S H I E L D M E T H O D A U T O M A T I O N S Y S T E M

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ABSTRACT

The automation system has been developed based on the purpose of unmanning the operation in shield work through robotization of excavation equipment (shield machine). The system consists of three components : data collection, automatic surveying and stance controlling. The data collecting section gathers and analyzes various data such as on earth pressure, thrust and speed during excavation performed by the shield machine. The automatic surveying section measures the position (X, Y and Z) and stance (pitching, yawing and rolling) of the shield machine. The stance control section decides (according to various data on the shield machine and its position and stance) which jack to use out of those which are designed to drive the machine to trace a pre-designed line. In this way the section controles the direction of movements of the machine.By organizing these sections, the shield machine can excavate and drive forward automatically. The special feature of this system is the employment of a workstation (SUN-4) and an incorporated intelligence - the "EXPERT SYSTEM", to the host computer. The EXPERT SYSTEM determines the changes due to excavation in the natural ground and the behavior of the shield machine. It compiles these data to alter its ergonomics to make accurate judgements. By incorporating the learning functions into the former shield auto-control system, a robotized, highly accurate shield excavation can be performed.

1. Outline of Shield Method

Recently, the demand for utilization of underground space has been increasing in urban regions. One of the methods of creating underground space is the shield method. The current growing difficulties in the construction of underground space have demanded that technology be more advanced. Moreover, the construction industry is confronting social problems such as a decline in the number of skilled workers and increasing number of elderly workers. To cope with these problems, we have been tackling the development of higher level, automated technology.

The shield machine is driven to excavate an adit to create large-diameter passages such as subways, underpasses, etc., or small-diameter routes such as sewerage, water suply lines, electric railways, etc. As shown in Fig.1, the shield machine is equipped with a disc with cutter bits, which rotates to excavate the earth. With the thrust jack pushed out, the excavated material is fed onto the screw conveyer while the machine proper is advancing. On completion of one ring, the machine installs segments in place, and then advances to deepen the adit (Photo 1).

To advance the shield machine, two important techniques are required; one controls the machine so that the ground surface of the road (or whatever surface is being excavated under) does not subside or upheave; and the other controls the attitude of the machine by measuring its location so that it moves along the planned route. A combination of the two techniques enables the smooth advance of the machine.

Conventionally, these operations are performed by skilled operators and manipulators.

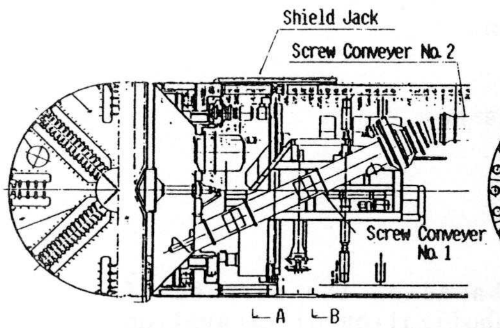

Fig.1 The characteristics of the shield machine

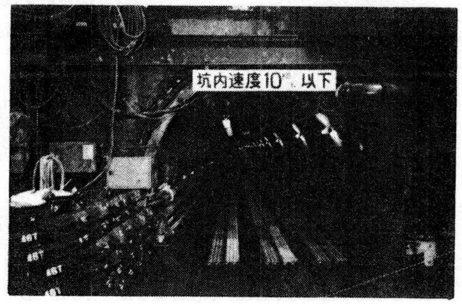

Photo.1 State of primary lining being performed

2. System Outline

This system is designed so that unattended, robotized excavation can be done by automating the combined technique.

The system consists of the excavation control system to ensure the safety of natural ground and the direction control system to return the shield machine to the planned route. With these two systems essentially linked, the intended purpose can be accomplished.

The system's configuration is as shown in Fig2. The machine proper is equipped with various sensors, laser targets, and a local microcomputer system to collect and control the data fed from these instruments; the main computer in the central control room does arithmetical processing and analysis to give commands to the local microcomputer; the host computer has a decision function to select the attitude control jack pattern.

