Development of Automatic Welding System for Crawler Crane Latticed Booms

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An automatic welding system for crawler crane latticed booms, made of thin steel pipes, was developed to improve welding quality and strength. This system rectifies distortions caused by real-time welding heat input. This paper introduces an outline of the system and main functions including: 1) The creation of saddle-type robot-programming data; 2) Detection of saddle-type welding seams; 3) High-reliability tracking functions.

Introduction

Lattice booms of crawler cranes (**Figure 1**) are safety-critical parts that have to meet stringent requirements for welding quality tests. At KOBELCO CRANES CO., LTD., most lattice booms have been welded manually by well experienced technicians, with only limited exceptions of small to mid sized, volume products which are welded automatically by arc-welding robots.

When welding small diameter pipes together to build a lattice structure, the heat of welding warps the work, changing the welding positions from time to time. Robotic welding has to make real-time corrections for those changing positions. In addition, welding lines in pipe-to-pipe welding are three dimensional saddle shaped curves, in which the shapes of welding grooves keep changing all the time. Since no means have been available to measure and correct for those changes of shapes[1), 2)], conventional robotic welding requires individual corrections of teaching data based on welding results, which consumes an excessive amount of time and labor. Thus, the application of robotic welding has been limited to small to mid sized, volume-production products.

However, large sized works, which have been welded manually by well experienced technicians, are becoming difficult to produce, due to the increasing scarcity of such technicians. In addition, the globalization of production sites makes "robotization" in this area a pressing need.

In order to resolve this issue, we have developed an automatic pipe welding system in which a laser sensor for arc-welding is used. The system mainly comprises;

1) a teaching data preparation capability for saddle-shapes,
2) a saddle-shaped welding line detecting capability
3) a highly reliable tracking capability for welding lines with small curvatures

1. Outline of the system

1.1 System configuration

The configuration of the developed system is shown in **Figure 2**. An ARCMAN-RON welding robot manufactured by Kobe Steel was used in the system. A factory computer (FC), robot controller and sensor controller constitute a network, in which data are transmitted and received among each other. A laser sensor (MSPOT90[3)] from Servo-Robot Inc) was located at the tip of the robot arm. The laser sensor is a flying-spot type and capable of measuring the position 30mm ahead of the welding torch. In order to make the sensor always measure ahead-positions

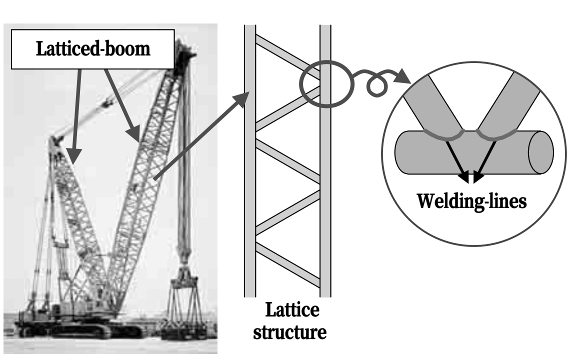

Fig. 1 Welding-lines at latticed-boom

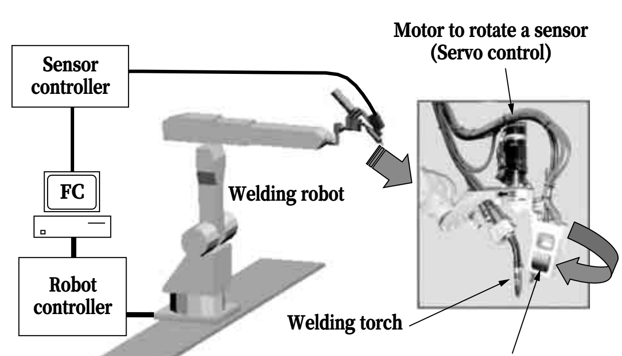

Fig. 2 System configuration

of welding lines regardless of the orientation of the welding torch, a servo controllable rotary motor was installed so that the sensor can rotate freely around the welding torch.

1.2 Features

The system comprises:

(1) a teaching data preparation capability for saddle-shapes,

(2) a work position detecting capability,

(3) a saddle-shaped welding line detecting capability, and

(4) a welding line tracking capability with high reliability.

