AN INTERNAL WELDING ROBOT SYSTEM FOR 600 MM STEEL PIPELINES

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ABSTRACT

To increase safety and reduce costs in maintaining buried pipelines, we have been studying various types of robots capable of inspecting and repairing such pipelines from inside, and we have recently succeeded in developing automatic welding robots to reinforce welds from the inside of a steel pipe with a diameter of 600 mm. It is now within our scope to put it into practical use. This paper presents a general description of three such robots models which we have developed. These robots, designed to travel over more than 100 m in a complex of piping with bends, can do welding to reinforce existing welds. This paper chiefly discusses techniques used in our development to solve the most difficult problems, namely the determination of the most appropriate travelling and welding methods. Through our activities, we have obtained useful findings to further the study of robotic systems for pipeline inspection and repair.

1. Introduction

Osaka Gas Co. has under its control a total of some 46,000 km of pipelines to supply gas. Some of the steel pipes in these pipelines were installed underground before the establishment of the penetration welding method. The purposes of our research were to reinforce welds of such pipes by welding from the inside as they remained buried (Fig. 1), and to increase the reliability of the pipelines further by preventing cracks and breaks such as in the case of unusually great force due to ground deformation. The current methods of replacing buried pipes or welding reinforcement steel bands onto welded joints require trenching and reinstatement, leading to higher operational costs, interruption of traffic and inconvenience to nearby residents. A solution to these problems is the internal welding robot system introduced in this paper, which is capable of repairing pipelines without trenching.

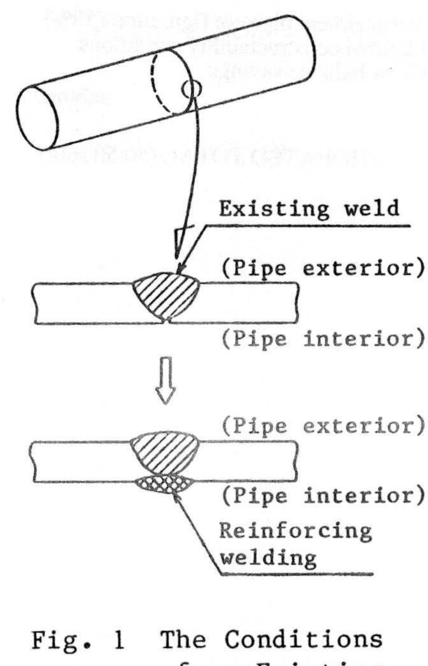

Fig. 1 The Conditions of an Existing Pipe and the Reinforcing-Welding Method

2. General Description of the Development

2.1 Target

Welded steel pipelines under the control of Osaka Gas range from 100 to 600 mm in diameter. These pipelines include radically curved bends (90° elbows and miter bends) with a radius 1.5 times larger than the diameter, and joints (with a pipe-to-pipe gap of 100 mm) such as sleeves. In attempts to develop robotic systems which can travel over long lengths in such pipelines and perform reinforcing welding for existing welds under very unfavorable conditions by the current criteria for welding techniques, we have encountered many technical difficulties (Fig. 2). Our initial targets were welding robots for a 600 mm-diameter pipeline. This was decided on in consideration of the degree of technical difficulty involved and the anticipated cost reduction in comparison with conventional band welding or pipe replacement.

Joint R&D was carried out separately with NKK Corporation, Sumitomo Metal Industries, Ltd. and Nippon Steel Corporation. Consequently, three different models of welding robots resulted.

