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Developement of Automatic Bolt Supply and Tightening Robot for Automatic Segment Assembly System

Katsumi NAKASHIMA Nobuhiro KONDOU
KAWASAKI Heavy Industries, LTD.
1-1 Kawasaki-cho Akashi-shi 673 JAPAN

Toshi NOMOTO Yoshitaka KUWABARA
NISHIMATSU Construction Co., LTD.

Abstract

We have developed an automatic bolt supply and tightening robot for an automatic segment assembly system that can support work in small-diameter tunnels. The segments are hex-head types, and the prototype handles segments with an inside diameter of 4.8 meters. The automatic bolt supply and tightening robot is separate from the erector used for positioning of the segment, which makes possible a compact segment gripper suitable for small-diameter tunnels. The bolt tightening robot consists of bolt tighteners that tighten bolts using AC servo motors, and a positioner that uses hydraulic servos. All bolts for the segment can be supplied automatically with high precision, and tightening torques is controllable. The bolt supply robot employs an pneumatic actuator. Bolts are equipped with the bolt cartridges in sets made up of all the bolts required by an entire ring, and a set is automatically supplied to the tightening robot for each segment. Bolt supply is performed in parallel with segment supply, which contributes to overall work efficiency.

1 INTRODUCTION

A shortage of skilled workers and an increase in the diameter and depth of tunnels have made it necessary to automate the assembly of segments. Until now, a number of different types of automatic segment assembly system have been developed, including hex-head bolt, both-nut bolt, medium-diameter, and large-diameter assembly systems. [1] [2][3][4][5][6] From the viewpoint of whether such systems provide automation of all processes or whether they can support both small-diameter and large-diameter tunnels, it soon becomes evident that they all leave something to be desired. Namely, problems with such assembly systems are the need for manual supply of bolts to the bolt tighteners, the large size of such systems making them unsuitable for small-diameter tunnels, or poor work efficiency.

Accordingly, we decided to develop a new automatic segment assembly system that supports all diameters from large to small, while being highly automated and efficient. This paper provides a general description of this new system, concentrating on its special automatic bolt supply and automatic bolt tightening robot.

2 SEPARATE TYPE ERECTOR

The greatest problem when trying to reduce the size of the automatic segment assembly system is size reduction in around the segment gripper. With conventional automatic segment assembly systems, there are a number of mechanisms installed around the segment gripper, including the segment orientation adjuster, thee automatic bolt tightener, and the automatic bolt feeder. A separate type erector was developed in order to overcome this problem. Instead of installing the bolt tightener onto the segment gripper of the erector, it positions the erector separately in the system.

