The 5th International Symposium on Robotics in Construction June 6-8, 1988 Tokyo, Japan

STUDY ON A ROBOTIC SYSTEM FOR PAVEMENT CUTTING WORK

Tomoki Kobayashi
The Tokyo Electric Power Company Inc.
No.1-3, Uchisaiwai-cho 1-chome, Chiyoda-ku, Tokyo 100, Japan

Syoji Honda
Kandenko Company Ltd.
No.1-18, Yushima 4-chome, Bunkyo-ku, Tokyo 113, Japan

Yuichi Tsukahara, Takatoshi Ueno, Hitoshi Sato,
Tetsuji Yoshida, Ryuichi Tsutsui
Shimizu Corporation
No.15-33, Shibaura 4-chome, Minato-ku, Tokyo 108, Japan

Abstract

A study has been executed for development of a robotic system for pavement cutting work. Targets for this study are 1)to make the cutting work safer than the conventional method, 2)to reduce the noise level and pavement surface slurry contamination. The conventional method is examined from the point of automation and robotization. As a result, the use of diamond sawing with load sensor feedback and remote operation was found to be necessary for reducing the probability of traffic accidents and for clean work without pollution. Four robotic system images are proposed for the future. The most feasible image is now under development to evaluate its effectiveness for actual cutting work.

1. Introduction

In Japan, a number of electric power cables, gas pipes and water pipes are buried under the pavement in the downtown areas of large cities. After the passing of several decades, these utility lines must be repaired or replaced by new ones. Differences in the placement schedule and life time of each utility line results in frequent road construction which causes heavy traffic jams and construction expenditure.

Pavement cutting construction is executed prior to excavating the soil covering on the cables and pipes. As daytime construction seriously disturbs traffic, night works are common in downtown or residential areas. On constructions sites, pavement cutting work generates noise and contaminates the surface of streets with waste slurry. (Photo 1)

Cutting machine Operators suffer from traffic accidents with vehicles which have been temporarily diverted or obstructed by these sites. Signs and barriers for vehicles are required by law, but they are not effective against mistakes of the operators and car drivers. (Photo 2) Night work wages, the short construction time, and requirements for safety materials make the construction cost higher and less productive.

This study was carried out to develop a robotic cutter for overcoming problems associated with pavement cutting.

2. Procedure for the study

The procedure for the study is composed of 6 phases. (Fig. 1) At phase 1, conventional cutting work is examined from the view of robotization and automation. Phase 2 distinguishes conditions and requirements for the robotic system design.

Standing on the results of the survey and analysis, phase 3 proposes robotic cutting system images. In this phase, several alternatives are proposed in accordance with technical levels and objectives.

In phase 4, one system image is selected to build a prototype for the next phase, based on verification of the benefits of the robotic cutting system. Phases 5 and 6 are proposed the prototype, confirming the performance of the robotic cutting system. Next, in Phase 6, feedback should be made at the appropriate phase to improve the system. This paper reports the survey results and system design from phases 1 to 3.

3. Survey of conventional cutting work

The purpose of the survey of conventional work is to determine the necessary functions for a robotic cutting system and the reasons for robotization. The survey has been executed on five items as follows:

1) Specifications of pavement to be cut by cutting machines
2) Method and organization for cutting works
3) Mechanical specifications for cutting machine
4) Operational aspects of cutting machine
5) Construction safety

3.1 Specifications of pavement to be cut by cutting machines

Pavement cutting work is generally executed on city streets for maintenance of buried electric cables. Overpasses, roads in tunnels and bridges are eliminated from the objectives for this survey.

Load sections show standard pavement specifications in Japan. (Fig. 2) The pavement to be cut by the machines is surface course or combined layer with surface and base course, of thickness about 20 to 25cm. These layers are composed of asphalt and stones, but the sub-base below the asphalt layer is composed of a soil mixture with crushed stone and sand. The sub-base and lower layer under the sub-base are easily excavated using excavators, but this layer is restraint to the rotating diamond blade of a cutting machine and sometimes crushes the diamond segments. Eventually, the cutting blade must reach the interior of the asphalt layer and the edge of the boundary between the base and the sub-base course. For actual cutting work, skilled operators adjust the blade near the boundary to prevent cracking or restraint of the blade. When the cutting depth is not sufficient, surplus excavation at the bottom of the asphalt layer sometimes causes cave-ins on the road surface from the weight of traffic.

