THE DEVELOPMENT OF A CONCRETE-CHIPPING ROBOT FOR REPAIRING TUNNELS

T.Kobayashi,[1] J.Yahagi,[2] T.Yamaura,[3] Y.Matsushita[4]

1) Tokyo Electric Power Company, 1-1-3 Uchisaiwai-cho Chiyoda-ku,Tokyo 100, Japan

2) Kandenko Co.,Ltd., 4-8-33 Shibaura Minato-ku, Tokyo 108, Japan

3) Todensekkei Co.,Ltd., 2-1-1 Uchisaiwai-cho, Chiyoda-ku,Tokyo 100, Japan

4) Kumagai Gumi Co.,Ltd.,2-1 Tsukudo-cho, Shinjuku-ku,Tokyo 162, Japan

ABSTRACT

The purpose of this development is to create a repairing robot which is able to perform chipping the deteriorated lining concrete in the wall of the power cable tunnel, exposing and derusting the reinforcement simultaneously.

As a chipping method, a super high pressure water jet method as actually used in the civil engineering and construction fields is employed for this project, and our study places stress on the application of its technology to the concrete repairing as well as the introduction of its system to the tunnel-reconstruction.

This report describes an overview of development and a chipping robot system the performance of which was corroborated through an on-site demonstration test.

1. INTRODUCTION

In general, reinforced concrete, if salt-injured, is deteriorated because of rusting and swelling of the inner reinforcement. Repairing is performed in the order of removing deteriorated section of the concrete, derusting the reinforcement, and conducting rust prevention treatment and to fill in with mortar.

In this case, the salt-containing concrete in the vicinity of the reinforcement is completely removed. The rust prevention treatment of the reinforcement is particularly important, but the work of removing the concrete and derusting the reinforcement by the conventional manual methods is very unpleasant work and the efficiency is very poor.

The inner cross-section of power cable tunnels is either circular or rectangular with an internal cross-sectional area ranging from 3 to 20 sq. m, and are made with either precast concrete or cast-in-place concrete.

In the narrow tunnel which accommodates the cables, in order to secure working space, it is necessary to relocate the cables, and, during repairing, a large amount of work and time is required.

Here, with this kind of problem as the background, with the purposes of research of chipping technology for underground power cable tunnels, and automatization of execution, we conducted the development of a robot which would perform simultaneously the chipping of concrete and the derusting of reinforcement.

2. RESEARCH OF THE CHIPPING METHOD

Concerning the developing of the concrete chipping method based on a super high pressure water jet (discharge pressure: 2000 kgf/sq. cm, discharge flow: 11 ℓ/min), some improvements in chipping performance and work efficiency were performed by adopting a rotary jet created by rotating the nozzle at high speed, pursuing perfection of the nozzle shape from the aspect of broadening the spray width and using not fresh water but a newly developed polymer-containing water which is proved to be effective for rust proofing. The research results and the features of the water jet are described below.

(1) The development of a polymer solution makes it possible to simultaneously perform concrete chipping, derusting of reinforcement and rust prevention treatment, with a chipping performance two times as large as in the case of fresh water. (Figure 1)

(2) In this system, no crack is produced in concrete outside the chipped section.

(3) No vibration no dust is produced.

(4) The flow is small so the chipping reaction force is small, and the robot can be made light-weight.

(5) Because the chipping section on the end of the arm (nozzle), as well as the swivel joint due to the small discharge volume are small sized, chipping work is possible on the back side of power cables already in place which was not possible by conventional methods.