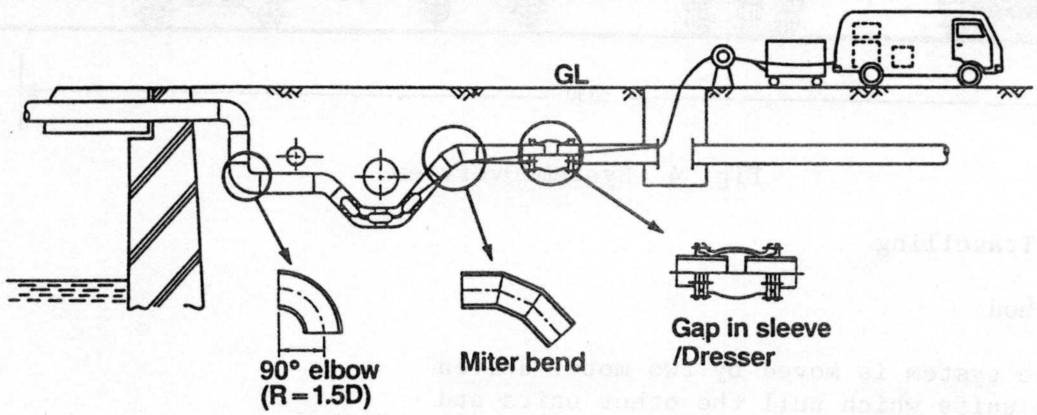

Fig. 2 Piping Conditions

2.2 System Configuration

The reinforcing system is as shown in Fig. 3.

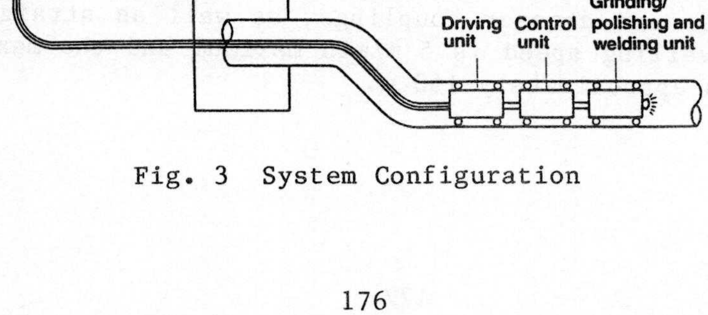

Fig. 3 System Configuration

3. Description of the Robot System

3.1 NKK Model

3.1.1 System Configuration

This welding robot consists of a front driving unit, a grinding/ polishing unit (or welding unit), a control unit, a rear driving unit, a cable connection unit and intermediate boxes A to D. The front and rear driving units have motor-driven wheels, and are capable of travelling under their own power (Fig. 4). The grinding/polishing unit and the welding unit are similarly constructed, making it possible to replace each other according to the purpose of use — grinding/polishing or welding.

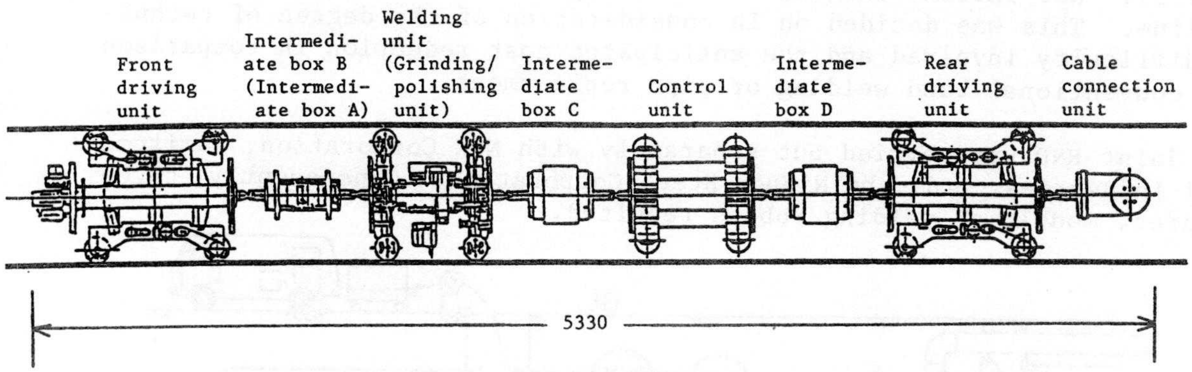

Fig. 4 System Overview

3.1.2 Travelling

(1) Method

The system is moved by two motor-driven driving units which pull the other units and cables. Each driving unit has a total of 12 driving wheels and axles, six on each end, which are radially expandable with air cylinders. Travelling by pressing the driving wheels onto the pipe interior, the driving units ensure a stable traction in any position. For this purpose, driving wheels each consisting of six barrel-shaped rollers (Fig. 5) have been employed, which, as they are pressed strongly against the wall, slide sideways more easily.