Cutting on the edge of the boundary is impossible for a human worker because the boundary location is not visible. Partial repair on the surface of the road is not uniform. Pavement at the actual cutting site is more than 30cm thick.

3.2 Method and organization for cutting work

The steped cutting method of 2 or 3 layers is the normal method of cutting work. The thickness of the initial cut is 5 to 10 cm to make a guide for deeper cutting from the marked line on the road. For the initial cut, a small diameter blade is used for depth of less than 10cm deep because of the ease of controlling the cut of the machine.

Roads where electric cables are buried have thickness of 20 to 25cm. The final step cutting fits the cut depth to the asphalt pavement thickness. The sequence for the cutting work is shown in Fig. 3.

The work organization for cutting work is a fraction of the formation for total road construction. For pavement cutting, the following roles are necessary;

- Supervisor/ as a director for the cutting
- Cutting machine operator/ for preparing the machine, marking, operating and maintenance,
- General worker/ to assist in marking, traffic control, setting signals and barriers, and cleaning the surface of the road.

Several general workers are employed only to clean-up the road surface contaminated by the blade cooling water.

3.3 Cutting machine

As a power source for the pavement cutting machine, an automobile gasoline engine is used and the cutting blade is driven by the transmission belts. A hydraulic oil unit driven by an electric generator attached to the engine drives the machine and lifts it to adjust the cutting depth. Stabilized cutting is executed when the machine is flat as shown in Photo 3. The cutting depth is adjusted using different diameter blade fittings for each depth. At the final cut, the oil lifter is used when cutting depth control is needed.

As the cutting blade is attached to the right side of the machine, the direction of the movement tends to the right. To prevent this turn and make operation easier, the drive wheel shaft is fitted at a small angle (about 2 degrees) to the left of the direction of movement. Fig. 4 shows the characteristics of machine mobility. When the operation is free, the trace is influenced by the road slope, but sometimes such influence is not common. (Fig. 5) Operational forces and the trace at the actual cut (trace displacement within -20mm to +20mm from the marked line on the road) is indicated in Fig.s 6 and 7.

The velocity of the machine is rather slower than that of a normal automobile, cooling capacity is minimal and the cover for the machine is minimal for enlarging the heat transmission area. The engine and cooling fan create a high level of noise up to 84dB at a distance of 10m from the machine. This level is hazardous to the operator.

3.4 Machine operation

The operator uses a control steering bar to maintain linear cutting and to change the cutting depth at the last layer of cutting. Fig. 7 shows the force applied to the steering bar by a skilled operator. To keep the cutting machine moving right on a flat road and to correct affection to the machine by the inclination of road, the operator pushes or pulls the bar less than 10kgf, normally 6kgf.

When the blade cuts into the sub-base, the increased load to the engine causes a decrease of engine drive shaft rotation and the tone of the engine changes to indicate that the blade is too deep. Searching the boundary of the asphalt layer and sub-base, the operator lifts or lowers the machine at slower than normal cutting speed. An expert cutting machine operator has a sense for predicting the depth of the boundary from the sound of the engine.

3.5 Work safety

During cutting on the road, traffic accidents are likely to occur and cutting machine operators have suffered from grazing by cars. Workers is sometimes walk into the traffic lane because of the length of the cutting machines, which are has about 3.5m long with the steering bar and indicator. Photo 4 shows the occasion when the operator steps out from the work area to set the machine at a right angle to the street. If the machine were smaller and could change cutting direction by itself, the probability of accidents in such cases would be decreased. Tele-operation of the cutting machine would also be applicable.

