

Automatization in Expansion of Slurry Feed and
Outflow pipes in Shield Tunnelling Construction

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ABSTRACT

With the increase of underground developments in the cities, shield method became important and widely used as one of the tunnelling methods. However, the labour shortage problem of the construction industry lead its introduction of high technologies of unmanned construction work. The recent developments in the shield technologies have advanced the automatization of the construction method and their satisfactory effects upon productivity and safety have been confirmed. For the overall unmanned shield work, it is very important that each incidental works to the main shield excavation are also automatized along the developments in the excavation method. This paper describes the fully automatized equipment for the expansion of the slurry feed and outflow pipes which is one of the most important incidental works for the slurry type shield machine.

1. INTRODUCTION

In line with the steady advances being made in the automation and robotization of shielding work, the automation of directional control in shielding machines, as well as slurry control, segment storage, warehousing/delivery control, transfer and assembly has already entered the implementation stage at job sites. The result will be substantial reductions in labor requirements and higher safety at job sites, providing a possible means by which the construction industry may address the increasingly severe labor shortage which it faces.

In addition to the two major tasks of drilling and segment assembly, slurry shielding work retains other important tasks, including the post-drilling laying of temporary materials and equipment - such as piping, sleepers and rails. Though these tasks are indispensable, their rate of automation has been relatively slow. Especially important task for the smooth promotion of slurry shielding work is the laying of slurry pipes, which may be compared to the formation of arteries and veins that accompany the growth of the human body.

2. OUTLINE OF A SLURRY PIPE LAYING ROBOT

2-1. Features

This system (hereafter called the fully automatic pipe layer) has the following features:

- a. The integration of slurry feed and outflow pipes into a single unit.
- b. The temporary attachment of couplings for slurry feed and outflow pipes onto pipe units to be installed.
- c. Grip type (strab) couplings for easy attachment.
- d. The laying of pipe units between the rails used by carrier behind the shielding machine.

- e. Fully automated mounting and dismounting of pipe units.
 Expected results of the use of the robot:
- The elimination of the need for the direct handling of heavy pipes filled with slurry by workers, thus enhancing working conditions.
 - The reduction of labor requirements by enabling a single operator to perform work conventionally done by two or three workers.
 - Shorter pipe-laying time, and therefore shorter construction periods.

2-2. Configuration

The fully automatic pipe layer is normally positioned at the rear of the vehicles of the shielding machine. Fig. 1 provides an outline of the fully automatic layer.

The fully automatic layer consists of a pair of arm cranes at its center for holding and laying pipes, and gripping and tightening devices on either side of the arms for connecting and disconnecting pipe couplings. The main unit is divided into three sections.

The fully automatic pipe layer stays at the same spot while the shield machine produces an excavation for a standard length of piping.