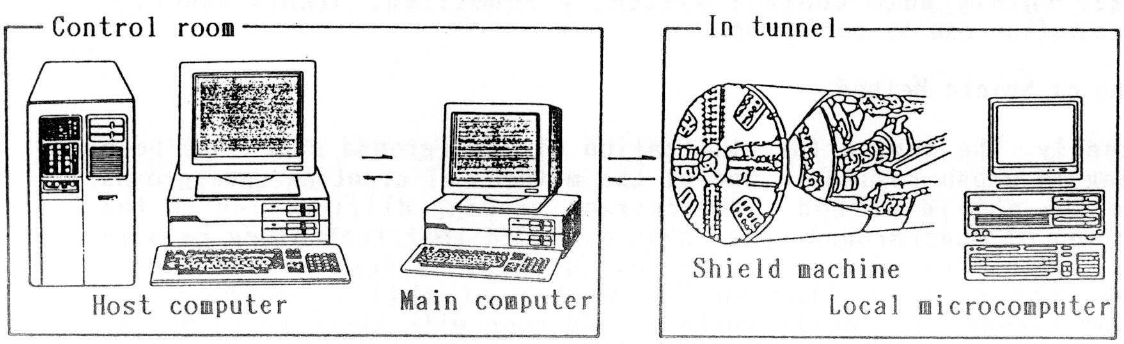

Fig.2 Outline of hardware system

The local microcomputer comprehensively controls the automatic measuring section which performs automatic measurement, the measuring control section which collects data, and the control section which controls excavation.

The main computer in the central control room is linked with the local microcomputer through a multitransmission system, and thereby various data and control commands are communicated bidirectionally. The main computer arithmetically processes the data transmitted from the local microcomputer and displays the results. It then analyzes the data, feeds it back to the microcomputer, and gives the control command to it. Moreover, between the main computer and the host computer, bidirectional communications are performed successively. In this way, these three computers are on-line linked to perform, in concert with each other, data collection and analysis, and, based on the results, feedback control.

3. Excavation Control System

The excavation control system is designed to ensure the safety of natural ground to protect the ground surface from settlement and upheaval, and thereby enable smooth excavation. The system consists of a subsystem that controls the excavation being carried out by the shield machine by measuring various data during excavation, and another subsystem that measures static earth pressures and excavating earth pressures by its earth pressure sensors attached to the cutter face and bulkhead, and thereby controls the earth pressures by combining with other data. Fig.3 outlines the system.

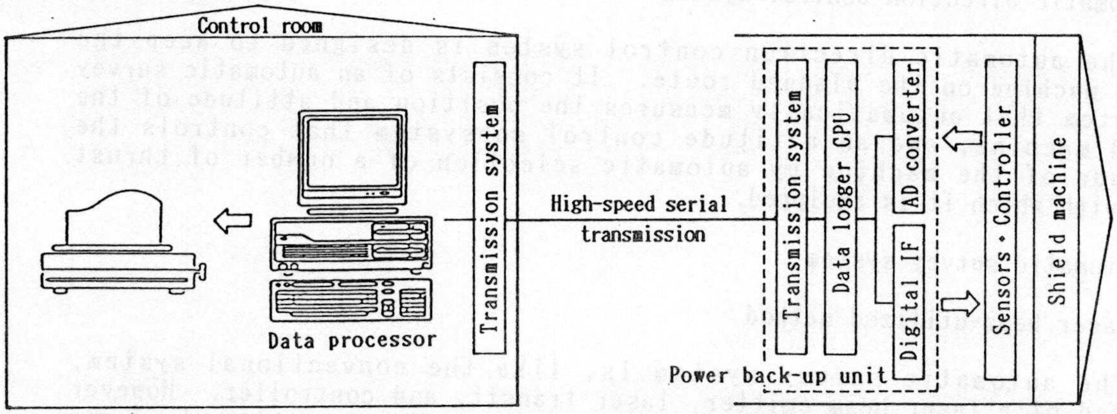

Fig.3 Outline of advance control system

The major data to be measured when excavation is performed by the shield machine include the following:

(a) speed, stroke, thrust, and positions of thrust jacks,

(b) torque and revolutions of excavation cutter,

(c) torque, speed, and gate opening degree of muck removal screw conveyer, and

(d) earth pressures at the front, top and within the bulkhead.

The abovementioned data are outputted as analogue signals from the various sensors mounted on the shield machine proper or from the shield control panel. In order for these data to be arithmetically processed and analyzed to maintain the predetermined facing pressure,jack speeds,screw conveyer speeds and gate opening degree are controlled automatically while the shieled machine is driving forward. Fig.4 shows the flow.

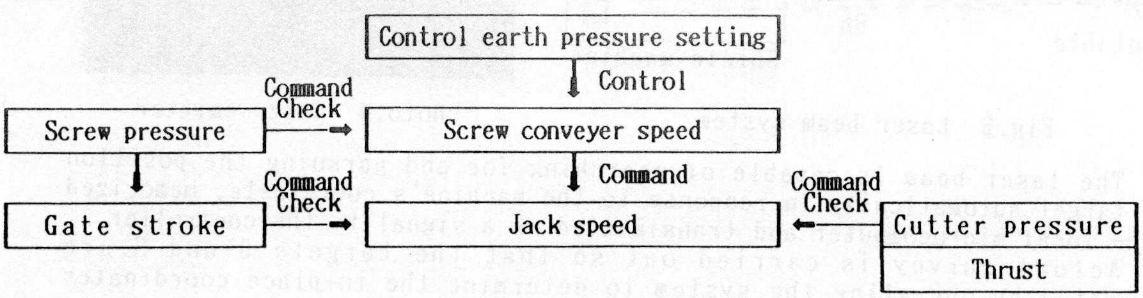

Fig.4 Earth pressure control flow

As mentioned above, these conditions are displayed by the main computer across the communication line. The pictures displayed can be selected from the menu page, and also automatically outputted upon completion of the excavation.

