DEVELOPMENT OF SEGMENT AUTOMATIC BUILDING INTELLIGENT SYSTEM (SABIS)

Toshiyuki Matsushita*, Ken-ichi Murano**
Tetsushi Sonoda***, Hitoshi Haino****

ABSTRACT

The shield tunneling method has been developed as a method of constructing tunnels in soft ground. The constructing process is that the shield machine drills the tunnel space, and a ring of segments is built by a few number of workers using nuts and bolts. Recently, tunnel diameters increased, so that the segment pieces are larger and heavier. There are some problems such as 1) Dangerous work, 2) Workers skill 3) Shortage of workers. To cope with these problems, NKK has jointly developed the Segment Automatic Building Intelligent System (SABIS) with HAZAMA-GUMI Ltd. In this paper, we describe three development steps, First we design mechanism by CAD system (CATIA ***** robotics) and simulate its motion, Secondly we made nuts and bolts supply/fastening machine and the mechanism of gripping segments as a verification, Thirdly we made prototype SABIS and try tests to build up a ring of segments, and get a result positioning accuracy is ±0.5 mm.

KEYWORDS

Shield machine, CAD/CAM, ROBOTICS, Servo control, Positioning

1. Introduction

The primary lining in shield tunnelling method is assembled by putting segments made of steel or iron bar concrete together using nuts and bolts. Usually this assembly work is manually carried out by a few number of workers, but there are following problems;

(1) Dangerous work
Workers are exposed to danger since they are forced to work in a limited space or high position handling the segments of heavy materials in a shield machine.

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* Manager, Shield Tunnelling Machine Engineering Sec., Heavy Machinery Dept.
** Engineer, Computer Systems Research Dept., Electronics Research Center. NKK Corporation 1-1, Minamiwatarida-cho, Kawasaki-ku, Kawasaki 210 JAPAN
*** Manager, Engineering and Design Division, Civil Engineering Dept.
**** Assistant Manager, Technical Research Institute
HAZAMA-GUMI Ltd. 2-5-8, Kita-aoyama, Minato-ku, Tokyo 107 JAPAN
*****The trade name of DASSAULT SYSTEMES S.A. in FRANCE

(2) Workers skill
Because the segments are assembled manually, accuracy of assembly and constructing quality depends on the skill of each individual worker. Besides, there is a certain limit for speeding up the construction operations.

(3) Shortage of workers
It is expected that recruiting workers will be rather difficult in the future. Further, advancement of technologies and enlargement of tunnel diameter in shield tunnelling method are also expected.

Under such circumstances, a development of a segment automatic building intelligent system (SABIS) is considered essential for the future shield tunnelling operations. To cope with these problems, NKK has jointly developed with HAZAMA-GUMI, Ltd. the SABIS as a first step toward the unmanned shield tunnelling operations. Under this system shield machine operation and surveillance are expected to be remotely controlled. This system is composed of the following four mechanisms:

(a) Segment transportation/supply mechanism that transports segments automatically from the segment trailer to the segment set position of the erector.
(b) Segment positioning mechanism that automatically controls setting, releasing and positioning of segments.
(c) Nuts and bolts supply/fasten mechanism that automatically supply/fasten the nuts and bolts for segment assembly.
(d) The total control mechanism handling each system as well as the main equipment of the shield machine.

This system follows the standard of Society of Civil Engineering concerning not only the automatic assembly for RC segments but also the wedge-shaped K segments which is becoming more popular in recent years for the higher level of assembly skill. In addition, this system does not require any major modification on segments as the grout holes are used for segment setting.

2. Features of The System

Fig. 1 shows a general drawing of this system. The main features of the system are as follows:

(1) The main body of the erector which requires a high accurate control is attached to the shield machine by sliding pins so that the erector will not be affected by deformation of the shield skin plate caused by external pressure. (Figs. 1 and 5 bellow)

(2) Faster positioning of segments with high accuracy is designed by means of reducing the control factors for segment assembly. It is realized by controlling the erector position which is intended to match revolutionary surface of the erector with the junction surface of the installed segments after carefully measuring the shape and position of the installed segment ring.