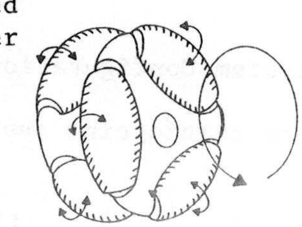

Fig. 5 Driving Wheel

(2) Travelling performance

These functions allow the robot to travel smoothly through 1.5 DR elbows, miter bends and dresser couplings, as well as straight lengths of pipe. The travelling speed is 5 m/min maximum and the maximum travelling distance is approximately 150 m.

3.1.3 Welding

(1) Method

The welding method used is GMAW (Gas Metal Arc Welding). Welding bead build-up is per-formed by five passes of stringer beads (without weaving) in a downward direction (Fig. 6). This method has been adopted for the following reasons: (a) damage to coatings is decreased because of the small welding heat input, (b) use of a large current stabilizes arcs even though the base metal surface is usually in bad condition, and (c) control is simple since welding can be performed at a nearly constant rate and current level.

(2) Contouring weld lines

Weld lines are contoured by teaching the control computer after moving the welding unit to the vicinity of a weld line and expanding the axles to fix the unit at the pipe center. Once the operator manually moves the welding torch and teaches the computer three points (0°, 90° and 180°) on the weld line (Fig. 7), it automatically calculates the torch course required, assuming that the three points are located on the same plane. The welding torch (distance from the pipe's inner wall), however, is automatically maintained at a certain height with an arc sensor operating on the principle that the electric current varies with the arc length.

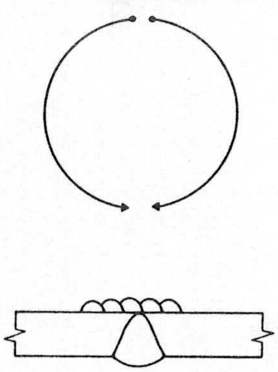

Fig. 6 Build-up Method

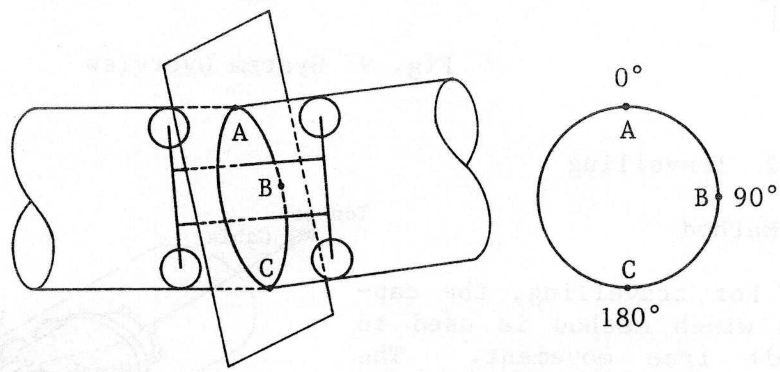

Fig. 7 Weld Line Contouring Method

(3) Principle and handling of the welding monitor

All welding work is remote-controlled above ground. The torch is controlled with four axes, whose movement is programmed in a specified sequence. The welding conditions can be monitored via two TV cameras.

If excessive spatter deposits on the nozzle, the nozzle is automatically cleaned with a spatter remover (Fig. 8).