(1) The teaching data preparation capability for saddle shapes shortens the teaching time significantly. The system copies the teaching data for a welding position when the contour line of crossing pipes at the position has already been taught. For a new contour line, the system picks up a closest contour line already taught and automatically converts the picked-up line geometrically to fit the new contour. This capability has enabled the application of the system to non-volume type products. (2) The work position detecting capability detects the welding positions of pipes to be welded, using the laser sensor installed on the robot, calculates displacements between the CAD data and the actual work positions and makes corrections for the starting position of the robotic welding. Our ingenuity and experience were used to develop the method for detecting the positional displacements on crossing pipes, the contour of which is three dimensional and hard to characterize. (3) The saddle-shaped welding line detecting capability accurately detects the groove shapes of the joint portion of pipes, of which angles and shapes vary as the welding proceeds. (4) The welding line tracking capability traces the welding line stably with high reliability, even in situations where welding positions cannot be defined clearly, as in the case of tack welding.

1.3 Outline of the tracking procedure

The flow of the welding tracking procedure is as follows. (**Figure 3**)

Step 1: A start command is notified from the robot to the sensor controlling the FC to start arc tracking.

Step 2: The sensor controlling the FC collects the latest positional information of the robot as the tracking proceeds.

Step 3: The sensor controlling the FC retrieves measured data from the sensor at predetermined sampling intervals.

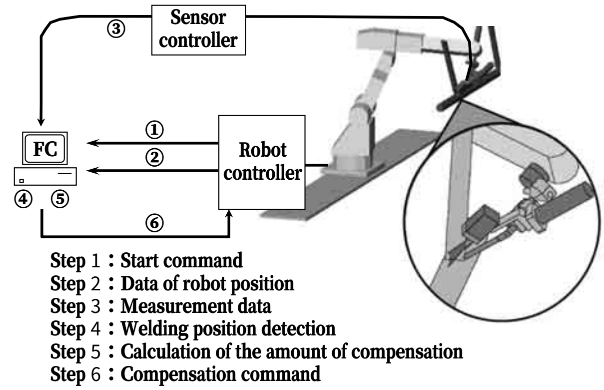

Fig. 3 Tracking procedure

Step 4: The FC determines the groove positions based on the measurement data retrieved at Step 3, converts the determined groove positions into positions on a robot coordinate and stores the data.

Step 5: The FC calculates the displacement amount of the robot tip as soon as the tip reaches the vicinity of the positions determined in Step 4.

Step 6: The FC transmits the displacement amount, calculated in the Step 5, to the robot to correct the tip position.

The real-time operating system (OS) developed by us, is used for the operation of the sensor controlling FC, and multi-task computations are carried out in the system.

2. Capability details

2.1 Teaching data preparation capability for saddle-shapes

Short teaching times are essential for practical systems used in the production of small-volume, specific-purpose products. To satisfy this requirement, there have been developed two capabilities. One capability (**Figure 4** (a)) is to automatically prepare the teaching

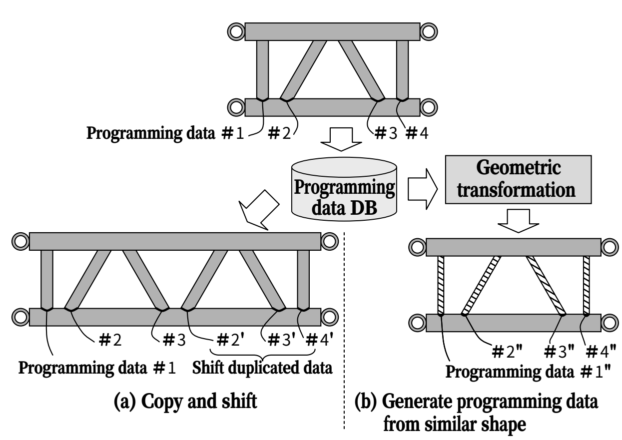

Fig. 4 Generate programming data of saddle type

data for the saddle-shaped welding lines, having the same shapes as have been prepared once, by copying the data from the teaching data base (hereinafter denoted as DB). The other capability (Figure.4 (b)) is to automatically prepare the teaching data for the saddle shaped welding lines, having a shape similar to the ones that have already been taught, by geometrically converting the most similar data, selected from the DB, to fit the welding line.