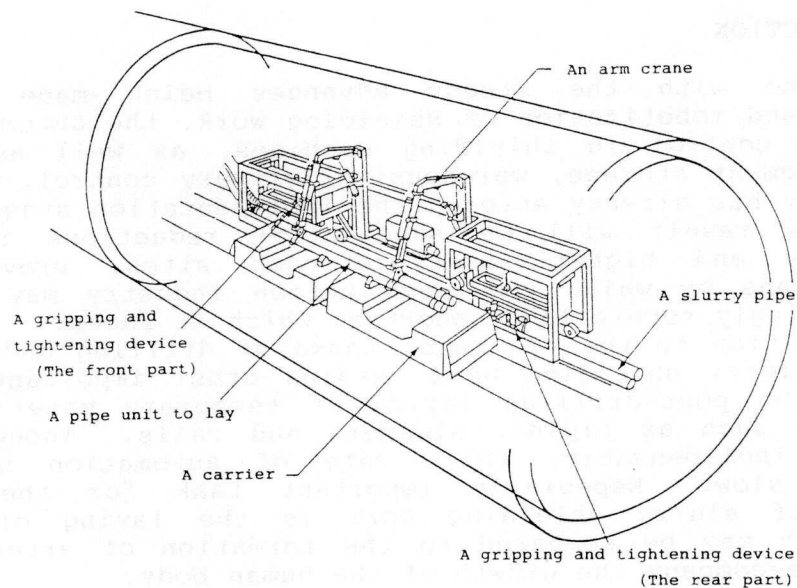


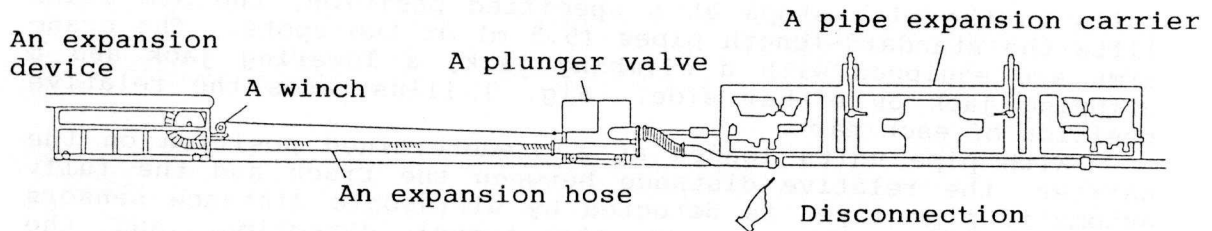
Fig. 1. Outline Figure of Fully Automatic Pipe Layer

2-3. The Slurry Pipe Laying Operation

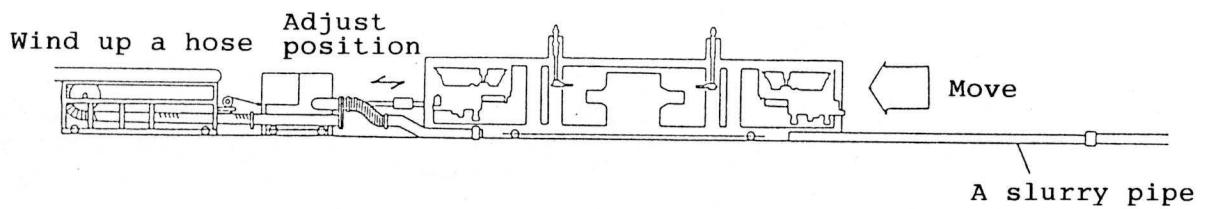
The slurry pipe laying operation shown in Fig. 2 is performed in roughly four processes.

In the drawing, mud-carrying and mud-removing pipe are depicted as a single pipe. In reality, they are two pipes of different diameters integrated into a single unit, both being lifted and jointed simultaneously. The plunger valve in the drawing is a device that prevents slurry in pipes from flowing out into the pit during disconnection of the pipes.

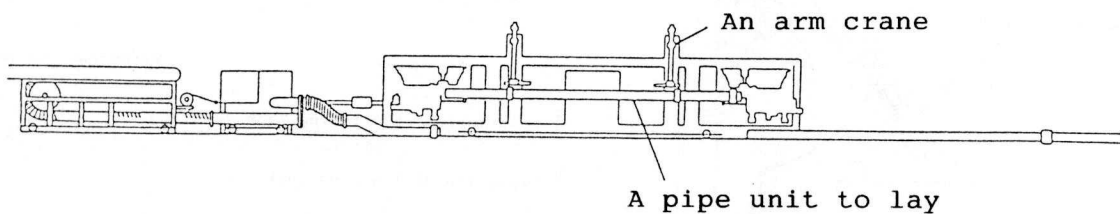
1. After shielding work drilling (after expansion of hose), disconnect a slurry pipe.



