DEVELOPMENT OF A PAVEMENT CUTTING ROBOT SYSTEM

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ABSTRACT

A pavement cutting robot system was constructed on a trial basis to automate pavement cutting when a road is to be cut and recovered. The system consists of the robot itself, the control panel, and a cooling water supply and recovery unit. All the units are electrically power driven and a small-size high-frequency motor is used to provide power for the cutter. The results of performance tests have proven that the work can be accomplished safely while ensuring the necessary cutting accuracy.

1. INTRODUCTION

1.1 Present Problems

A very wide variety of electric cables and pipes are laid under paved roads in Japanese cities. Pipes are newly buried when successive buildings are constructed as the city expands both outwardly and upwardly. Frequent work of such new construction and repairs causes traffic jams in the cities and problems such as noise during cutting and pollution by slurry because the work is conducted in both commercial and residential areas. There is an additonal disadbantage in that the workers employed in the work are exposed to great danger since cars pass very close to them even though they work in an established safety zone.

Photo 1 Pavement cutting work

1.2 Required System Functions

The required functions for maximizing robot performance have been determined as follows to solve problems such as safety, work efficiency, waste water treatment, and noise.

1) TRAVEL	a. Linear travel along a designated cutting line b. Direction change (revolving) c. Correction if cutting differs from the designated cutting line
2) CUTTING	d. Measures against fluctuation in cutting load e. Measures for soundproofing during cutting
3) WATER TREATMENT	f. Supply of cooling water for the cutter blade g. Recovery of slurry (waste water) generated during cutting
4) REMOTE/AUTOMATIC OPERATION	h. Remote/automatic operation for steps a. to g. above

2. DESIGN LEVEL FUNDAMENTAL TESTS

One great difference between the robot developed in this study and conventional machines is that the cutting and traveling units of the robot are electrically powered. Conventional machines have a mechanism incorporating a gasoline engine as the main power source. However, it is difficult for the engine to control the machine during traveling and cutting. Accordingly, all required sections of the robot are electrically powered. Since only a very few examples using motors for cutting asphalt are available, we conducted the basic cutting experiments ourselves.

We used a small-size high-frequency motor (15 ps) which is driven by an inverter (400 Hz) because a motor with a standard commercial power frequency of 50/60 Hz is extremely large and heavy.

2.1 Outline of Basic Cutting Experiments

Two experiments were carried out using the experimental equipment in order to ascertain the fundamental cutting characteristics:

1) Change in cutting efficiency depending on vertical cutting speed and depth;
2) Change in cutting efficiency depending on horizontal cutting speed and depth.

To understand the characteristics involved during vertical cutting, asphalt was cut vertically at a fixed speed, and the cutting depth was checked. During horizontal cutting, the asphalt was cut to fixed depth at several different cutting speeds.

2.2 Experimental Results

It is apparent from the plots (Fig.1 and 2) outlining the

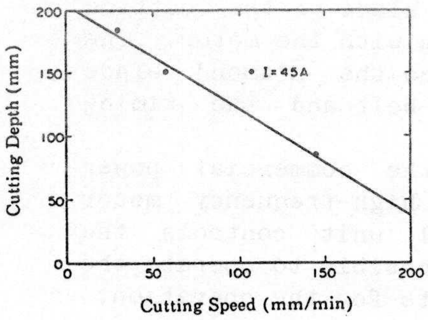

Fig.1 Characteristics of vertical cutting

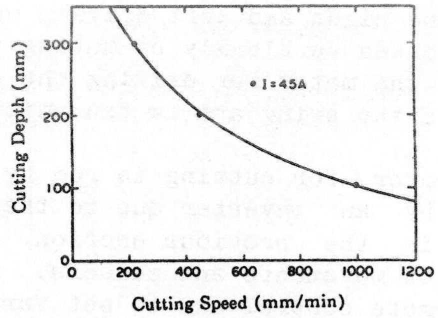

Fig.2 Characteristics of horizontal cutting

experimental results that the cutting efficiency is extremely decreased as the cutting depth increases. In particular, during horizontal cutting the relationship between the depth at which the cutting is performed and the maximum cutting speed is not a linear inverse proportion but rather the cutting speed is extremely reduced if cutting is performed to a very deeply.