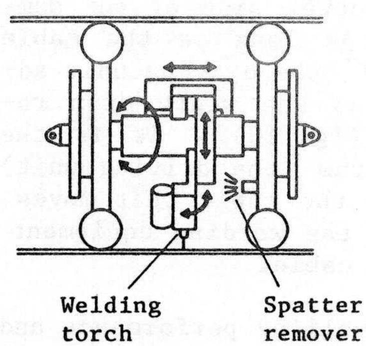

Fig. 8 Welding Unit

3.2 Sumitomo Metal Model

3.2.1 System Configuration

This robot system consists of a number of units which have certain designated functions. The system configuration is as shown in Fig. 9, in which equipment B is the welding unit. This part is replaced with a grinding/polishing unit when the area to be welded has to be ground and polished. Equipment D is the driving unit. Intermediate unit C accompanying unit B carries wires, solenoid valves, camera control units (CCUs) and other material required for welding. Guide units A and E at both ends assist travelling.

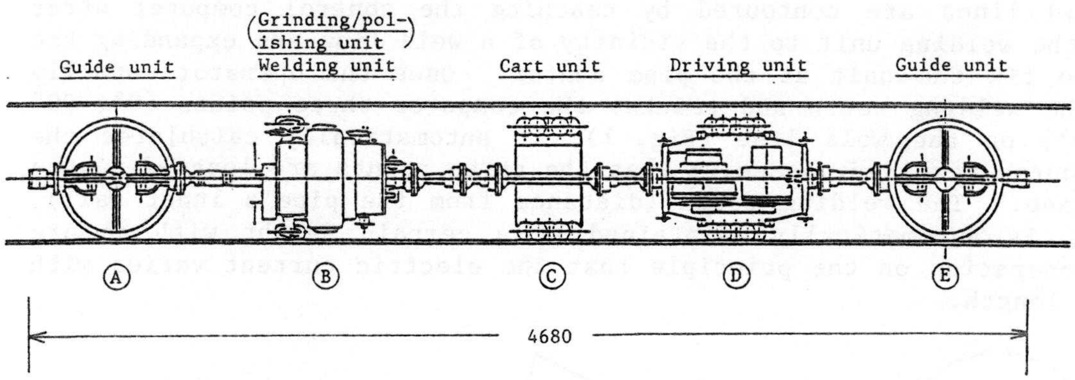

Fig. 9 System Overview

3.2.2 Travelling

(1) Method

For travelling, the capstan winch method is used to permit free movement. The capstan winch allows the cable to be wound up around the winch drum at one side and unwound at the other side at the same time. As long as the cable is tight, the driving unit advances as the winch drum rotates (Fig. 10). It is the winch drum (the driving unit) and not the cable that moves. Thus, all the units in this system, including the welding equipment and the universal joint, must have a hole for the cable.

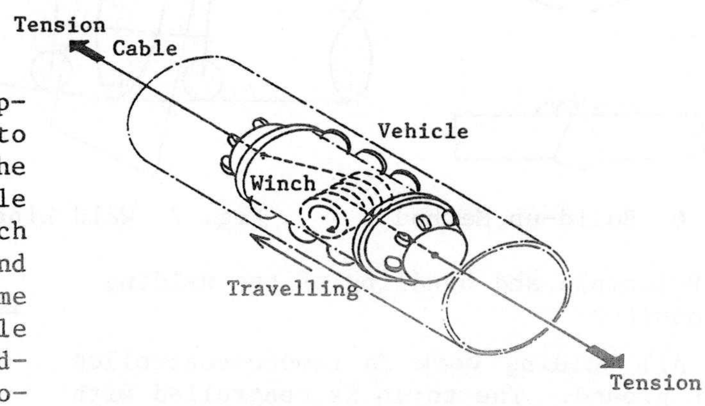

Fig. 10 Travelling Mechanism

(2) Travelling performance and features

(a) This travelling method is mechanically simple and the travelling speed and traction can be freely designed by determining the motor capacity and reduction gear ratio. The maximum travelling speed is 7.8 m/min and the maximum traction is 2 t horizontally and 0.9 t vertically.