4. Requirements for a robot cutting system

From the investigations of the pavement cutting site work and experiments with the cutting machine, the requirements for a robotic cutting system were determined as follows.

```
Travelling -----1) travelling along the line to be cut
                2) turning
                3) course correction

Cutting    -----4) up and down motion of the cutting blade
                5) coping with an unexpected cutting load change
                6) soundproofing
                7) supplying cooling water

Waste water-----8) collecting waste water
collection

Control    -----9) remote control and automatic control for above
                   functions
```

4.1 Travelling

The basic function for the robotic cutting system is travelling. The shape of the cutting route is generally rectangular. The robotic system should trace the line to be cut and should adjust its direction to turn at the corners of the rectangle.

4.2 Cutting

A diamond blade is used for cutting. The maximum cutting depth is limited by the diameter of the blade. So, the up-down function of the blade is necessary to adjust the cutting depth if the cutting is to be done by one blade, without changing blades. The thickness of a pavement is not constant at all. Cutting the gravel layer is harmful for the blade, and it should be avoided it. The cutting load is increased when the gravel layer is cut, so cutting load feedback should be given to the robot.

The water supply function is necessary for cooling the blade. Soundproofing is important because diamond blade cutting is ordinarily noisy work. The cutting blade should be covered with a soundproofing blade protector.

4.3 Waste water collection

Cooling water is used for diamond blade cutting. This water becomes a slurry comprised of cut concrete or asphalt. After cutting, the workers clean up the surface of the road. (Photo1) Consequently, a waste slurry suction and collecting function is necessary.

4.4 Control

Traditional cutting work is dangerous because the worker sometimes leaves the safety barrier. The robotic system should be operated by remote control or automatic control. (Photo 4)

5. Image designs for robotic cutting system

Four robotic cutting system images were designed. These images were designed according to the considerations described in section 4.

5.1 Four-blade system

The system image of a four-blade type of robotic cutting system is shown in Fig. 8. In the pavement cutting work for buried electric cables, the cutting lines are normally about two meters in width and rectangular in shape, and these cutting lines are cut one by one.

Two cutting machines are used when the cutting depth is deep in conventional cutting work. The front cutting machine has a small blade to cut about 10cm deep as a cutting guide, and the rear cutting machine has a large blade to cut the final depth.

The four-blade type cutting system enables these cutting procedures to be executed simultaneously. The cutting depth of the front blades are fixed, for example 10cm, and that of rear blade is controlled by the cutting load to avoid cutting gravel.

5.2 Two-blade truck mount system

Fig. 9 shows a two-blade truck mount type robotic cutting system. This is also a multi-blade system which can cut two grooves at one time. A distinctive feature of this system is that the cutting device, a water tank and other utilities are mounted on the truck, so that the cutting work is easy and safe.

The cutting course is controlled by a beam guide system which consists of a beam transmitter and a beam detector. This system is able to increase work efficiency, to decrease noise level, and to extend the blade life. Using this system, an operator need not work on the road, so that this is safer than the conventional method.

5.3 Improved system of the conventional machine

The conventional machine improved type robotic cutting system is shown in Fig.10. This system is considered to be the most effective and feasible.

The special features of the system are described as follows.

1) The system can cut various depths with one blade by using a blade up-down mechanism.
2) The cutting blade is driven by an electric motor, so it is easy to adjust the cutting depth using a cutting current feedback system.
3) The powered wheel steering mechanism, which steers the robot by differentiating the speed of each driving wheel, is adopted for reliable travelling.

4) Steel tape is used as a travel guide for the robot. Guide tape setting is fast and easy, even though it should be done by a worker.

5.4 Future model

An ultimate style of the robotic cutting machine is shown in Fig.11. This system is a vehicle type which carries a water tank, power unit, operator cabin and all the facilities for the cutting system. The system is a model of the future, and it will take a long time to realize it.

6. Conclusion

The amount of pavement cutting work has been increased recently in Japan. However, there are many problems with safety, waste water treatment, noise and work efficiency. Characteristics of the pavement cutting work were clarified through investigations of pavement cutting site work and a laboratory test of the cutting machine.

Four robotic cutting system images were designed and proposed in this study for the purpose of overcoming the problems of traditional cutting work. These robotic cutting system images are as follows:

1)Multi-blade type
2)Improved conventional machine type
3)Future type

In these images designs, the improved conventional machine type will be designed in detail as a practical one. After this study, a prototype of a robotic cutting system will be manufactured, and its performance tested on site.