The data obtained from the experiments was used as a reference when conditions such as the cutting speed of the robot were determined.

3. OUTLINE OF THE OVERALL SYSTEM

3.1 Overall System Structure

Photo 2 shows the overall system of the cutting robot. As is clear, the system consists of three units: the robot, the control panel, and a cooling water supply and recovery unit.

A signal cable for control and a power cable to drive the motor are connected from the robot to the control panel, and hoses to supply and recover cooling water are connected to the cooling water supply and recovery unit. All units can be operated from the controller on a remote control basis.

3.2 Robot Structure

The structure of the robot is roughly divided into traveling, cutting, and control sections (Fig.3, Table 1). The traveling section uses a powered wheel steering mechanism with two servo motors. Directional correction and turning are attained by the difference in

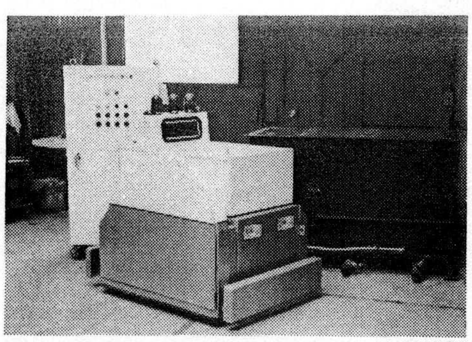

Photo 2 The pavement cutting robot system

speed of the right and left driving wheels. The blade of the cutting section is moved vertically by moving the swing arm with the motor. The output of the motor for driving the cutter to turn the diamond blade attached to the swing arm is transmitted by the V-belt and the timing belt.

The motor for cutting is run by increasing the commercial power frequency by an inverter due to the use of the high-frequency motor described in the previous section. The control unit controls the overall robot movements and sensors. It is also possible to operate the robot by remote control and to set various constants for the operation.

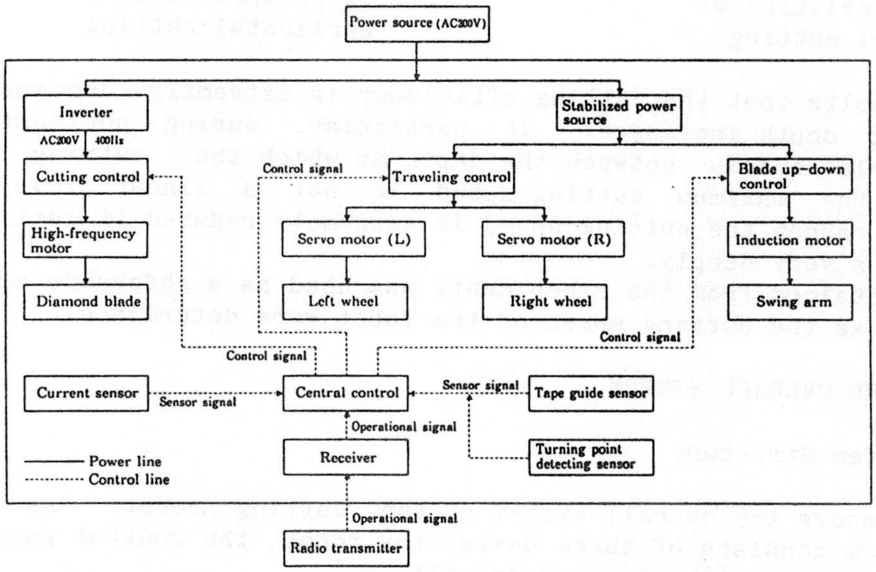

Fig.3 Schematic diagram of the cutting robot

Table 1 Specifications of the pavement cutting robot

Traveling device	Type Actuator Travelling speed	Powered wheel steering AC servo motor max. 10m/min
Cutting device	Actuator Power source Rotating speed Up-down speed Cutting depth	High-frequency motor (11kW) AC200V, 400Hz 1,150rpm (final output) max.1,000mm/min max. 300mm
Control functions	Course correction	①Course correction with magnetic-sensor and metal tape (Pattern cutting mode) ②Course correction with gyro-sensor (Block cutting mode)
	Cutting load control	Cutting load control with CT and current comparator
	Manual operation	Wireless remote oparation (Moving back and forth, left or right turning)
Others	Dimensions Weight Power source Safety devices	H 1,340×L 1,380×W 860mm 700kg AC200V, 50/60Hz, 50A Bumper switch, Emergency switch