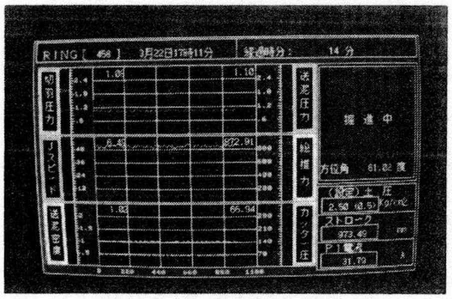

Photo.2 Display 1

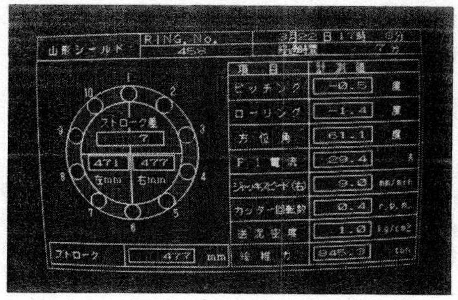

Photo.3 Display 2

4. Automatic Direction Control System

The automatic direction control system is designed to keep the shield machine on the planned route. It consists of an automatic survey subsystem that automatically measures the position and attitude of the shield machine, and an attitude control subsystem that controls the attitude of the machine by automatic selection of a number of thrust jacks with which it is equipped.

4-1 Automatic survey system

(1) Laser beam-utilized method

The automatic survey system is, like the conventional system, composed of a laser beam emitter, laser transit, and controller. However the laser beam emitter is a non-fixed type, capable of shaking the laser beam because the laser beam receiver is restrictively positioned (Fig.5). The laser target consists of phototransistors arranged at 6mm intervals in several rows. The laser digital transit is located in the turntable. A pulse motor capable of turning the table at a minute angle with a 7.2-second resolution is incorporated.

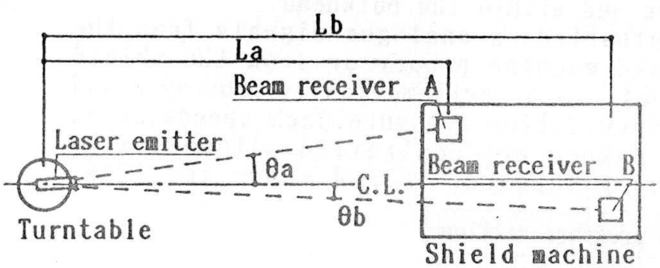

Fig.5 Laser beam system

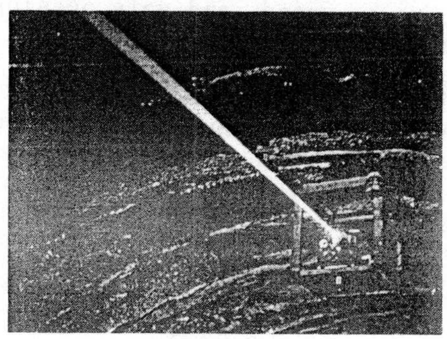

Photo.4 Laser emitter

The laser beam is capable of searching for and pursuing the position of a target automatically in response to the machine's coordinate, memorized by the local microcomputer and transimitted as a signal to the controller.

Actual survey is carried out so that the targets B and S are collimated by operating the system to determine the in-place coordinates

Xa and Xb of the beam section. The pulse motor drive turns the laser beam from left to right to detect the slips of position through which the beam has passed (Ya and Yb) with respect to the zero points to which the beam was turned, and the anglesof turning (θa and θb). The distances (La and Lb) to the targets are fed from the stroke sensors incorporated in other measuring systems through the data line. This method is advantageous, on the one hand,in that it is effective for a linear section and capable of measuring the attitude in the absolute position,but on the other hand, disadvantageous in that, as it uses a beam wave, the excavation of multi-curved sections require the laser emitter to be relocated.

(2) Combination gyrosensor and level gage method

In the case of the shield machine advancing along a planned route with many curves, the use of the combination gyrosensor and level gage is effective . With this combination method, the yawing attitude of the machine can be assessed by the machine's angle of direction obtained from the gyrosensor, and the machine position can be estimated by integrating the machine's angle of direction.

The pitching attitude of the machine can be assessed by inclinometers while its height can be assessed by the two level gages using a communicating tube. However, this method is disadvantageous in that the machine's plan position is the position estimated by integrating the machine's angle of direction, and therefore a cumulative error cannot be avoided in some cases. For this reason, this method needs regular correction at certain intervals, by conventional, manual survey.