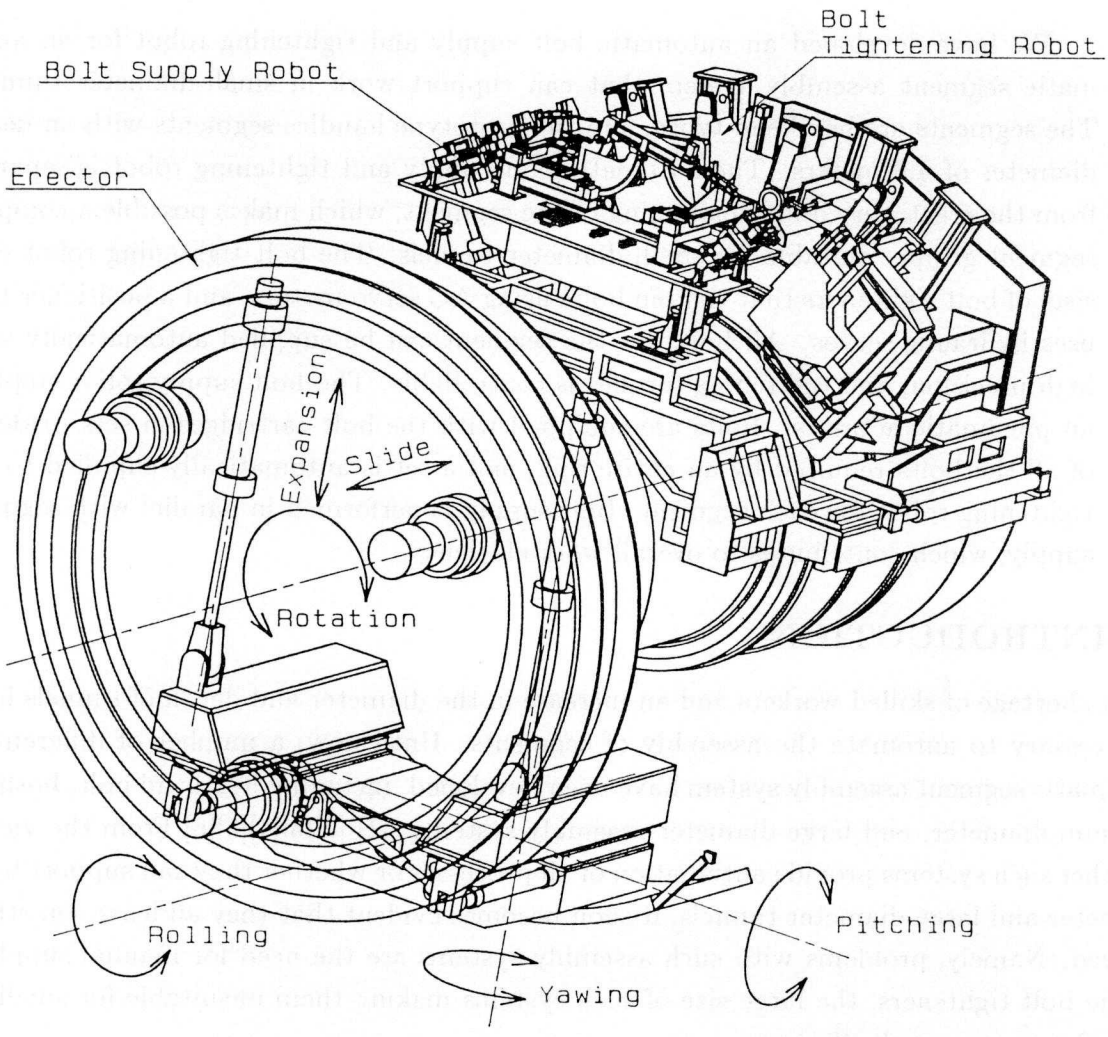

Fig.1 Automatic Segment Assembly System

The automatic segment assembly system is shown in Figure 1. The erector positions the segment in a 3-dimensional space, so six degrees of freedom are provided. Rotate, expand, and slide are provided for positioning, while roll, pitch, and yaw are provided for orientation. Hydraulic motors are used for rotation, while hydraulic cylinders are used for the other movement.

3 AUTOMATIC BOLT TIGHTENING ROBOT

Bolt tighteners, which are separated from the automatic erector, have a positioner. The bolt tighteners and positioner combination are referred to as the bolt tightening robot, which is shown in Figure 2.