2. Concurrently wind up an expansion hose, move a pipe expansion carrier in front.



3. Take a pipe unit into an expansion carrier by a crane.



4. After gripping a pipe unit and adjusting a care, tighten trough sliding a coupling.

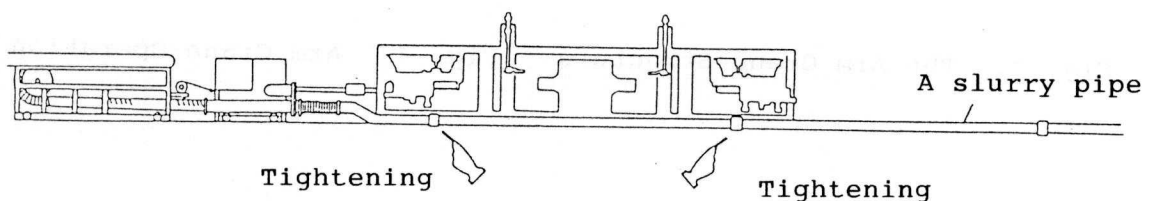


Fig. 2. Tightening Pipes Laying Operation Sequence

2-4. Arm Crane

When a carrier, loaded with piping and running on the main rails in the pit, stops at a specified position, the arm crane lifts the standard-length pipes (5.5 m) at two spots. The crane arms are equipped with a climbing jack, a lowering jack and a gripping jack on either side. Fig. 3 illustrates the relative position of each part.

With pipe units loaded at a predetermined position on the carrier, the relative distance between the truck and the fully automatic pipe layer is detected by ultrasonic distance sensors installed at two spots in the tunnel direction, and the operating radius of the crane arms is automatically adjusted.

As long as the carrier stops at the predetermined position, pipe units can be lifted by the layer, even when the main rails and the carrier vehicle rails are not exactly parallel due to curvature in the shield line. Fig. 4 shows the flow of operation in the lifting of pipe units by the arm cranes.