7. Acknowledgement

The authors would like to express their thanks to Miss Naomi Hirose and Mr. Mark Dispenza for their assistance in preparing this manuscript.

Photo 1 Conventional cutting work(1)

Photo 2 Conventional cutting work(2)

<u>Phase 1</u>:
Conventional cutting work survey

<u>Phase 2</u>:
Conditions and requirements for a robotic cutting system

<u>Phase 3</u>:
Robotic cutting system conceptual design

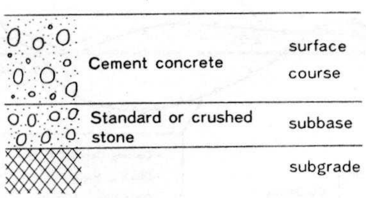
<u>Phase 4</u>:
Detailed design of proposed system

<u>Phase 5</u>:
Cutting robot prototype

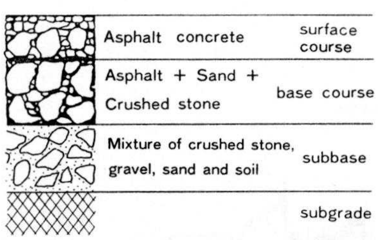
<u>Phase 6</u>:
Robot performnce confirmation through actual use for pavement cutting construction

Fig. 1 Study sequence

Photo 3 Conventional cutting work(3)



① Cement Concrete Pavement



② Asphalt Concrete Pavement

Fig. 2 Sections of standard pavement

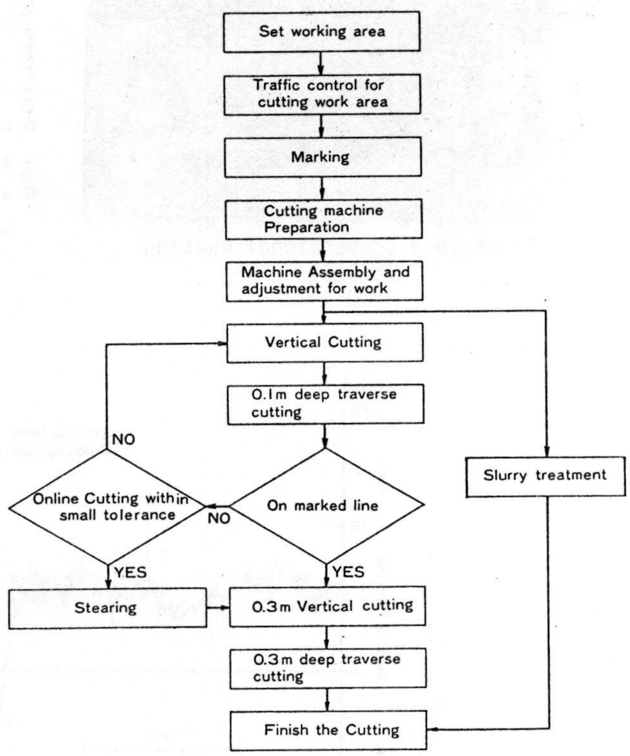


Fig. 3 Cuttihg work procedure

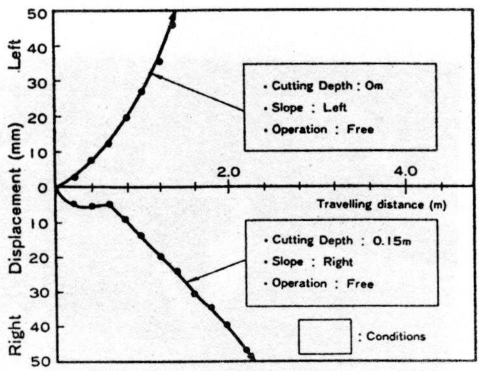


Fig. 4 Characteristics of machine mobility(1)