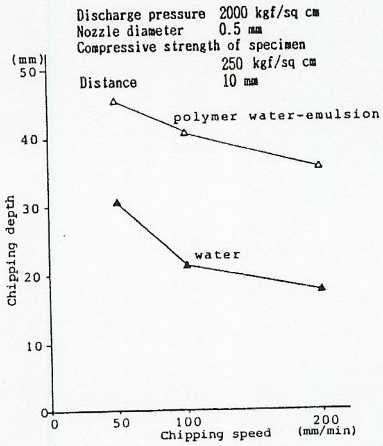


Figure 1 Chipping speed and chipping depth

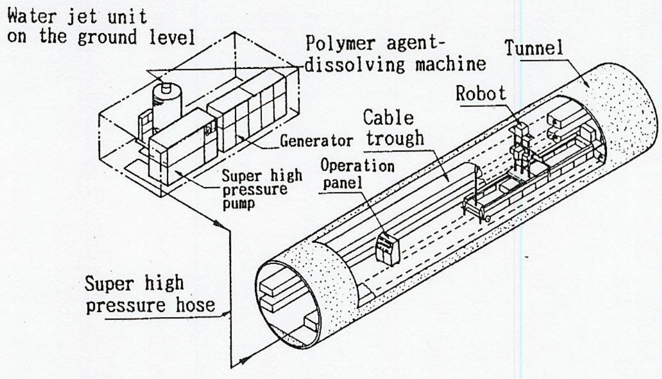


Figure 2 Schematic drawing of the chipping system

3. CHIPPING SYSTEM

As shown in Figure 2, the chipping system has equipment above ground, consisting of a super high pressure water jet pump, a generator, and a polymer dissolver, and in the tunnel the chipping robot, control panel, and drainage equipment are set up. The specifications for the super high pressure water jet pump are shown in Table 1, a full view of the chipping robot in Photograph 1, and its specifications in Table 2.

The drive of each of the axles of the robot, except for nozzle rotation, employs electricity, and the nozzle rotation because of miniaturization, employs an air motor.

4. ROBOT FUNCTIONS

(1) WORK ENVIRONMENT

The robot can chip the entire circumference of the inside wall of a tunnel of 2 m in diameter, and if there are at least 100 mm between the wall and an obstacle, it can avoid the obstacle and chip the wall surface on the back side. The set up condition of the robot in a circular cross section is shown in Figure 3.

(2) WEIGHT AND SIZE

The robot has 7 partitions, assembly and disassembly inside a tunnel are possible. After disassembly, each piece weighs less than 60 kg, can be carried through a 750 mm diameter manhole, and for movement along a tunnel walkway, was made less than 600 mm.

(3) CONSTRUCTION

It has dust prevention and moisture prevention treatments, and was designed to be light weight, using aluminum materials.

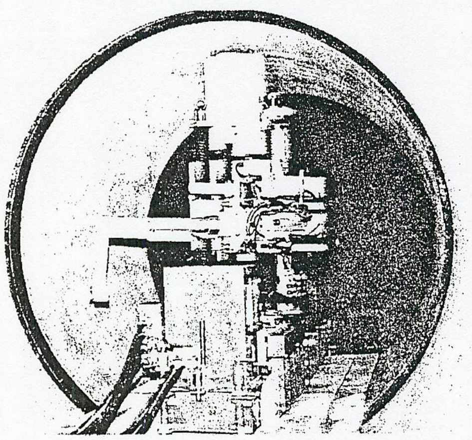


Photo 1

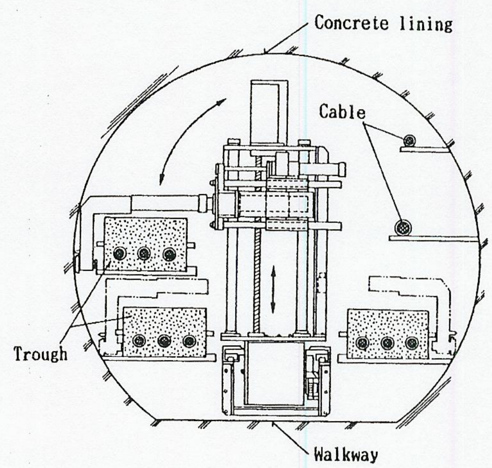


Figure 3 Setting of the robot in the tunnel of round section

Table 1 Specifications of the high pressure water jet pump

Discharge pressure	max. 3000 kgf/sq cm
Discharge flow	max. 14 lit./min (at 2500 kg/sq cm)
Power required	75 kW (400V)
Dimensions	2400 length x 1200 width x 1300 height(mm)
Weight	3200 kg

Table 2 Specifications of the chipping robot

Robot	
Degree of freedom	7 + 1 (nozzle rotation)
Handling weight	20 kg
Positioning accuracy	+/- 5 mm
Admissible environment conditions	temperature 5 to 50 °C humidity 100%
Weight	380 kg (total weight)
Dimensions	overall dimensions: 3100(L) x 500(W) x 1680(H) mm
Power	AC 200V