To the data obtained thus in Item (1) and/or (2)above, the data from the built-in rolling gage of the machine proper is added,and arithmetically processed together to display the time-dependent relationship between the planned route and the machine's position. It is, at the same time, fed to the subsequent attitude control system as important data.

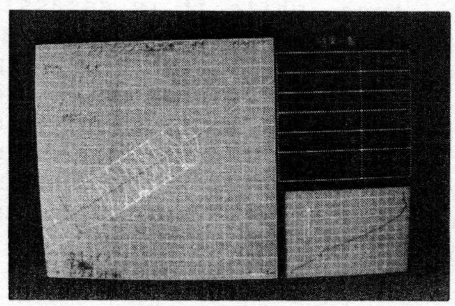

Photo.5 Plan view monitor display

4-2 Attitude control system

The attitude control system is designed to automatically control the shield machine so that it is placed on the planned route pursuant to the survey data obtained by automatic or manual survey The data obtained by survey consist of the machine's positions (X and Y) and attitudes (pitching and yawing).

The slip of these data from the planned route is arithmetically processed by the main computer. If the slip is found to be excess of a certain level, the system drafts a new, corrected, planned route so that the machine is placed on the new route smoothly. The horizontal and vertical angles of direction (curves) are arithmetically processed in order for the machine to be placed on the plannned route or new, corrected, planned route. In order for these angles of direction to be assessed, the turning moments in the horizontal and vertical directions must be developed,therefore it is necessary to induce the required torque with due consideration given to the type and pressure of the earth in front of the machine and its idiosyncrasies.

The required torque can be obtained by developing a turning moment by ON-OFF selecting and controlling a number of jacks with which the machine is equipped.

The selection of jacks is performed by seeking a combination to obtain the nearest torque.

With the abovementioned jack selection pattern determined, a control command is given from the main computer to the local microcomputer. However, if the desired angle of direction cannot be obtained, and is deviating greatly when the machine has been controlled with the determined jack patttern, the jack pattern will be changed and the machine controlled so that a more proximate angle of direction is obtained. Even if the machine begins advancing in the corrected direction, there is no absolute assurance that it will continue on that route to reach the required position. The state of the natural ground in front of the machine, its idiosyncrasies etc. are the main causes of deviation of the position of the machine. Conventionally, this algorithm is performed based on a fixed operating formula, where the slip is considered by an operator, the factor of sensitivity control inputted to the main computer's algorithm, and thereby the control responsive to the change is performed. This cannot be a perfect, automated, unattended, system, so we have endeavored to develop a new decision function that can be substituted by the expert system of the host computer (SUN-4). Fig.6 shows its overall flow. The objective of the new decision function is to provide a function whereby the system itself can alter the fixed operating algorithm. In other words, the system keeps feeding the jack patterns selected by computer and slips of the machine from the true position, etc. into the data base, while it is assessing the changes in the state of natural ground, the machine's idiosyncrasies etc., and by changing its own algorithm attempts to bring the machine smoothly to the nearest, inferred position. Moreover,in linkage with the adbvance control system,data collection and analysis can be performed to build up new intelligence bases, and, by accumulating information from continuing experience in shield excavation work, new rules can be established with these bases. Thus, the data base will be more broadened to help obtain decisions of higher accuracy.

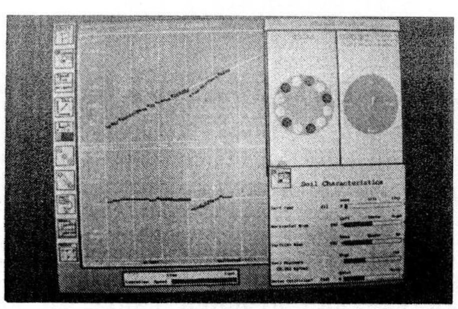

Photo.6 System control monitor

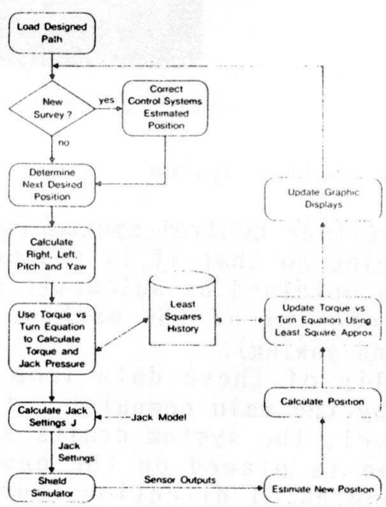

Fig.6 Control system

From the present time onward,the author will strive to perfect this expert system, and thereby provide a network between the Center and construction fields, with the common data base jointly owned. The hope is to effect the excavation of underground space with greater acurracy by the shield machine.