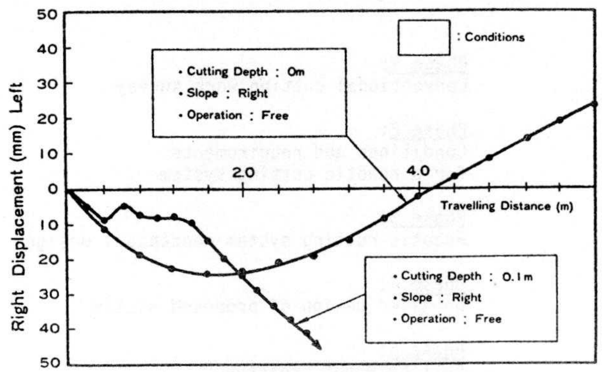


Fig. 5 Characteristics of machine mobility(2)

Photo 4 Conventional cutting work(4)

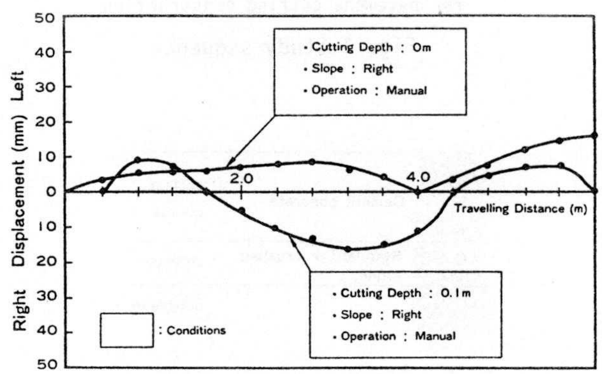


Fig. 6 Characteristics of machine mobility(3)