Axis	Movement range	Speed	Driving method
Cart movement		37m/min	motor w/brake
Robot movement	1500mm	50 - 1000mm/min	AC servomotor
Robot rotation	200°	20° /sec	motor w/brake
Arm ascending/ descending	450mm	400mm/min	motor w/brake
Arm revolution	150°	0.5 - 5° /sec	AC servomotor
Arm rotation	200°	15° /sec	motor w/brake
Arm telescoping	150mm	400mm/min	motor w/brake
Nozzle rotation	360° continuously	200rpm	air motor

Control

Item	Specifications
Power	AC 100V air pressure: 6 kgf/sq cm
Type of computer	sequencer
Programme	ladder type programme
Manual operation	remote control panel, control panel
Dimensions of control panel	width x depth x height: 550 x 500 x 1330 (mm)

(4) HANDLING WEIGHT

It is possible to handle the 20 kg total of the chipping reaction force and the nozzle section weight.

(5) SPEED CONTROL

Speed control of the robot movement as well as arm revolution is implemented through use of an AC servomotor.

(6) COUNTERMEASURES AGAINST MAGNETIC DISTURBANCE

An insulated transformer is used for the electric source, and the signal lines are shielded.

(7) DEGREES OF FREEDOM

As shown in Figure 4, there are a total of 8 degrees of freedom.

(8) OPERATION

Operation can be implemented from the operation panel or the handy type remote control box. The three operation modes, provided as follows, can be selected and implemented; a) automatic chipping which functions by designating the starting and ending points of the chipping, b) semi-automatic operation which performs chipping by selecting a movement axle and inputting the target value and c) manual chipping based on the push button by the operator.

The automatic chipping method employs a teaching method, so by manually moving the robot to the starting position, the starting point data is put into memory. Next the robot is moved to the ending position, and the ending point data is put into memory. When automatic operation is started, the nozzle automatically moves, chipping the extent of the rectangle which has the starting and ending points in memory as opposite corners, computing a path taking into consideration the chipping width. The automatic chipping method is shown in Figure 5.

5. ROBOT CONTROL

The robot is equipped in each axis with position detecting potentiometers, and is controlled through limit switches at the boundaries of movement and through soft limits, software defined movement ranges.

As is shown in Figure 6, the nine processes J1 to J9 are scanned approximately every 100 msec. Among these, through the safety circuit of J6, abnormalities of the robot, if occur, are software-determined, and the start permission and the stop of water jet are controlled referring to the nozzle position and posture of the robot.

Concerning safety measures, in addition to the safety measures recorded above, limit switches, touch switches as sensors in the arm sections are utilized. Along with aiming for hardware based safety which will stop immediately upon contact with an operator or conduit equipment, even if the water jet sprays the power cable directly, protective material is utilized that will be able to prevent penetration for a certain period of time.

Movement range and speed of the axes

Axis	Movement range	Speed
① Cart movement		37m/min
② Robot movement	1500mm	50--1000mm/min
③ Robot rotation	200°	20° /sec
④ Arm ascending/descending	450mm	400mm/min
⑤ Arm revolution	150°	0.5--5° /sec
⑥ Arm rotation	200°	15° /sec
⑦ Arm telescoping	150mm	400mm/min
⑧ Nozzle rotation	360° continuously	200rpm

