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The Development of the "Mark II" Mobile Robot for Concrete Slab Finishing

Sommaire

La finition du béton de dalle directement réalisée est un travail dur qu'il est souvent nécessaure d'exécuter pendant la nuit, et la fatigue engendrée par cette tâche est énorme. Par suite, c'est une tâche pour laquelle les ouvriers qualifiés sont de moins en moins nombreux. C'est pour ces raisons que nous avons concentré nos recherches sur le développement d'un robot autoroulant à parcours illimité pour exécuter ledit travail. Dans ce cadre, nous avons mis au point le premier prototype MARK I qui s'est avéré capable de procurer une bonne qualité de finition sur le chantier. Cette fois, nous avons réussi à développer un robot plus pratique par sa légèreté, sa compacité, et sa facilité de commande, un robot dénommé MARK II. Nous rapportons ci-dessous le processus de développement et les grandes lignes du MARK II.

Abstract

Concrete slab finishing is a construction task which presents a number of problems for the job site manager. First of all, curing times often require that work be carried out on a round-the-clock basis. Secondly, it is exhausting work because the posture that must be assumed by finishing workers is extremely tiring. And thirdly, it requires a high degree of skill – and skilled plasterers and finish workers are not always available. To help solve some of these problems, we began development of a trackless, self-propelled concrete slab finishing robot. In Phase I of our development, we created the Mark I prototype which gave excellent finish results in on-site tests. Now, in Phase II, we have created a more practical model which is lighter, more compact, and easier to operate. Herein we report on the development process for this robot, the MARK II, and present an overview of its functions and capabilities.

Introduction

Construction work requires the execution of many dangerous and demanding tasks. To relieve workers of some of this work, and to cut costs and improve productivity, many of Japan's leading construction firms have turned to robotics technology. As part of this trend, we developed a prototype concrete slab finishing robot in 1984, which we called the Mark I. Based on the results of on-site tests conducted with the Mark I, we have now developed a truly practical successor model, the Mark II. While the Mark I produced finish results equal to those of a skilled plasterer and was suitable for use in certain situations, the Mark II is much more compact, lower in weight, and easier to use, making it suitable for use in a much wider range of applications.

1 – Development Objectives

Although concrete slab construction techniques vary from site to site, Fig. 1 outlines the process as it is most commonly carried out. In the surface finishing process, the following problems can be identified:

- Since work is performed by hand, finish quality varies greatly, depending on the workers' experience and level of skill.
- Due to the long curing times required in colder weather, overtime and all-night work is common.
- The work is physically demanding because the posture that must be assumed by finish workers is extremely tiring.
- There is a growing shortage of skilled plasterers and finish workers.

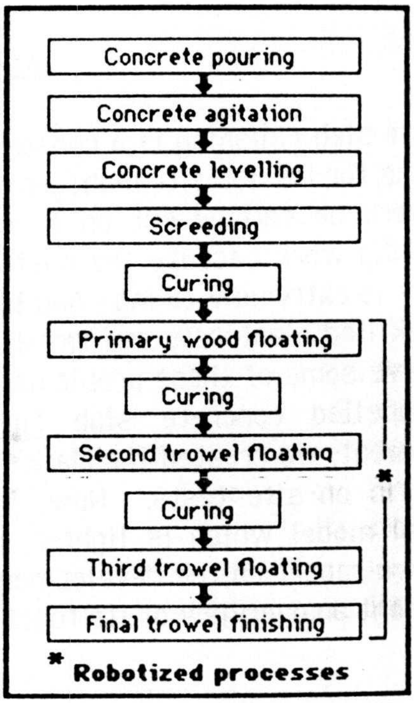


Fig. 1: Concrete Slab Finishing Process

As such, development objectives were focussed on achieving greater efficiency in the surface finishing process, with particular emphasis placed on reducing the personnel required for late-night operations and eliminating the uneveness in finish quality that results from differing skill levels within the work force.