(b) The guide units are provided at the front and rear of the linked system to guide the cable, and can respond appropriately to any complex bends or fittings.

(c) If the driving unit fails in the pipe, the system can be drawn out by manually operating the cable.

3.2.3 Welding

(1) Method

Based on GMAW, the welding method has been developed as a fully-automatic GMAW which permits automatic holding of joint peripheries in all welding positions.

Welding in all positions requires not only accurate position control but also a mechanism to adjust dislocations which vary according to joints. Hence, seven welding conditions are preset according to the range of dislocation (from +8 to -8 mm), so that the optimum welding conditions (such as welding current level, welding speed, and torch inclination) can be automatically calculated (by linear interpolation) based on the data taught. For build-up, a continuous process combining both upward and downward passes is employed, which permits four welding passes without an arc interruption. The welding efficiency is, therefore, very high (approximately 45 min/joint).

(2) Welding line teaching method and dislocation measuring method

Teaching is automatic and can be simply performed by pressing two contact sensors onto the pipe's inner wall astride a welding line and moving them in the peripheral direction (Fig. 11). The output from one of the two sensors indicates the distance from the torch to the inner wall; the difference between the outputs from the two sensors indicates the amount of dislocation. Accurate positioning of the sensors astride a welding line is assisted with a TV camera. When the sensors have moved through the entire inner periphery in this way, 720 pieces of positional information at a 0.5-degree pitch over the entire periphery are automatically sent to the memory of the computer.

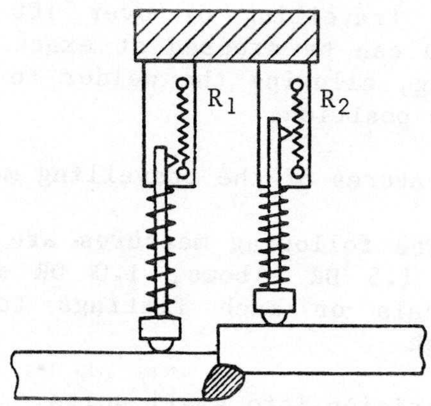

Fig. 11 Conceptual Diagram of the Sensors

3.3 Nippon Steel Model

3.3.1 System Configuration

This robot system consists of seven units as shown in Fig. 12. Unit A at the fore-end is the welding unit loaded with grinding/polishing equipment, a welder and monitors. Unit B is the wire unit loaded with welding wires. The four units C, D, E and F are used to move the system. Units C and F make up the clamp unit which fastens the system in the pipe, and units D and E comprise the stroke unit which moves the system back and forth. Unit G at the rear-end is the valve unit and is loaded with solenoid valves to drive the cylinders of the stroke and clamp units.

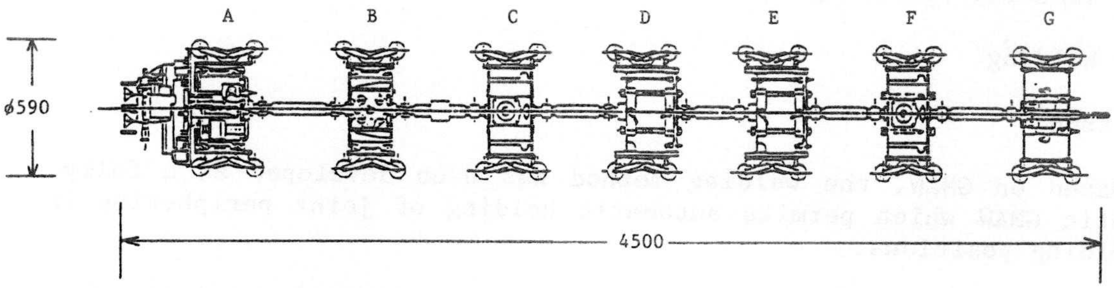

Fig. 12 System Overview

3.3.2 Travelling

(1) Method and performance

The travelling method is of the measuring worm type (Fig. 13). The robot advances by repeating the sequence shown in Fig. 13. These operations, performed with air cylinders producing a force of 1 t at 5 kg/cm^2 air pressure, permit travelling of over 100 m. Stroke unit D can be stopped at exact position by inching, allowing the welder to be adjusted to any position.