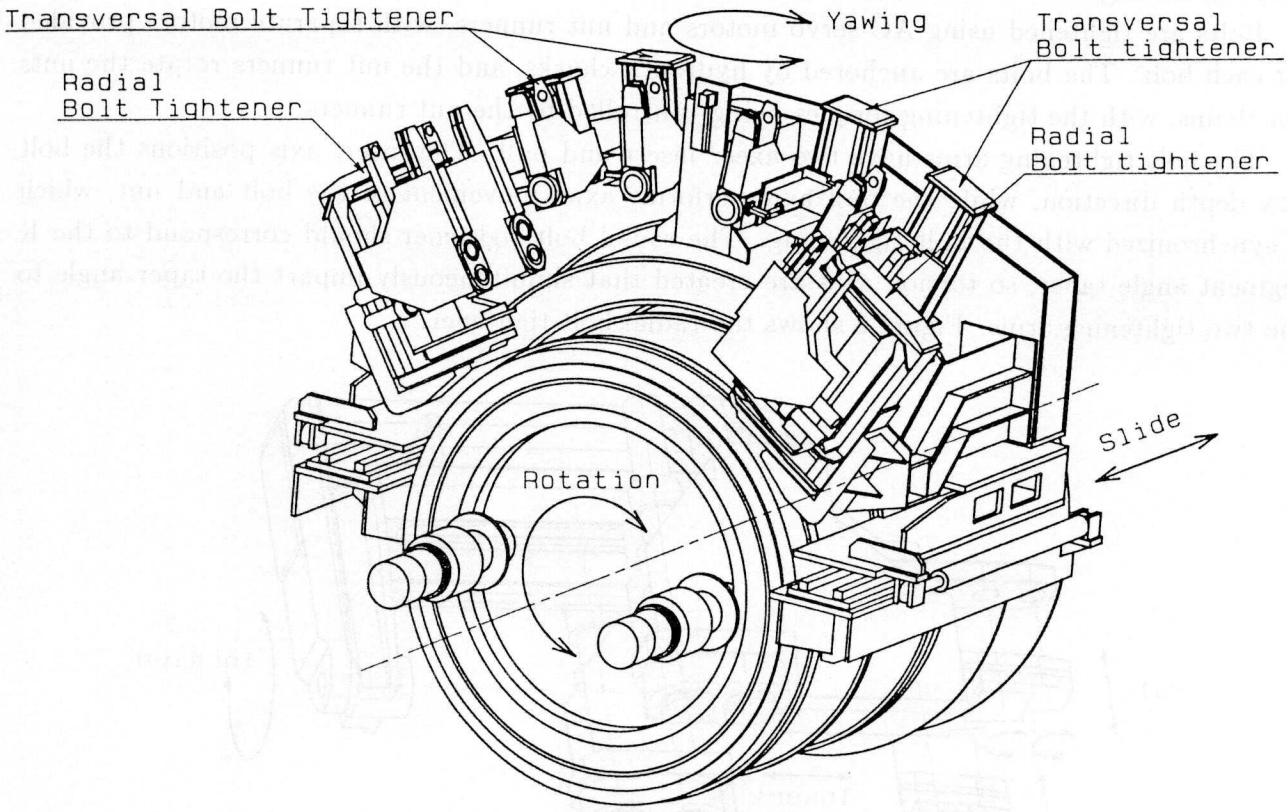

Fig.2 Automatic Bolt Tightening Robot

3.1 Positioner

The positioner possesses three degrees of freedom, which are rotate, slide, and yaw, and it positions eight tightening arms simultaneously. Each tightening arm has two degrees of freedom: insert and pull, and a combination of five degrees of freedom are used to position bolts and nuts in segment holes.

Though the automatic erector has six degrees of freedom, the positioner of the tightening robot has only three. Misalignment in the other three degrees of freedom are corrected as follows. Expansion misalignment can be corrected by adjustment with the insert axis of each tightening arm. Roll and pitch misalignment is manifested axially and in an orthogonal plane relative to

the bolt. In the case of axial misalignment, there is no problem with allowing an axial margin. Planar misalignments involve the bolt and hole, and the hole will no enter. Adjustment can be accomplished, however, by using a combination of slide and rotate, as well as the insert of each tightening arm.

3.2 Tightening Arms

The tightening arms consist of four transversal bolting arms that tighten the bolts securing the segment in the tunnel transverse direction, and four radial bolting arms that tighten the bolts securing the segment in the tunnel radial direction.

Bolts are tightened using AC servo motors and nut runners, with separate motors provided for each bolt. The bolts are anchored by hydraulic chucks, and the nut runners rotate the nuts via chains, with the tightening torques being controlled by the nut runners.

The bolt tightening arms have two axes: insert and pull. The insert axis positions the bolt box depth direction, while the pull axis performs axial movement of the bolt and nut, which is synchronized with the bolt tightening. The radial bolt tightener should correspond to the K segment angle taper, so torsion axes are created that simultaneously impart the taper angle to the two tightening arms. Figure 3 shows the radial bolt tightener.

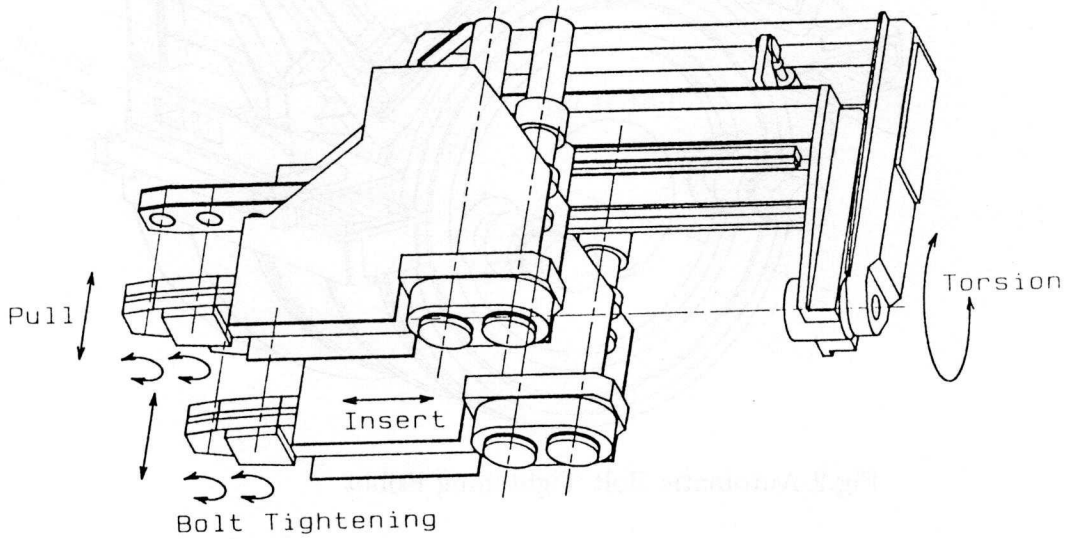

Fig.3 Radial Bolt Tightener

4 AUTOMATIC BOLT SUPPLY ROBOT

Conventionally, automatic bolt supply to the automatic bolt tightener is accomplished by locating a supply machine near the bolt tightener. This configuration, however, results in an increase in the size of the machinery around the bolt tightener, and so it cannot be easily adapted to small-diameter tunnels. The system being introduced here takes advantage of a separate erector and bolt tightening robot, so that while the erector receives the segment, the bolt tightening robot receives its supply of bolts at a different location.