3.3 Traveling Correction and Turning Function

The traveling correction and turning function have two control systems which depend on the two cutting modes. One is for control using the signals from the two sensors in the center for traveling correction and the two outside sensors for turning. The employed sensors are actually sensors for metal detection which are resistant to dirt and dust. The guide used as a reference for linear traveling is a metal tape about 0.2 mm thick. The other control system uses a gyro-sensor to measure its direction and encoders for the traveling distance.

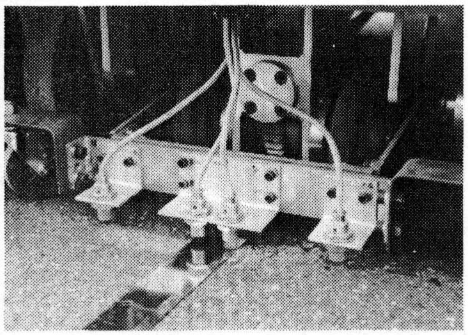

Photo 3 Guide tape and sensors

3.4 Cutting Load Detection Function

The cutting load detection function is capable of countering unexpected loading which may occur during asphalt cutting. The current of the cutting motor during operation is detected by a current comparator in order to control the vertical cutting speed.

The current is comparated at two points. The cutting speed is slowed down at the first point by using the current value as a guide, and an overload current is set at the second point. The system is controlled to prevent overloading in such a manner that when the current reaches the set value the blade stops descending and begins to ascend until the current becomes lower than the set current.

3.5 Cutting Mode and Operation Algorithm

The robot has two cutting modes: pattern cutting and block cutting. Pattern cutting is a method for cutting rectangular cutting lines. Such rectangular cutting is usually conducted during pavement cutting work. Thus, the pattern cutting mode is also a basic mode in robotized work.

The cutting accuracy required for pavement cutting is approximately $\pm$20 mm at which no restrictions are placed on the lining plate settings carried out after cutting and covering. Because the pattern cutting mode requires such high cutting accuracy, we adopted a traveling control system using a metal tape as a guide.

Block cutting is a cutting mode for cutting the inside of the rectangular cutting lines into more block-like shape. Since block cutting does not require the same accuracy as that for pattern cutting, we employed a traveling control system in which the distance is measured by the moving wheels and the direction is controlled by the gyro-sensor (vibration gyro). The procedures of the pattern and block cutting modes are shown in Fig.4 and Fig.5 .