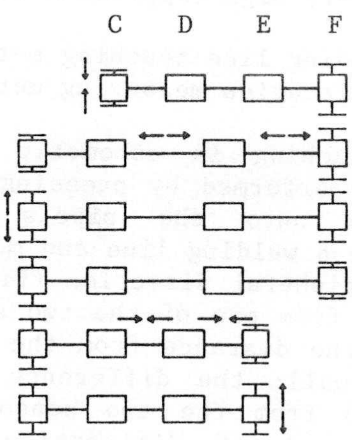

Fig. 13 5-stroke Travelling Sequence

(2) Features of the travelling mechanism

The following measures are provided to allow 1.5 DR elbows, 1.0 DR miter bends, verticals or such fittings to be passed through.

(a) Division into small units

For the system to pass through radically-curved bends as well as straight lengths, the system is divided by function into seven small units.

(b) Limited bend angle of joints

When a universal joint is used between units in the measuring worm travelling method, they are often caught, as shown in Fig. 14. To prevent this, a special jig is installed at each universal joint to limit the bend angle of the joint and control the unit's position.

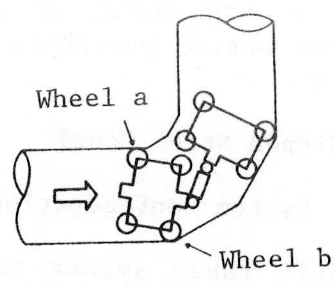

Fig. 14 Struck Units

3.3.3 Welding

(1) Method

The welding method is PAW (Pulsating Arc Welding). In this method, the welding current is periodically switched between two levels, high and low, in a mixed gas atmosphere of argon and carbon dioxide, and the arc voltage is synchronized with changes in the welding current level. In this method, welding in all positions is possible without changing the current levels or voltage according to position. Furthermore, large dislocations (8 mm max.) and gaps (5 mm max.) can be handled, and stable welding quality can be obtained.

(2) Measures against rust and deposits on welds

Joints to be welded often have rust, tar or similar deposits. If they are welded as they are, welding beads cannot be satisfactorily obtained. Hence, two measures are taken against rust and other deposits on joints to be welded.

The first measure taken is to grind and polish the area to be welded. A composite material with a wire brush sandwiched between flap wheels is used as a grinder/polisher (Fig. 15). The other measure is to do preliminary welding. The area of the joint to be welded is often covered with tar or such, which is not removable by grinding or polishing. These types of deposits can be burned away by preliminary welding. When multilayer build-up welding follows this, stable welding beads of good quality are obtained.

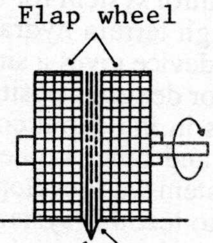

Fig. 15 Grinding

(3) Automatic welding

All welding work is performed via above-ground remote control. Teaching precedes automatic welding. Since automatic welding requires accurate teaching, this robot system uses a non-contact teaching method consisting of a monitor and a projector which emits a cross-slit light beam. The slit light projector and the welding torch used for teaching are designed to move in three directions (axial, peripheral and radial).

4. Conclusions

The R&D activities for these welding robots have been completed and the current stage is testings on site. Results of these field tests indicate that the systems are satisfactory and meet the target specifications for travelling and welding performance. It is expected that the new systems can achieve a cost reduction of 20 to 40% in comparison with conventional methods such as band welding and replacement. Although these welding robot systems have been developed for the purpose of reinforcement of existing welds, they are also applicable to the welding of new pipes and the build-up repair needed for pipe walls thinning due to corrosion. With the completion of R&D for 600 mm welding robots, we have commenced studies of robots for pipes up to 200 mm diameter.