Since the erector receives the supplied segment when the segment gripper is in the bottom position, the bolt tightening robot stops when the supplier is at the top position, and so it is able to receive the bolts being supplied. The number of tightening heads provided matches the number of bolts required to secure one segment, are all supplied at the same time the segment is supplied. Because of this, the automatic bolt supply robot is installed on the opposite side from the erector's segment gripper.

The role of the automatic bolt supply robot is to quickly and correctly supply bolts to the 8 tightening arms or 12 nut runners of the automatic bolt tightening robot. To accomplish this, one robot arm is provided for every two tightening arms, and a single robot performs two consecutive supply operations. Each of the four radial bolt tightening arms has two nut runners, so it can receive two bolts simultaneously. In a hex-head bolt system the bolts and nuts have to be supplied separately to the tightener, but in this system the bolts and nuts are supplied in pair and the tightener separates them.

The automatic bolt supply robot we developed is shown in Figure 4. All of the actuators are pneumatically driven.

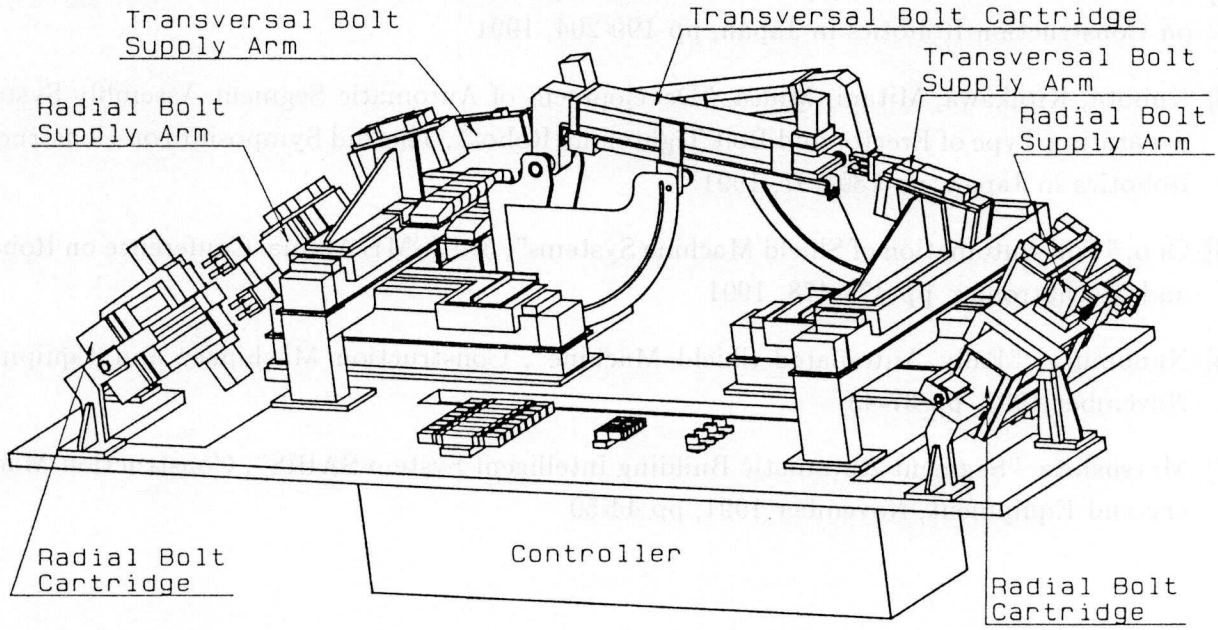

Fig.4 Automatic Bolt Supply Robot

5 CONTROL SYSTEM

Control of the system is performed using a sequencer. One sequencer controls the erector and bolt tightening robot, while another sequencer controls the bolt supply robot. Automatic operation is achieved through data interchanges between the two sequencers.

Segment positioning is performed using a laser-type distanse sensor, while tightening robot positioning is achieved photoelectric bolt hole sensor. Since the supply position is always fixed, positioning between the bolt tightening robot and the bolt supply robot is performed using an

internal sensor.

6 CONCLUSION

We have developed an automatic bolt supply and bolt tightening robot to enable that an automatic segment assembly system can be used in small-diameter tunnels. A separate-type erector is employed to provide both reduced size and more efficient operations. The automatic segment assembly system supports everything from a 5m diameter earth pressure balance shield up to more than 15m shields. It is our hope that this robot will be used in a wide range of shield tunneling operations.

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