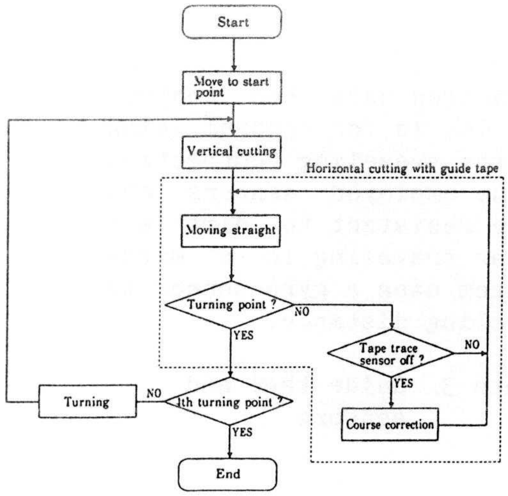

Fig.4 Pattern cutting procedure

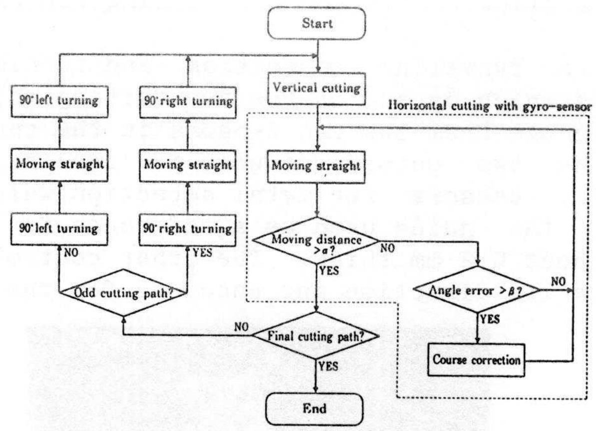

Fig.5 Block cutting procedure

4. FIELD TEST RESULTS

Experiments were carried out to assess the performance of the pavement cutting robot system. Figure 6 shows the layout of the test field. This road has a 2% water gradient from the road center to the sidewalk. The basic cutting pattern is a 2 m by 4 m rectangle with the cutting lines divided at a pitch of 0.8 m drawn inside the rectangle. The cutter robot cut the periphery in the pattern cutting mode and the interior in the block cutting mode. Data including cutting accuracy and efficiency were obtained.

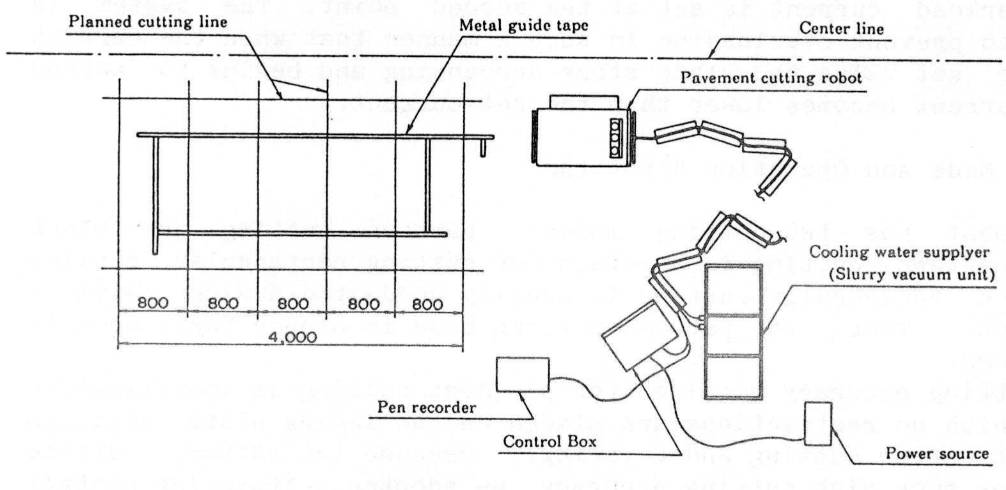

Fig.6 Experiment layout

4.1 Cutting Accuracy

Figure 7 shows the result of the measured cutting accuracies of the robot in comparison with those obtained from conventional methods.