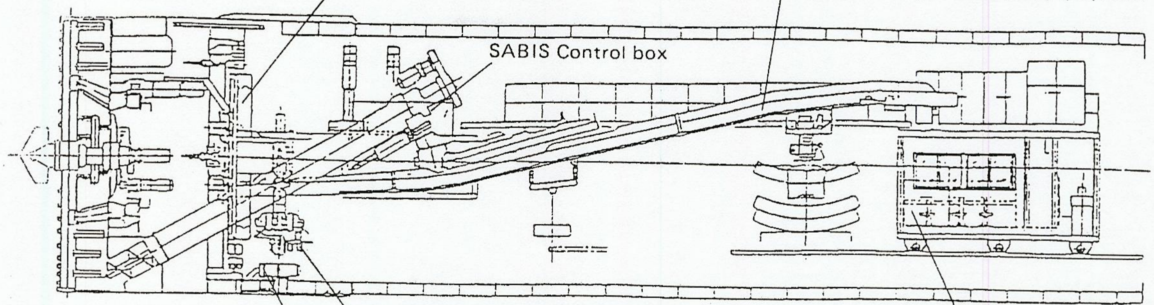

Fig. 1 General drawing of the SABIS

(3) Nuts and bolts for fastening segments required for at least one ring have to be present for automatic supply operations.

(4) A series of work beginning with the receiving of segments from the segment trailer to the designated position can be managed by an operator in the operating room.

3. Control System

3.1 A Flow of Automatic Assembly

A flowchart for automatic assembly is shown in Fig. 2.

(1) In order to determine the position and orientation of segments, it is required that the segments are to be moved in six free direction. For this reason, the target positions xyz and an orientation angle θx (pitching angle), θy (yawing angle) and θz (rolling angle) for the segment assembly which are stored in the memory as a trigger of completion of excavation (start of assembly) have to be input in CPU.

(2) It is not possible to assemble the segments even when the target position mentioned above is determined by a program control (numerical control). The reason for this is that the installed segments are slightly moved from the target position by the external pressure from the surrounding ground or the reaction force from the cutting face side. Therefore, it is required to measure the distance between the erector and the installed segments so that the orientation of the erector and the installed segment can be matched. That distance measured by oil pressure cylinders that include liner encoder, around the erector (minimum 3 point required).

(3) The distance of radius direction within the plane xy from the center of erector ri is measured by a laser type displacement