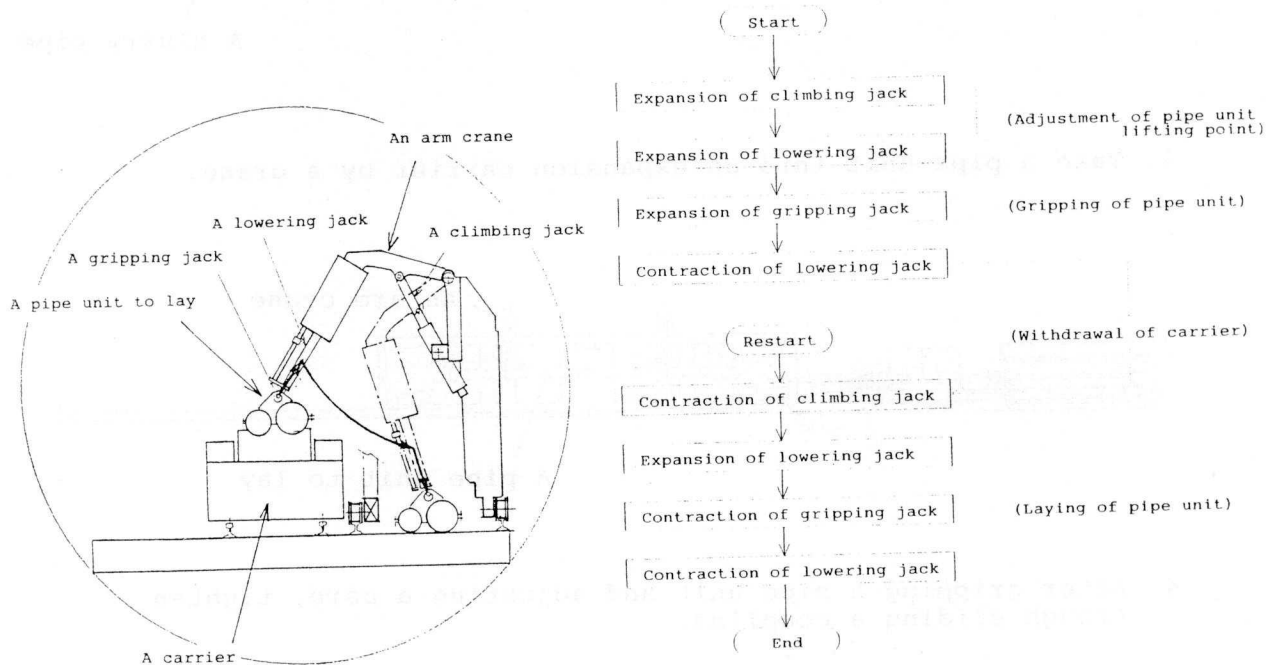


Fig. 3. The Arm Crane Structure

Fig. 4. Arm Crane Operation Flow

2-5. Gripping and Joining Devices

Pipe units picked up and laid by the arm crane are placed on sleepers positioned between pipe units already laid in the rear and shorter pipes fixed onto the fully automatic pipe layer in the front.

(1) Gripping Devices

Pipe units are connected or disconnected by the tightening or loosening of coupling bolts or by the horizontally sliding of couplings. To facilitate these procedures, gripping devices provide the necessary function of aligning and holding the pipes.

The gripping devices are mounted on the fully automatic pipe layer at three spots, two in the rear and one in the front part (as they are unnecessary for fixed piping), and are operated by a hydraulic jack. Fig. 5 shows a structural configuration of a gripping device, while Photo 1 shows a released gripping device.

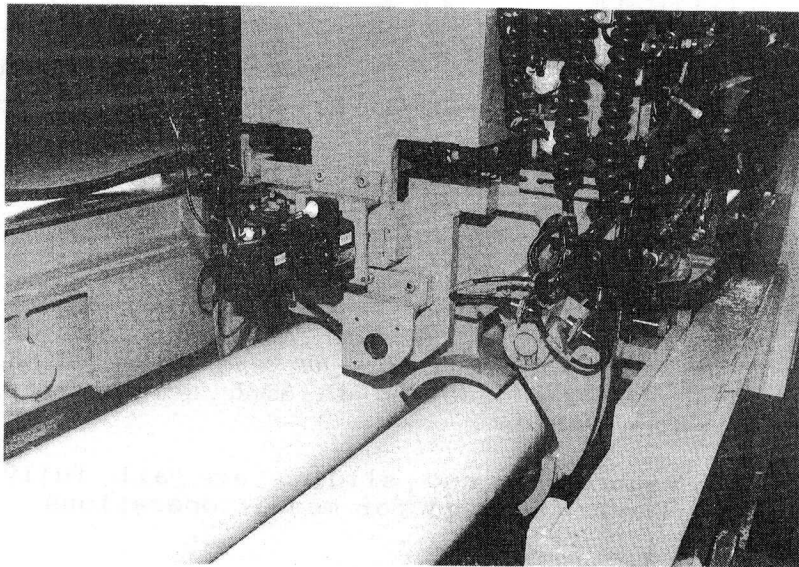


Photo. 1. Gripping Device

(2) Tightening Device

A tightening device are used in the loosening and tightening of coupling bolts. A total of four tightening device units are mounted on the layer, two in the front part and two in the rear. Fig. 6 shows the configuration of a tightening device.

Equipped with a hexagonal columnar spanner at the end, the tightening device is driven by a hydraulic motor through a spring type torque transmission unit, allowing detailed alignment with the bolt center. Fastening torque can be set to any value within the capacity of the layer, and rotation speed is also controllable. A bill-shaped correction device is inserted to prevent rotation of coupling during the fastening of the bolts.