2 – Overview of the Mark I Concrete Slab Finishing Robot

2-1 Specifications of the Mark I

Fig. 2 shows the structure of the Mark I robot; an external view is shown in Photo 1. The Mark I features a 2-axis horizontally articulated arm with a 4-bladed revolving trowel which swings back and forth as the robot moves along a preset course.

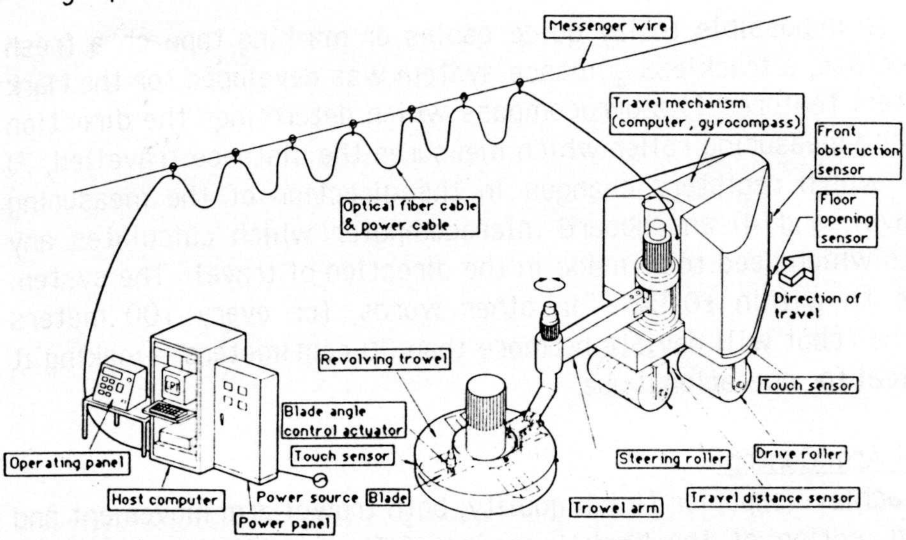
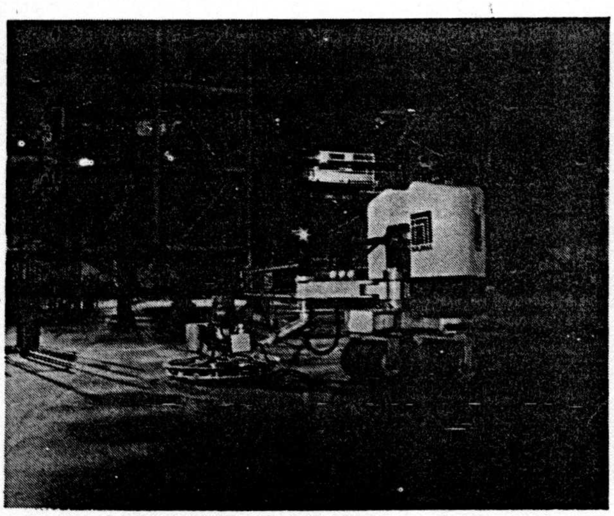


Fig. 2: Diagram of the Mark I Concrete Slab Finishing Robot



- Main unit dimensions:
  1260mm (W) x 1270mm (L)
  x 1750mm (H)
  When disassembled for storage:
  1050mm x 1450mm x 1570mm
- Trowel dimensions:
  Ø 1020mm x 690mm (height)
- Travel speed:
  Variable, 0-200mm/sec.
- Work speed:
  200 - 300m²/hr.

Photo 1: Mark I Concrete Slab Finishing Robot

2-2 Control of Directional Movement

Since it is necessary for the robot to follow its preset course as smoothly and accurately as possible, the Mark I is designed to be able to determine its position at all times, and continuously and automatically make corrections in the direction of travel to ensure that it does not deviate from the designated course.