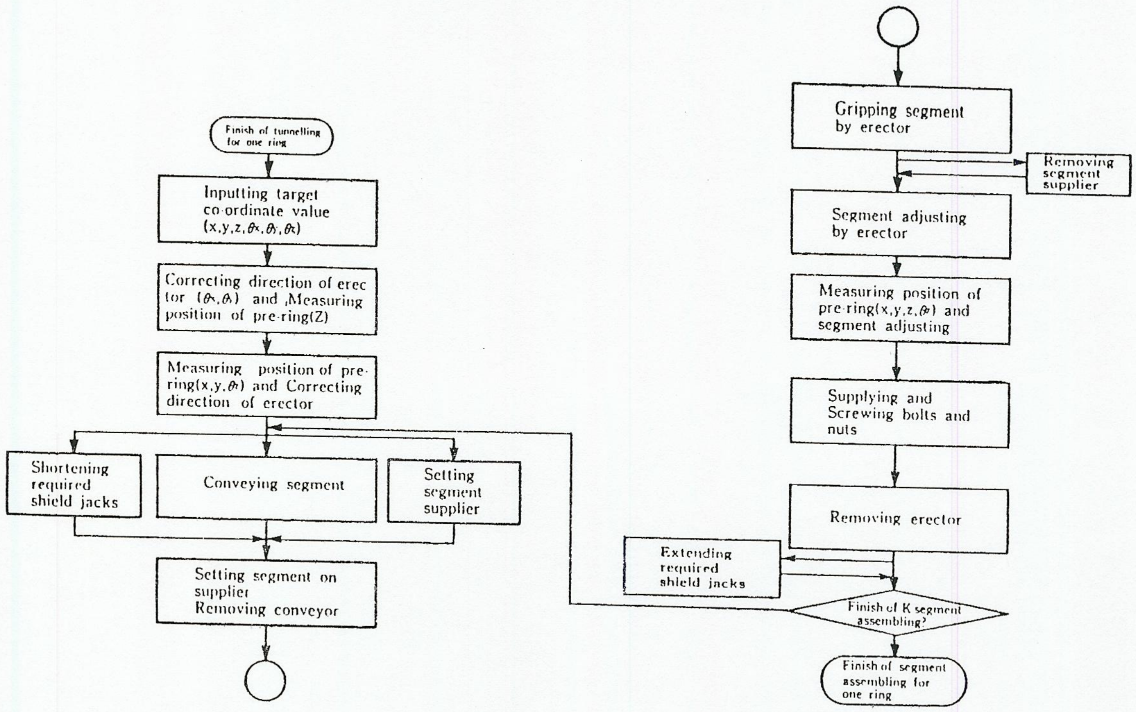

Fig. 2 Flow chart of system control

sensor. In this case, the rotation angle θ_{zi} at the time of measurement is checked simultaneously by a rotary encoder. Then having it rotate once around the Z axis, and measure at the multiple points applying a minimum square method in order to obtain the deviation of position (Δx, Δy) between the center of the erector and the installed segment.

(4) The grout hole are used for segment delivery by the transfer equipment. This applies to the case in the erector also. In setting the grout holes the center of grout hole on segment surface is detected by a laser type displacement sensor using segment bolt box's edge (as shown Fig. 3).

(5) While a segment is being transferred, the shield jack at the segment assembly position is fully contracted and the setting table for segment supply is set at the erector setting position. This table brings the orientation of the supplying segment and the erector together so that detection of the position by a laser and the setting become easier.

(6) As soon as the supplying segment is set on the table, the segment transfer equipment is moved back.

(7) Segment positioning is carried out on the based of a measured value as explained above. However, in order to increase accuracy, it is measured by laser type sensor that the installed segment bolt box's edges as shown in Fig. 4. And the new segment position calculated

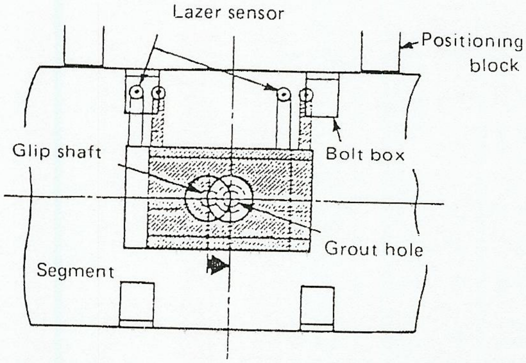

Fig. 3 Positioning of grip

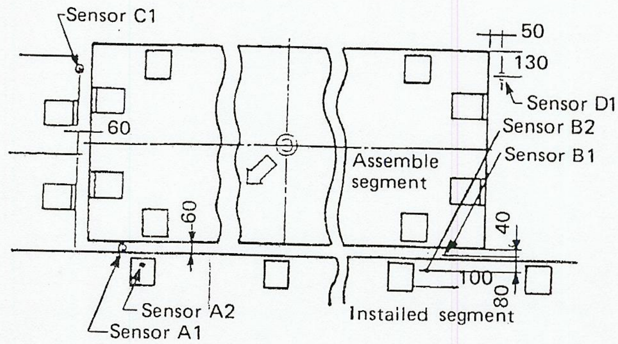

Fig. 4 Measurment of positioning

by applying 4 x 4 matrix method. The erector has 6 degree of freedom (θy, θx, θz, Z, r, θr) as shown in Fig. 5. So we measure an installed segment position from on erector beam as relative coordinate of gripping segment which will be assembled. This means that if erector has been deformed by heavy segment (2500 kg), a correcting position is easier based on relative coordinate than on absolute coordinate.

(8) The nuts and bolts for segment assembly are automatically supplied and the fitting of bolt to its hole is confirmed by the laser fiber sensor.

(9) After the bolts are automatically fastened, the erector is removed and the shield jack positioned at the assembly completion is fully extended.

(10) The above operations are repeated and a ring is completed when K segment is finally assembled.