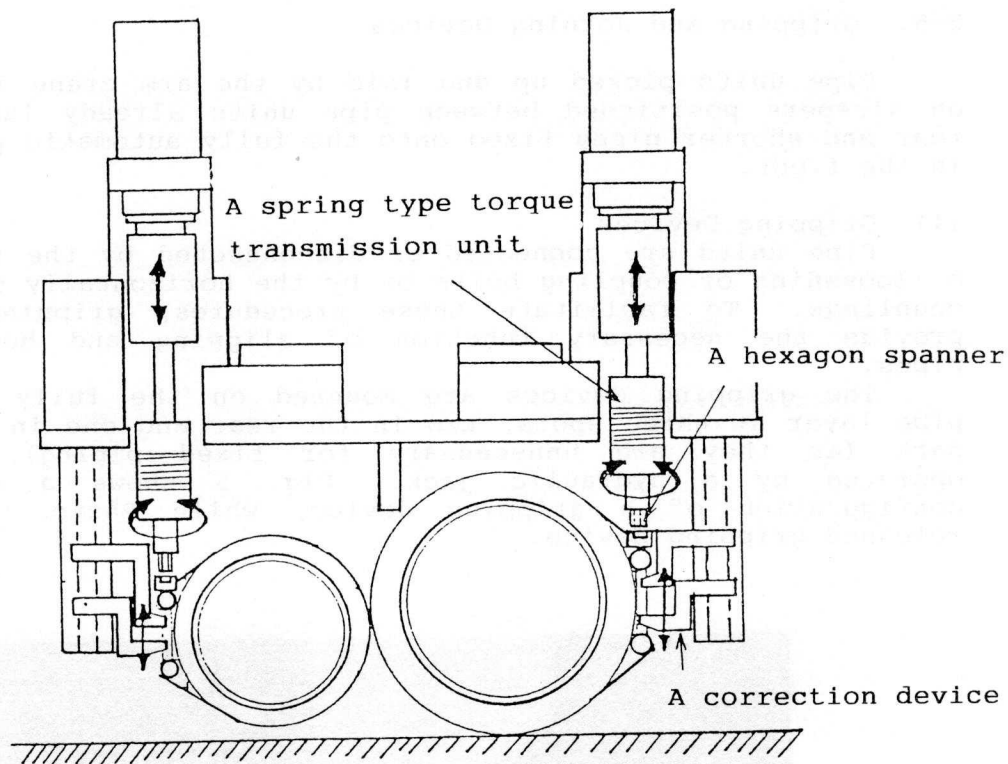


Fig. 6. Outline of Tightening Device

(3) Coupling Sliding Device

The coupling sliding device is used to slide loose couplings along pipes, pressing the end side of a coupling. Sliding is done by the coupling sliding device in conjunction with the tightening device.

Gripping, tightening and sliding are all fully automatic and performed without the need for manual operations.

2-6. Control Method

The fully automatic layer can be controlled through button operations by a single operator. The operator controls the pipe layer while confirmation the status of the operation. In the event of an emergency, the user can press the stop button and resume fully automatic operation thereafter. All movements can also be controlled manually.

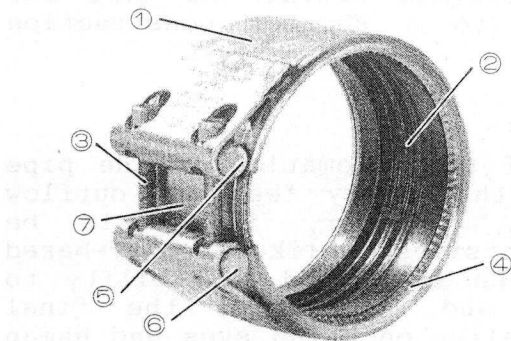
3. PIPE UNITS AND COUPLINGS

Integrated inflowing and outflowing slurry pipes are the main features of this system. Integrated operations are performed in advance outside of the tunnel with couplings temporarily tightened at predetermined positions at one end of a pipe in the specified direction. Grip type strap couplings are used. Fig. 8 provides a picture of the coupling and the name of its components.

Features of the coupling:

- a. No need for special processing of the pipe end.
- b. Large rubber seal width to allow the connection of pipe whose ends do not exactly conform with each other, thus providing a certain allowance in gap range.