Because it is impossible to lay guide cables or marking tape on a fresh concrete surface, a trackless guidance system was developed for the Mark I. The system features 1) a gyrocompass which determines the direction of travel, 2) a measuring roller which measures the distance travelled, 3) an encoder which registers changes in the direction of the measuring roller's travel, and 4) an onboard microcomputer which calculates any adjustments which need to be made in the direction of travel. The system is accurate to within ±0.3% – in other words, for every 100 meters travelled, the robot will deviate no more than 30 centimeters – making it fully practical for operational use.

2-3 Trowel Arm Control

In order to achieve superior finish quality, both trowel arm movement and the forward motion of the Mark I are carefully regulated to ensure a uniform overlap pattern. Photo 2 shows a computer graphics display of the trowel arm path when the robot is at rest, while Photo 3 shows the trowel arm path when the robot is in motion. The range of the trowel arm movement shown in Photo 2 can be adjusted to suit the particular needs of each site.

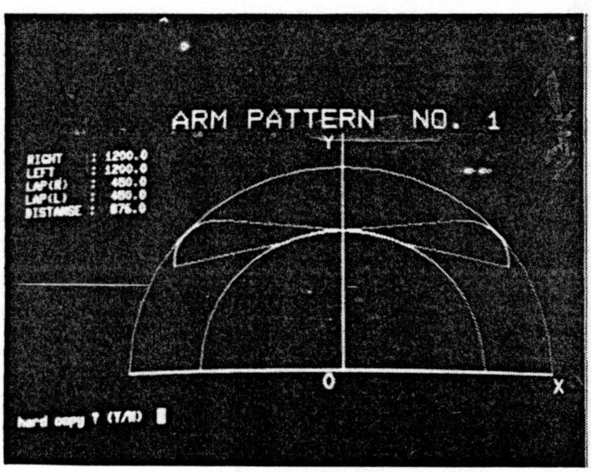


Photo 2: Path of Center of Trowel (robot at rest)

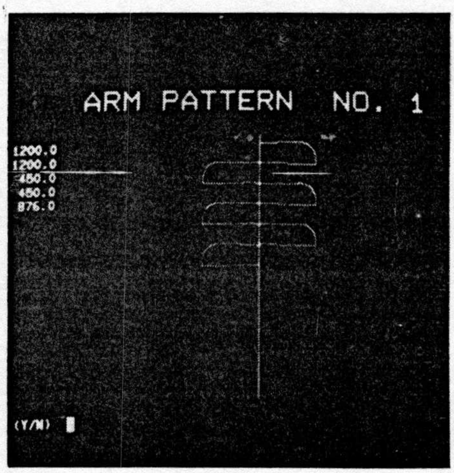


Photo 3: Path of Center of Trowel (robot in motion)

3 – Evaluation of the Mark I

3-1 On-Site Test Results

Results of finish quality tests conducted with the Mark I are shown in Fig. 3. As these results show, variations in horizontality of the surface over a distance of 3 meters averaged only ±1.94 millimeters, with a maximum variance of only ±3.5 millimeters. These figures are well within Architectural Institute of Japan standards (±7mm per 3m), and are comparable with the results that can be achieved by a skilled plasterer.

3-2 Improvements to the Mark I

Although the Mark I performed well in the critical area of finish quality, it was felt at some job sites that mobility and maneuverability could be improved. Where the surface to be finished had relatively few obstructions – such as factory/warehouse floors – there was no problem, but in office building construction where there were many pillars and other obstacles, and where the unit had to be moved frequently from one floor to another, it became clear that a more compact and maneuverable unit was desirable.

(i) Size/Weight Reductions

To permit use in buildings where the maximum floor load is 200kg/m^2, and to make frequent relocation easier, the robot needs to be light enough that 2-3 workers can move it. In addition, frequent moves mean that set-up procedures have to be as simple as possible. (The Mark I's gross weight of 696kg applied a floor load of approximately 500kg/m^2, and every time it was moved, the host computer, power supply panel, and control panel also had to be moved and set up again.)