3.2 System Assembly by CATIA

For developing the SABIS, CATIA which is a three dimensional CAD/CAM system was employed after the completion of basic system design. This system can perform a three dimensional modeling or a system simulation by ROBOTICS module as Fig. 6 shows. By this simulation, checking of structural interference, analysis of static load (strength calculation) and calculation of drive power were conducted and the result was transferred to the basic design.

4. Experiment of Trial Equipments

With regard to the main equipments in this system such as the nuts and bolts supply/fasten equipment and segment griping equipment, functional and movement tests have been completed on the trial equipments. (refer to Photo 1,2)

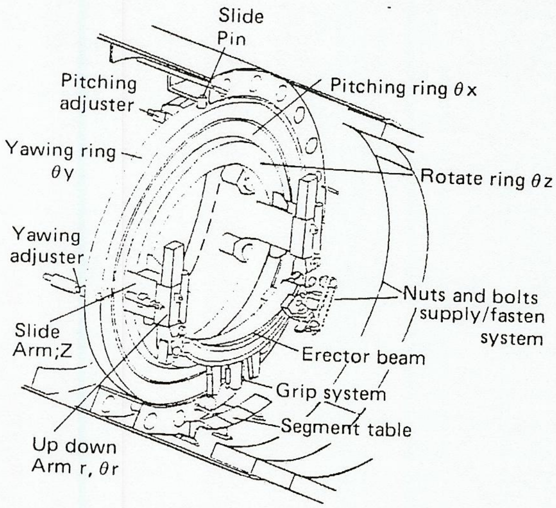

Fig. 5 Construction of erector

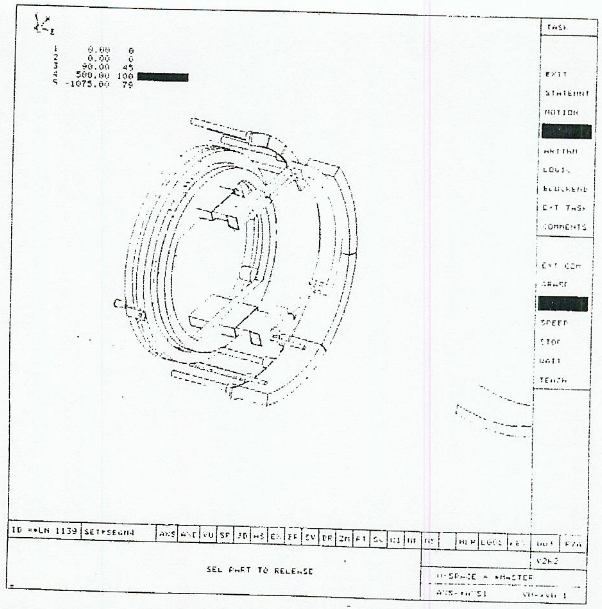

Fig. 6 Example of system simulation by CATIA

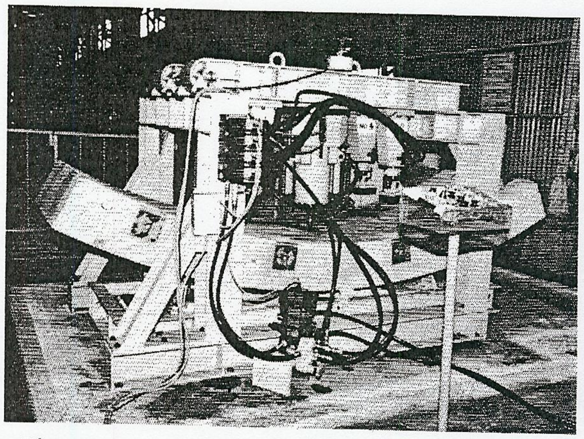

Photo 1 Segment Griping Equipment

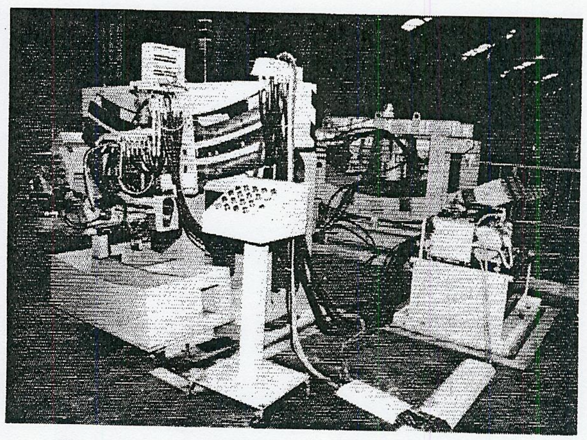

Photo 2 Nuts and Bolts Supply/ Fasten Equipment

5. Experiment of Prototype SABIS

5.1 Out Line of Prototype SABIS

We made prototype SABIS for the shield machine (ø7450 mm). This system test in our factory in order to prepare the control system of SABIS, and to confirm function of this machine, experiment of assembling segment automatically. This control system shown as Fig. 7. It is sharing these functions by three programmable sequencers connected by LAN and personal computer connects to the master sequencer. When it is in manual operations, only sequence programs run, and in automatic operations, personal computer decides an order.

Photo 3 shows a whole view of the SABIS in our factory. The whole system is set up on an experiment stand which is made as a tail part of the shield machine. The segments which shown are the real size ones which are used in construction work. Photo 4 shows a segment which is just remodeled with an accuracy of grout hole of ±0.1 mm and setup projection on surface in order to grip it accurately.