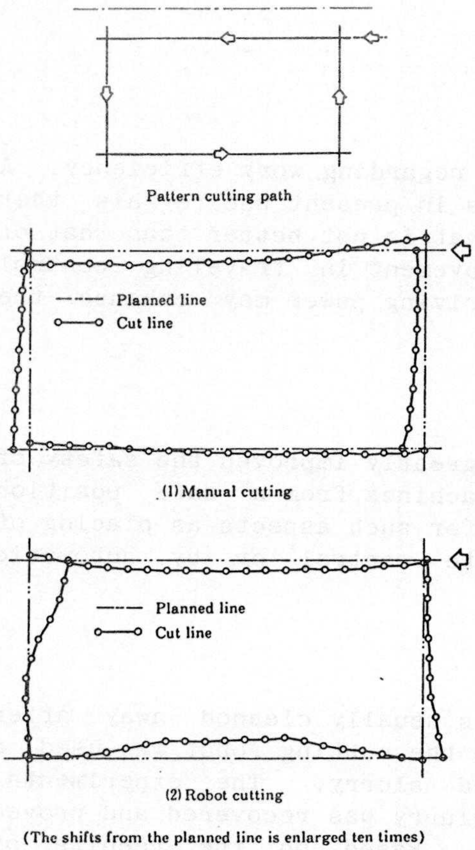

Fig.7 Experimental result of pattern cutting

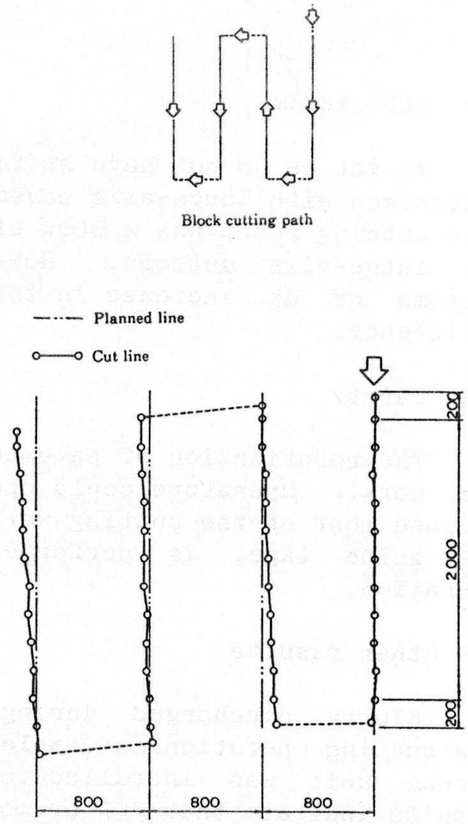

Fig.8 Experimental result of block cutting

The shifts from the reference lines have been enlarged ten times in order to accentuate the tendency clear; actually, the line is much straighter. It is evident, the robot attained the cutting accuracy required for pavement cutting except for one part of the cut field, although the linearity is slightly inferior to that of the conventional manned cutting method.

The reason for the inaccuracy in the upper left-hand corner may be that the robot shifted from the right position when it turned at the corner. A comparison between the linear parts after the start point found that this cutter robot achieves better linearity than manned cutting since the average of the manned shifts is about 10 mm and those of the robot about 8 mm.

Figure 8 shows the result when the robot cut asphalt in the block cutting mode. When compared with that of pattern cutting, the cutting accuracy decreases as the cutting proceeds. This is because the traveling control system during cutting is different. In other words, the traveling is controlled based on the number of rotations of the wheels and the gyro-sensor in the block cutting mode. Therefore, shifts of the wheels during turning and errors attributable to gyro-drifting accumulated.

However, block cutting is used for easier pavement removal and, therefore, very accurate cutting is not necessary. The robot seems to be satisfactory for practical use if the road is cut by dividing it into two-to three-meter sections.

4.2 Efficiency

As yet we do not have sufficient data regarding work efficiency. A comparison with large-size pavement cutters in present use reveals that this cutting robot has a work efficiency that is not better than that of the large-size cutters. However, improvement in traveling control systems or an increase in the cutting driving power may enhance the efficiency.

4.3 Safety

The robotization of pavement cutting greatly improved the safety of the work. Operators could operate the machines from a safe position because most of the cutting work, except for such aspects as placing of the guide tape, is performed by remote control or by automatic operation.

4.4 Other results

Slurry discharged during cutting is usually cleaned away after the cutting operation is completed. When the cutting robot was used, a vacuum unit was installed to recover the slurry. The experimental results indicate that 70% or more of the slurry was recovered and proved that only a small area needed cleaning. Based on the results of comparative measurements, the noise level averaged about 2 dB lower than that of conventional machines. When the first cut is made, the noise level of conventional machines is about 4 dB higher than that for the robot since the blade of the conventional machines is fixed outside the cover.

5. FUTURE THEMES

Success in the robotization of pavement cutting has been attained and cutting work can be performed by remote control while the necessary cutting accuracy is maintained. Thus, safety has been improved, though problem remaining to be solved is achiving greater efficiency.

One of the causes of the lowering of cutting efficiency is insufficient performance of the traveling control of the robot. If the robot can be made to move straighter during road cutting, it is possible to improve the efficiency.

The recovery of slurry generated during cutting will require further study for recycling methods from the standpoint of a decrease in the volume of the waste.

Our aim is to make cutting robots more practical by improving or resolving these problems in the near future.

REFERENCE

1) T. KOBAYASHI, et al.: "Study on a robotic system for pavement cutting work", Proceedings of The 5th International Symposium on Robotics in Construction, Tokyo, 1988.