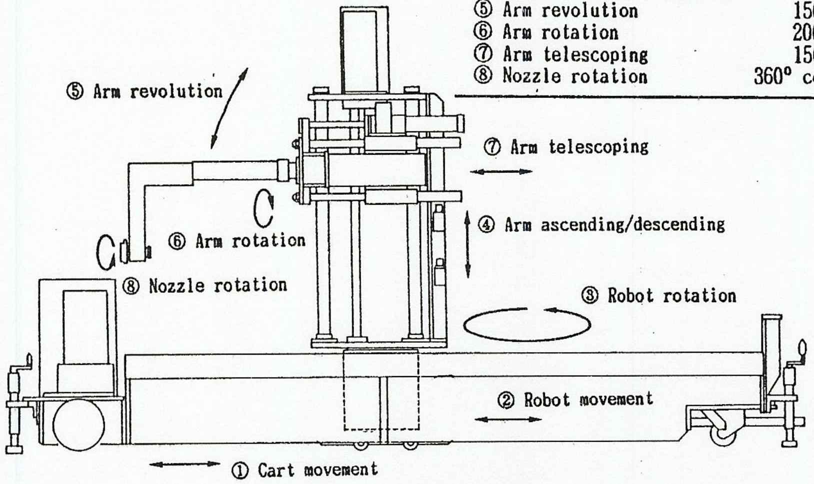
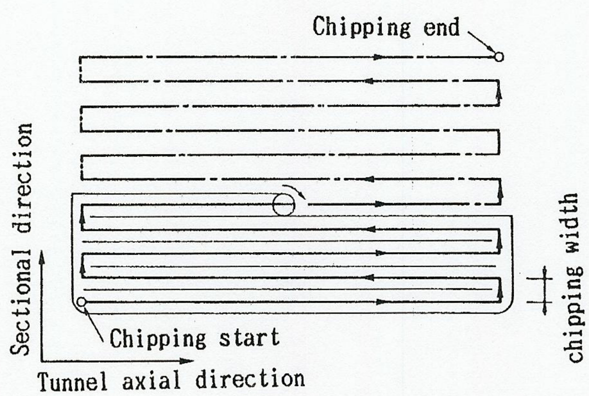


Figure 4 Movement of the axes



Input the chipping width and teach the starting and ending positions.

Figure 5 Automatic chipping method

The safety measures based on the software, hardware, and protective material are shown in Figure 7.

6. ON SITE OPERATIONAL EXPERIMENT

6.1 OPERATION PROCEDURE AT THE TIME OF EXECUTION

The chipping robot is disassembled above ground into 7 pieces, carried in through the shaft (750 mm in diameter), moved and assembled at the site of execution, 4 outriggers are lowered, and the cart section of the robot is affixed.

The body of the robot moves on the cart, under normal conditions chips for 1500 mm in the tunnel axial direction, moves the nozzle only the length of the chipping width in a cross-sectional direction at both ends, and then repeats robot movement.

The work of setting the nozzle is performed manually. So that the distance between the nozzle during chipping and the chipping surface will be 10 to 20 mm, it is adjusted through telescoping of the arm, the robot chips automatically up to the moment it begins avoiding an encountered obstacle. As for the back side of the cables, because the nozzle is attached to the end of the arm bent at right angles, it is possible to insert the arm on the back side and is able to perform chipping.

After completion of the above work of the 1500 mm distance on both the left and right cross sections, the cart outrigger is lifted and moved to the next location.

6.2 RESULTS OF OPERATION

(1) Performance: The work area of salt-injured concrete that can be repaired by the conventional method of chipping by a pick hammer and then derusting of the reinforcement by sandblasting in a day is about 1.0 to 1.5 sq. m per person, but this robot carries out these processes at about ten times this performance rate. (Work capacity: 2 sq. m/h)

(2) Quality: The chipping robot is able to chip the concrete wall surface to an even depth of about 30 - 40 mm while moving along inside the tunnel, and derusting, rust prevention, and exposure of cables are possible.

(3) Safety: Safety performance was able to be attained through monitoring from the ground surface and placement of an overseer during the teaching of the automatic operation and safety measures through robot hardware and software, as well as protective materials.

(4) Pollution: When compared with conventional methods, the working environment is greatly improved since less dust and vibration are produced.

7. CONCLUSION

The social capital items here in Japan, that were expanded through the opportunity of the high level of sustained growth since the mid 1960's, are numerous and from this point on, this indicates the occurrence of the phenomenon of old age deterioration of a large number of concrete structures. In the power cable tunnels located near coastal areas as well, deterioration phenomenon due to chloride has been observed. As a countermeasure, the establishment of a maintenance repair technology of high efficiency and superior operability is in demand, and the chipping robot system was developed as a part in that process.

The results of on site experiments were that even in narrow confined work places, it could effectively and efficiently chip concrete, and furthermore after-treatment and working environment were tremendously improved.