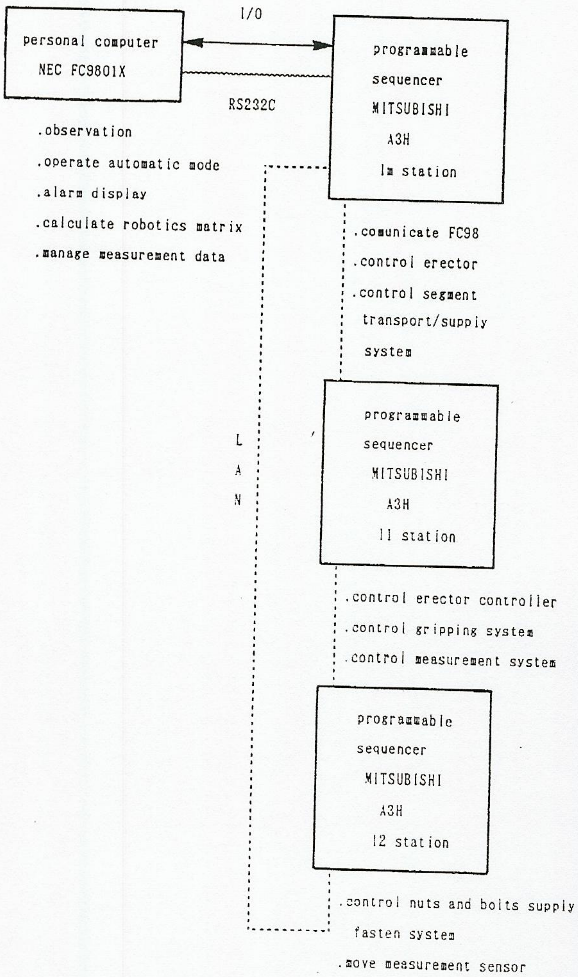

Fig. 7 Control system

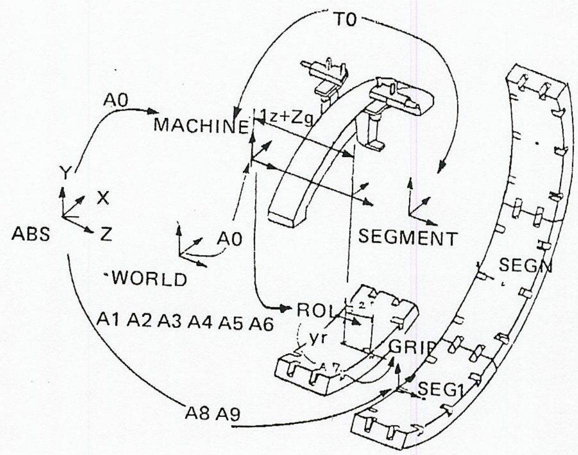

Fig. 8 Coordinate system

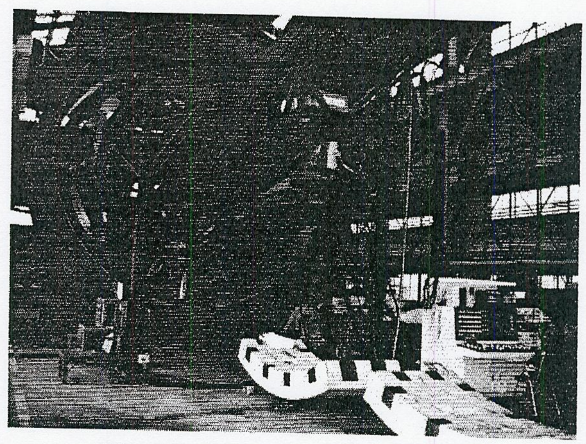

Photo 3 Whole view of Prototype SABIS

5.2 Positioning by 4 x 4 Method

The erector has 6 degree of freedom as shown in Fig. 5, and it is shown by the coordinate axis as Fig. 8. The erector's basic coordinate is MACHINE and its hand which is gripping segment is GRIP. By 4 x 4 method, 6 degree of freedom show the multiplication of 4 x 4 matrix of A1 to A6. First, the system gives first position of segment by the matrix T0. The position and orientation of the erector (θy, θx, θz, Z, R, θr) is determined by Equation 1.

$$A1A2A3A4A5A6 = T0 \tag{1}$$

A1: θy, A2: θx, A3: θz
A4: Z, A5: r, A6: θr

Secondly, the system measures an assembly position of segment at the erector beam (the coordinate GRIP), by calculating the measuring data, adjusting matrix A10 is determined. Adjusting position and orientation get by Equation 2.