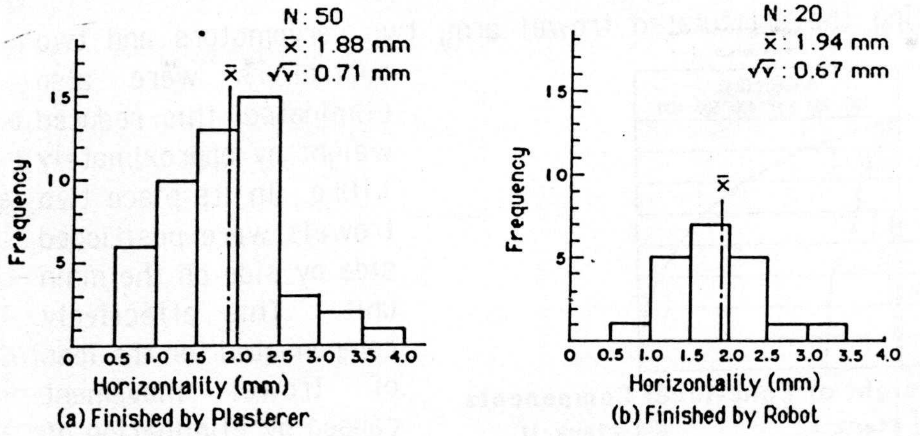


Fig. 3: Horizontal Accuracy of Surface Finished by Plasterer and Robot

(ii) Simplified Operation

To simplify operation even at job sites where there are many pillars, or where the shape of the area to be finished is complex, it is necessary to minimize the number of variables which must be inputted each time the robot is set up. Furthermore, the programming of the robot should not require specially-trained personnel. (In operating the Mark I, it was necessary to program the location and dimensions of all pillars into the unit before work could begin, a task which required the presence of a specially-trained engineer.)

4 – Development of the Mark II

4-1 Analysis of Weight Factors

Fig. 4 shows the weight of each of the major components in the Mark I slab finishing robot. As can be seen, the servomotor power supply unit accounts for much of the Mark I's weight; and since the power supply unit is comprised mostly of servomotor controllers, a reduction in the number of motors was clearly the key to achieving any major reductions in weight. In addition, we also determined that the weight of the travel mechanism and trowel arm could be reduced.

4-2 Proposed Improvements

After extensive analysis of Mark I on-site test results and careful consideration of various options, the following five improvements were decided on.

(i) Elimination of the Trowel Arm

By eliminating the articulated trowel arm, two servomotors and two controllers were also eliminated; this reduced weight by approximately 110kg. In its place two trowels were positioned side by side on the main unit. This effectively compensated for the loss of trowel movement caused by elimination of the arm.

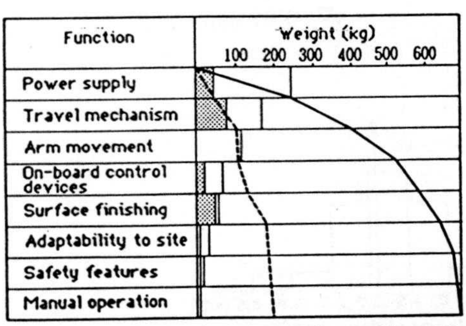


Fig. 4: Weight of Functional Components
Mark I Mark II

(ii) Elimination of Secondary Rollers & Steering Mechanism
By redesigning the drive rollers so that steering could be effected by varying the speed/direction of the drive rollers themselves, it was possible to eliminate the secondary rollers and the servomotor and controller associated with them.

(iii) Elimination of the Power Supply Panel
Elimination of the trowel arm, steering mechanism, and automatic trowel blade angle adjustment mechanism meant that the only controllers which remained were the two required for the drive rollers. As such, it was decided to mount these controllers and the trowel motor circuit breaker inside the robot itself, thereby eliminating the need for a separate power supply panel.