From now on, we plan to conduct research concerning restoration technology after chipping and implement the robotization of a repair system.

BIBLIOGRAPHY

1) Kobayashi, Okano, and others, “Concrete Chipping Robot”, Robot, No. 67,’89.3, Japan Industrial Robot Association.
2) Matsushita and others, “Chipping of an RC Structure by Means of a Polymer Solution Jet”, VOL 6,NO2,’89.9, The Water Jet Technology Society of Japan.
3) Matsushita and others, “Concrete Chipping Robot Using a Water Jet”, The Fifth Water Jet Technological Research Conference,’89.
4) Jibiki, Tsuburaya, and others, “An Effective Chipping Method of Tunnel Surface Concrete Repair Using a Water Jet”,’89.9, International Tunnel Symposium.

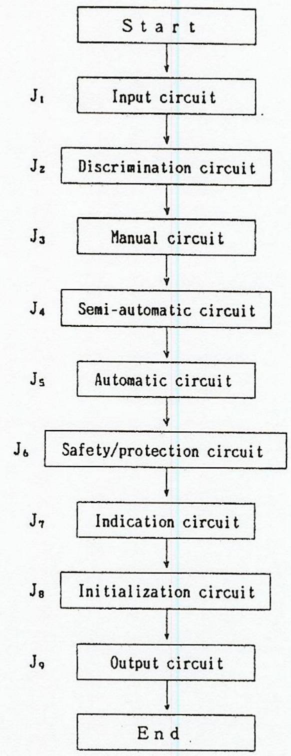


Figure 6 General flow chart

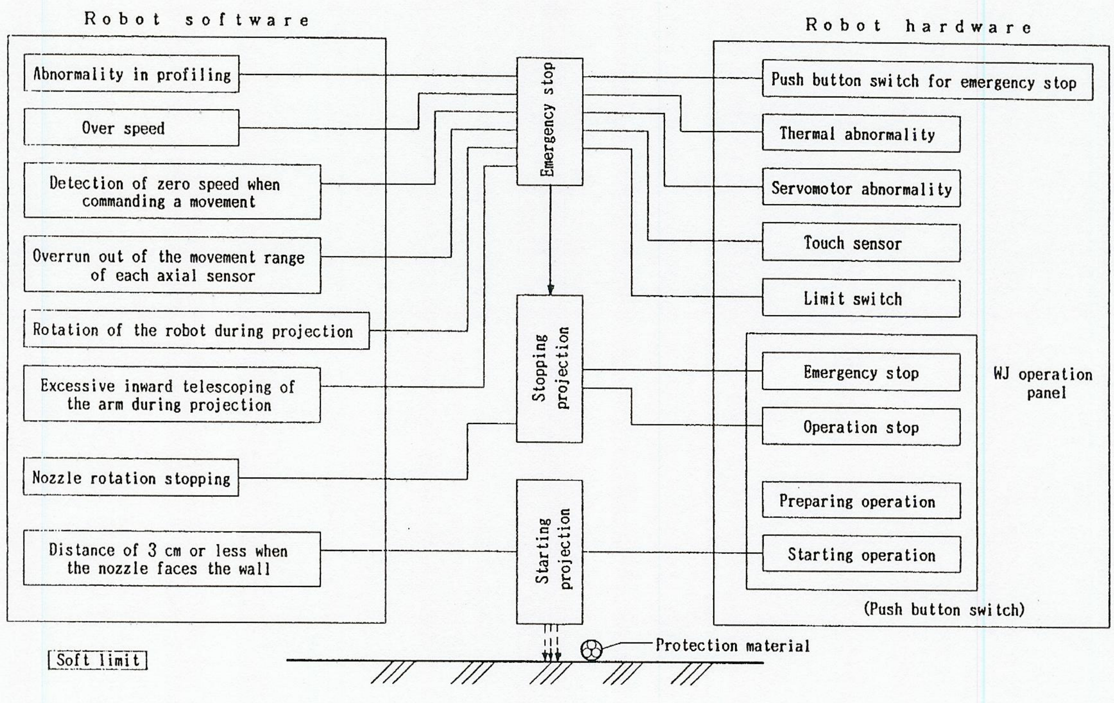


Figure 7 Safety measures