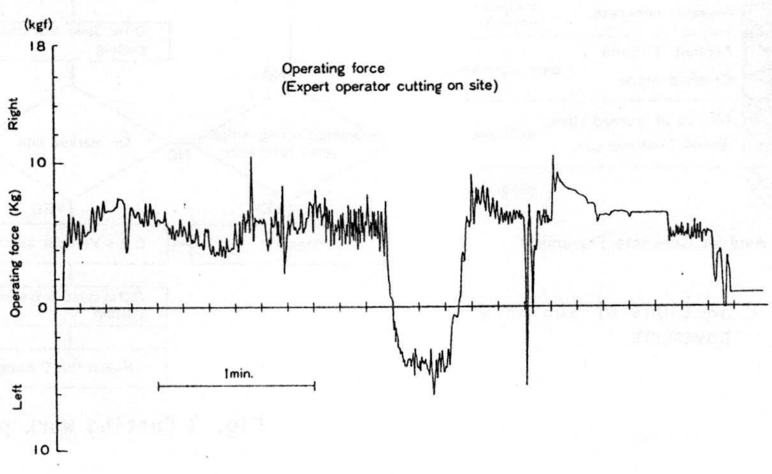


Fig. 7 Operating force of a conventional cutting machine

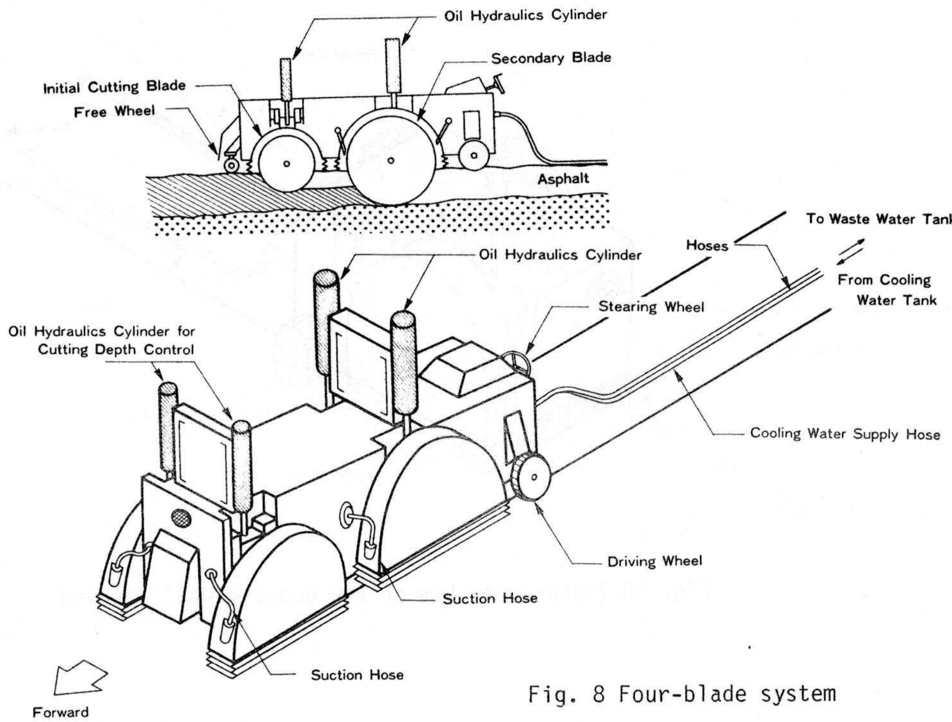


Fig. 8 Four-blade system

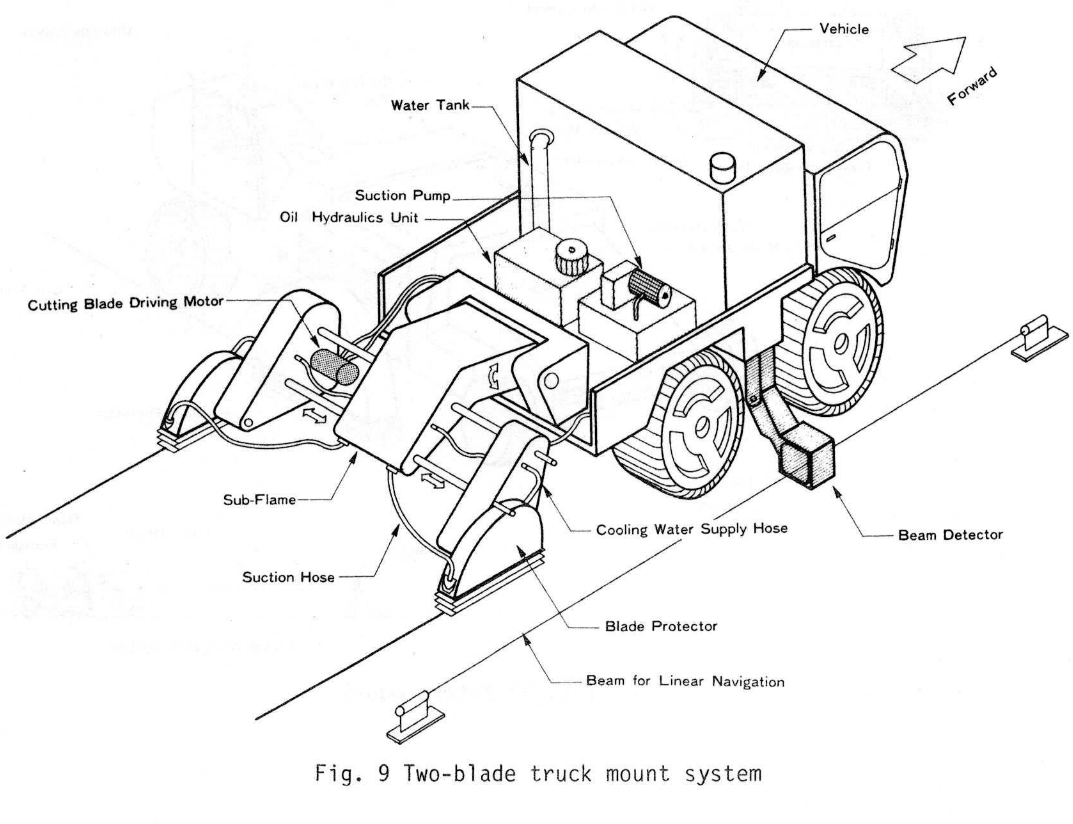