(iv) Elimination of the Host Computer
Since it was the complex relationship between the motion of the articulated trowel arm and the direction of travel that made the use of a host computer necessary, the elimination of the arm meant that a simple microcomputer could be mounted inside the robot itself.

(v) Development of a New Lightweight Gyrocompass
In developing the Mark I, precision had been given top priority when deciding which type of gyrocompass to install. For the Mark II, however, the subcontractor supplying the gyrocompass was instructed to give priority to reducing the size and weight of the unit, and various design changes were made to ensure that adequate precision would still be maintained.

4-3 Overview of the Mark II
By carrying out the improvements outlined in the preceding section it was believed that the goals of reducing size and weight could be achieved. At the same time, however, it was recognized that any new design might present a new set of problems to overcome. As such, various pieces of testing equipment were developed to carefully check the performance of each component. The result is the new Mark II, shown in Photos 4 and 5.

(i) Compact and Lightweight
The Mark II weighs just 200kg and quickly disassembles into three pieces for easy transport by two or three workers. Furthermore, no support peripherals such as a power supply panel or host computer are needed.

(ii) Simplified Operation

Fig. 5 shows the floor plan of a typical job site where the Mark II might be used. The size and position of pillars is not uniform, and obstacles such as protruding reinforcing steel are found. With the Mark I it was necessary to program the location of each of these obstacles into the robot before operation could begin, but with the Mark II only dimensions *a* and *b* need to be inputted. The Mark II will then navigate around any obstacle that it encounters within this area by means of a touch-sensitive bumper that automatically activates the steering mechanism. In addition, the Mark II is equipped with radio control that permits the operator to steer it manually.

(iii) On-Site Test Results

In final on-site tests, the Mark II was used to finish the 1000m^2 concrete floor of a municipal government office. The work was carried out over a two-day period, and excellent finish quality was achieved. Photo 6 shows the Mark II in operation at the site.

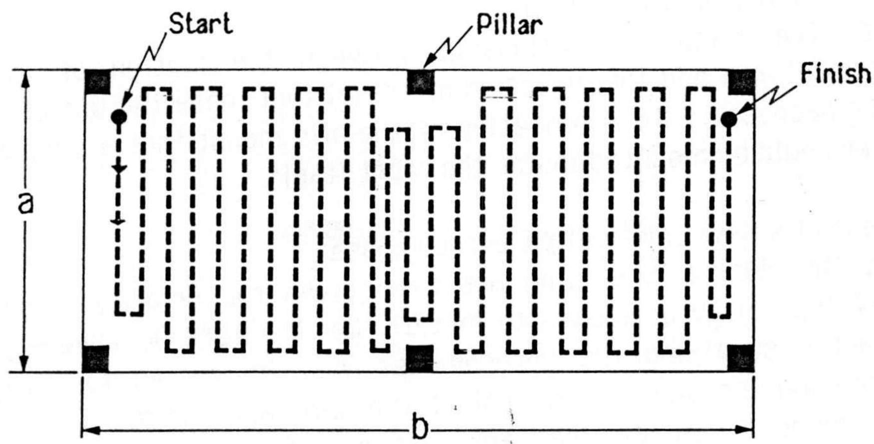


Fig. 5: Typical Operating Path of the Mark II

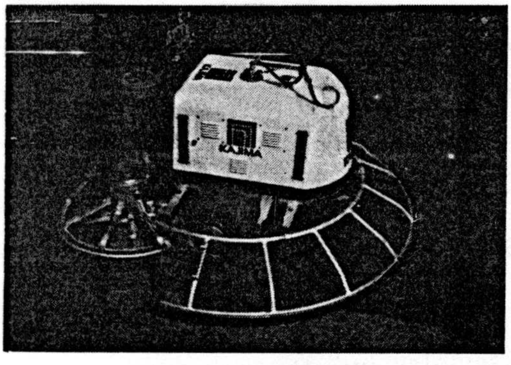


Photo 4: The Mark II (fully assembled)