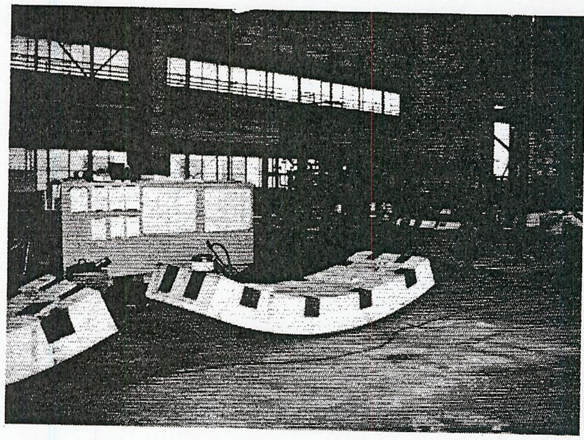

Photo 4 A segment piece

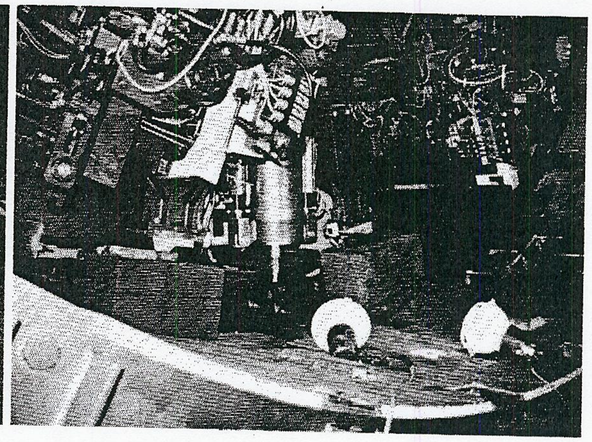

Photo 5 The erector beam

A1'A2'A3'A4'A5'A6 = A1A2A3A4A5A6 A10 (2)

' is adjusting matrix.

5.3 Results of The Experiment

Positioning accuracy is ±0.5 mm on the surface of a ring (diameter is 6650 mm). And assembly speed in automatic mode is minimum 60 minutes per a ring of segments.

6. Conclusion

The basic performance of the SABIS have been confirmed in our factory. This system can locate a segment (2500 kg) any 3D position accurately in case of that the machine is deformated. Because the sensor for positioning locates at the hand of this robot (erector), so that the system operates displacements for modifying the coordinates of the hand. This method has been corroborated by our tests.

Now we have successfully achieved those tests in our factory and it will be used to build the tunnel in Tokyo in May 1990.

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