Fig. 9 Two-blade truck mount system

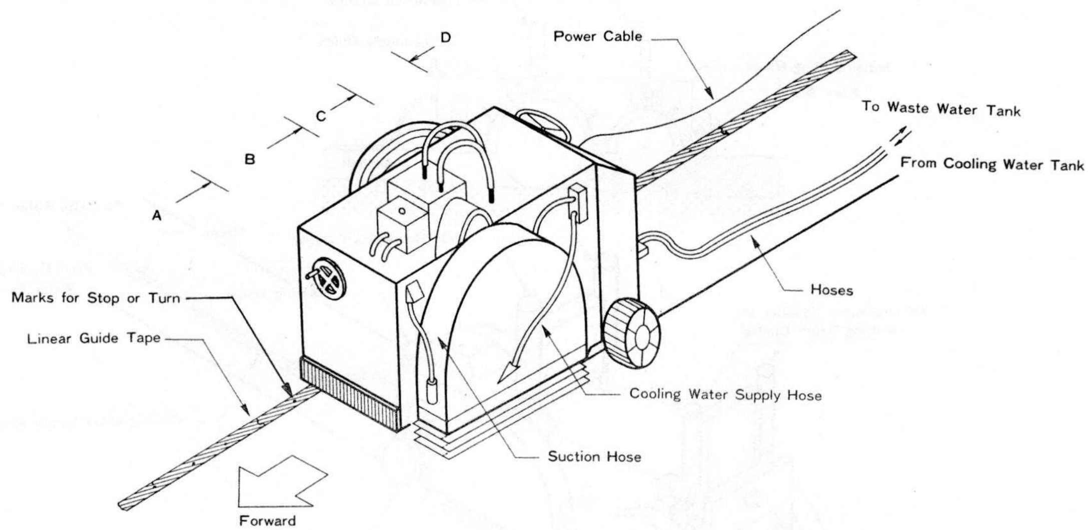


Fig. 10 Improved system of the conventional machine

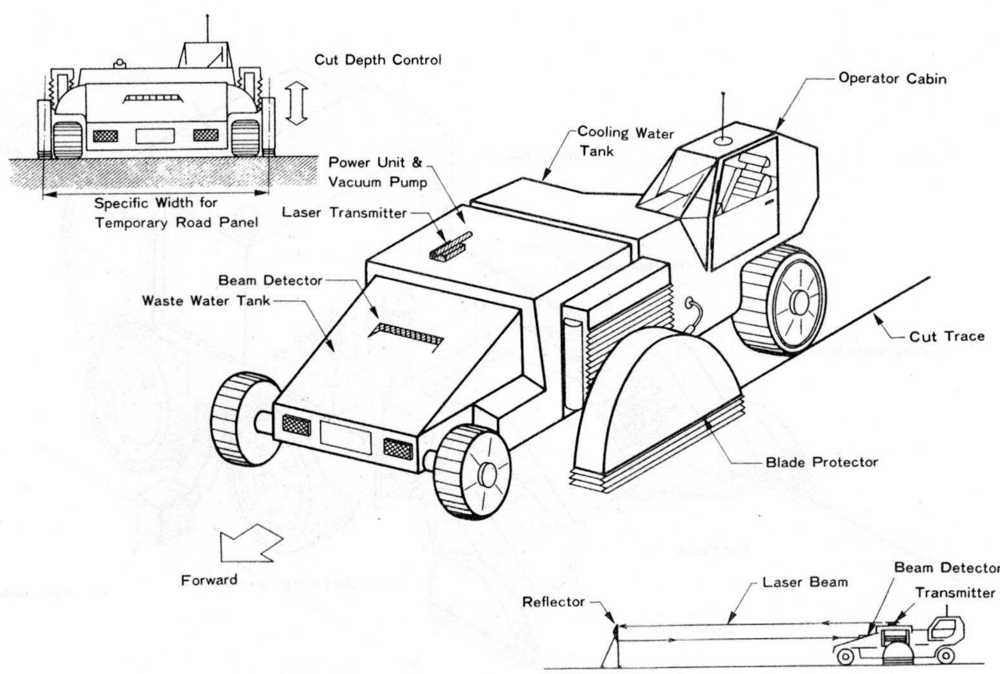


Fig. 11 Future model