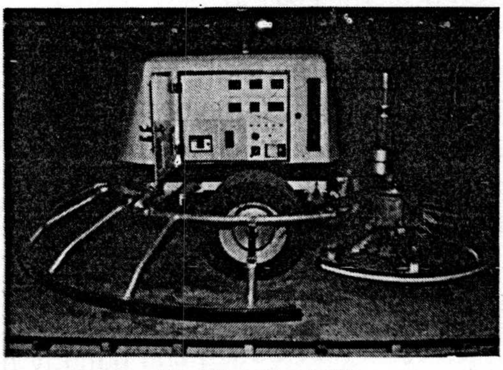


Photo 5: The Mark II (disassembled for transport)

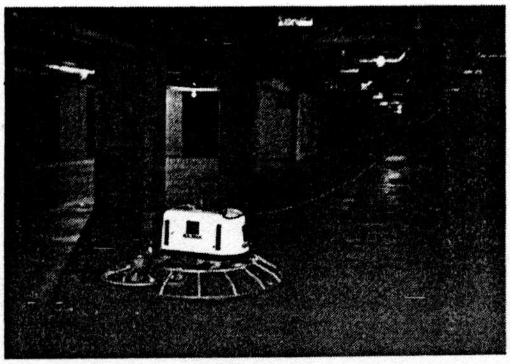
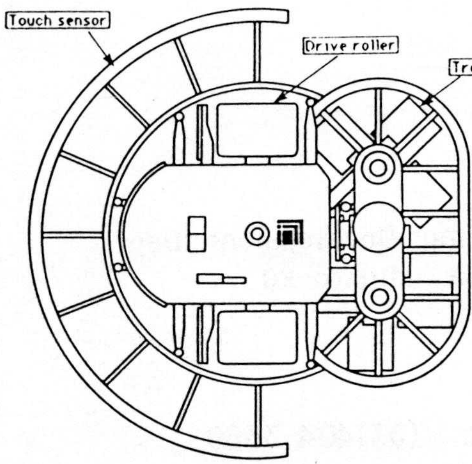


Photo 6: The Mark II in Operation

Mark II Concrete Slab Finishing Robot Specifications	
Dimensions	1400mm (L) x 1200mm (W) x 670mm (H)
Weight	200kg
Work speed	$400 m^2/hr$
Travel speed	variable, 0-300mm/sec
Drive system	variable speed AC servomotor
Trowels	ø 600mm x 2
Control system	computerized (on-board microcomputer)
Guidance system	independent gyroscopic system
Operating system (1)	unattended
(2)	radio-controlled
Obstacle avoidance	software-supported touch sensors
Power supply	AC 200V, 3kVA



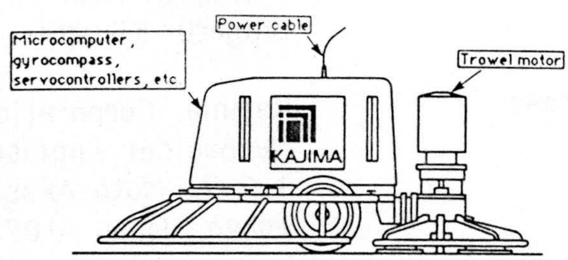


Fig. 6: Diagram of the Mark II Concrete Slab Finishing Robot

Conclusion

In developing the Mark I concrete slab finishing robot we were able to study in detail the various mechanisms required to achieve superior finish quality and smooth operation. Now, with the development of the Mark II, we have succeeded in putting these capabilities into a truly practical unit that is lighter, more compact, and much easier to operate. As we use the Mark II in the days ahead, we will seek to further improve its performance characteristics and cost effectiveness, and will begin preparation of operating and service manuals in order to begin full production.

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