The coupling provides a joint that is not affected by variations in slurry pipes caused by curvatures in the shield line, thus facilitating automated executions. The coupling can be practically applied even with a deflection of up to 2 degrees between the pipes to be connected. This represents a curvature radius in the shield line of about 150 meters with a pipe unit length of 5.5 meters. Photo 2 shows the installation of pipe units.



(Appellation of Various Parts)

1. A casing
2. A rubber sleeve
3. A tightening bolt
4. A gripping ring
5. A rod washer
6. A rod nut
7. A sliding plate

Fig. 8. The Gripping Coupling and Parts name of Composition

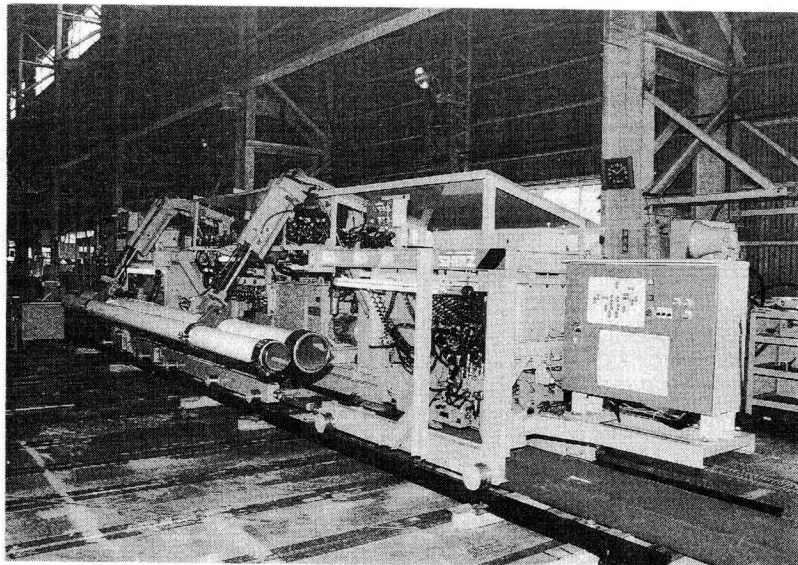


Photo. 2. Appearance after Lifting Pipe Units

4. CYCLE TIME

Theoretical study and experimental data suggest the following cycle time for full automation from the arrival of a carrier to the complete connection of new pipes:

| | |
|---|---------------|
| Delivery and gripping of a pipe | Approx. 1 min |
| Loosening of coupling bolts and sliding | Approx. 2 min |
| Tightening of coupling bolts | Approx. 4 min |
| Total..... | Approx. 7 min |

In addition to the above, the total time for a laying slurry pipe include about 10 minutes for the stopping of slurry circulation, about 1 minute for disengaging units and about 5 minutes for hauling the fully automatic pipe layer. Thus 30 minutes or less could be needed. Considering that this system requires only one operator, the figure suggests that the system will enable pipe laying to be performed during the time for segment assembly, thereby leading to a shorter construction period.

5. CONCLUSION

In this paper, the validity of the automation in the pipe laying operations is examined for the slurry feed and outflow pipes in slurry shielding work. However, it should be remembered that construction work on sites, unlike factory-based manufacturing work, need to have the speed and flexibility to cope with a possible emergency, and, therefore, the final checking of work completion still relies on human eyes and human judgement. Manual labor still plays an important role in the laying of railroad sleepers, rails, and air pipes, and the hanging of power and communications cables. There is a long way to go before the dream of fully unmanned shielding operations is achieved.

However, in view of the steadily growing shortage and ageing of the construction worker population in Japan, it is concluded that the development of this system, which releases workers from a poor working environment by reducing the heavy manual labor, already has considerable value.

Further research and study should be continued in the actual conditions in construction work and the applicability of advanced technology, leading to the creation of a worker-friendly environment on the construction site.

The kind support and assistance of Mitsubishi Heavy Industries, Ltd. in developing this system is highly acknowledged.