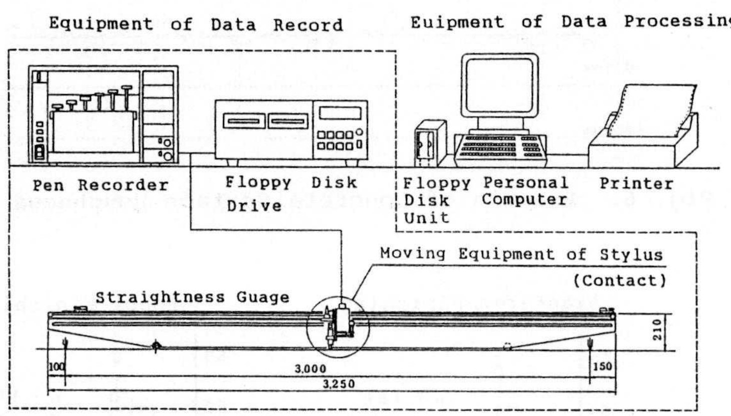

Fig. 4. Surface Roughness Measuring System

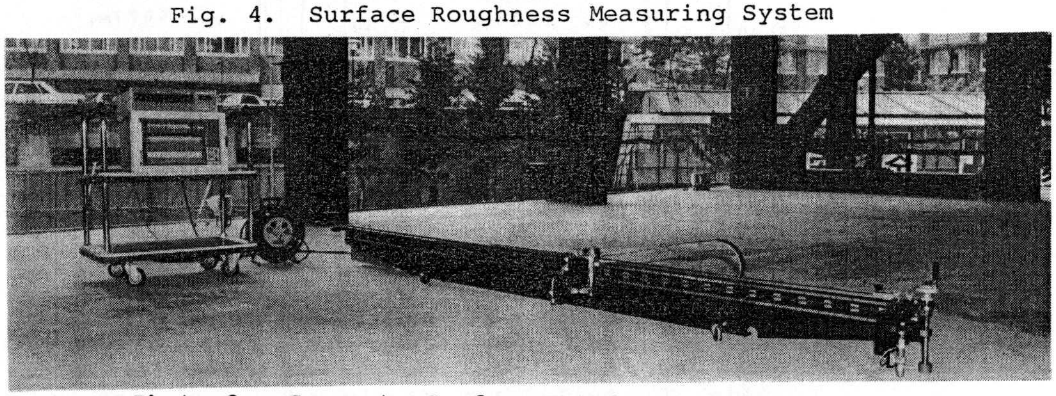

Photo 2. Concrete Surface Roughness Measurement

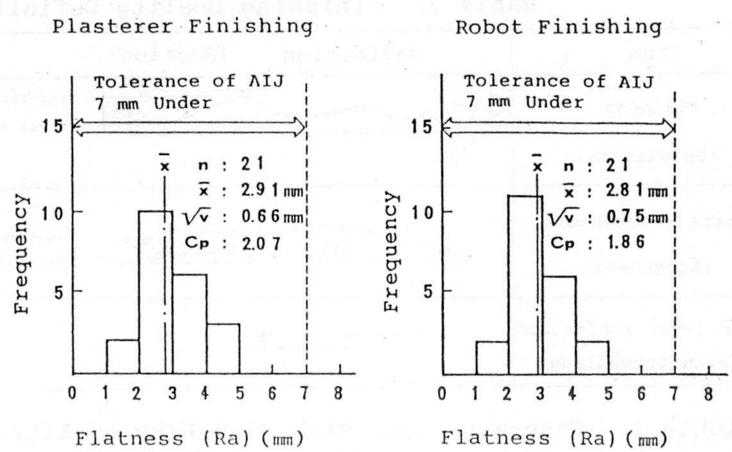

Fig. 5. Flatness Measuring Results (Measuring Length: 3 m)

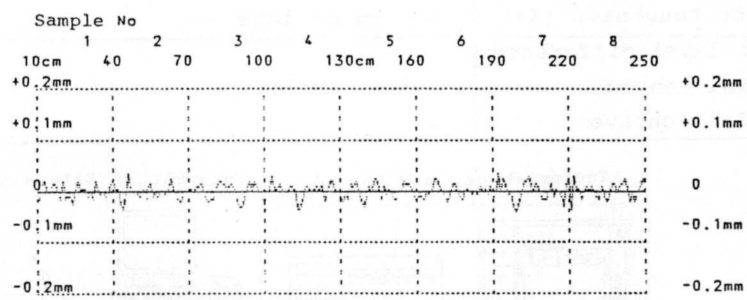

Fig. 6. Example of Concrete Surface Roughness Waveform Output

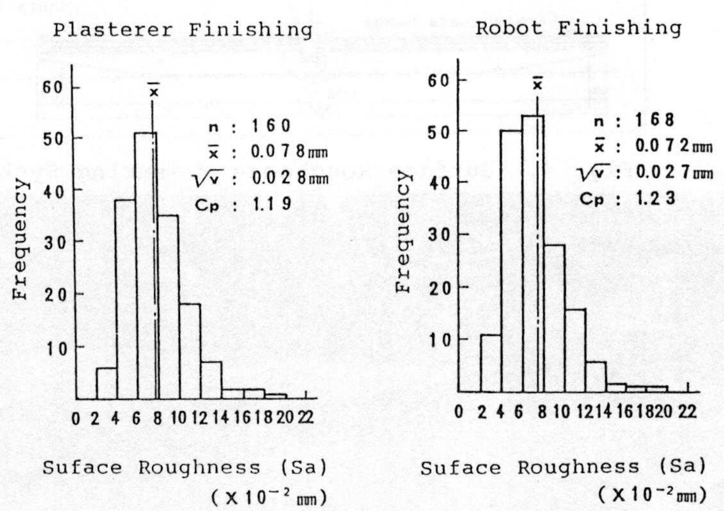

Fig. 7. Analyzed Surface Roughness Results