In order to realize the capabilities, development was carried out based on an off-line teaching system[4)] for welding robots manufactured by Kobe Steel. The development led to a teaching data preparation tool, having capabilities of determining robot orientations through space interference checking; instructing welding conditions and weaving patterns; and selecting teaching data from the DB, in accordance with the shapes of the works to be welded. The developed system fully utilizes the high-level skills of well experienced technicians. When existing teaching data can be utilized, any operator can now determine the work shapes in a simple interactive manner. In addition, the capability of converting similar data reduces time for the preparation of a new teaching data by approximately 75%.

2.2 Work position detecting capability

We developed a system to measure assembly errors and to correct for the errors, using the sensor for welding line tracking. (**Figure 5**) The developed system was further improved for actual applications. Since the welding is done on pipes, the cross sectional projections by laser from oblique angles are elliptical. The work position detection was made possible with accuracies of 0.5mm, or better, by using data for directions which are less prone to errors. The system enables corrections of displacements at the time of welding start and improves the welding qualities of the beads in the welding-starting portion, a portion which has been difficult to track with a sensor.

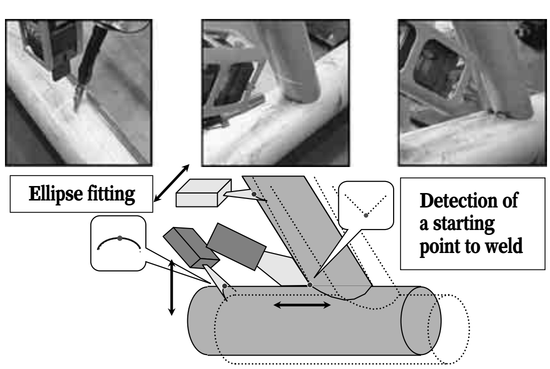

Fig. 5 Detection of a work position

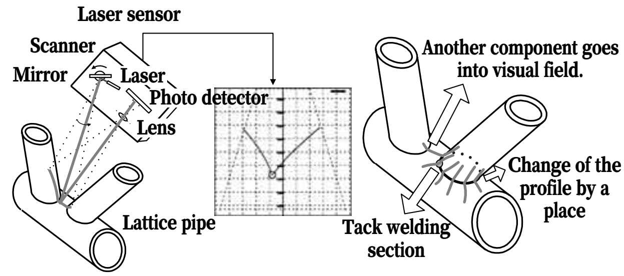

Fig. 6 Problem of detecting saddle type welding line

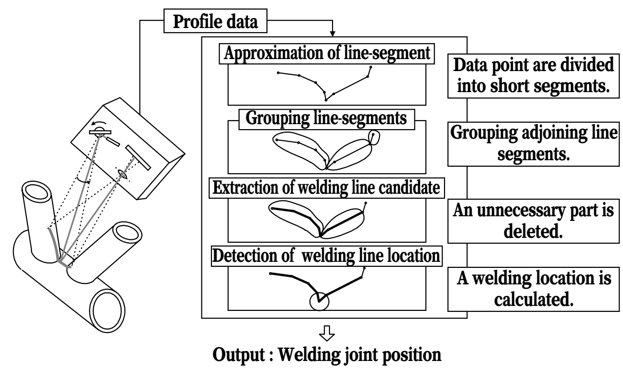

Fig. 7 Detection of a welding joint position

2.3 Saddle-shaped welding line detecting capability

There have been methods for detecting welding lines, such as of corner welding and groove butt welding, in which the shapes of the welding portions remain constant. However, no method has been available for detecting saddle-shaped welding lines as shown in **Figure 6**, in which the groove shape keeps changing as the welding proceeds.

An innovative method was developed for detecting welding positions by using decision-tree detection logic, which is suitable for the saddle-shapes appearing in the lattice booms. The new method detects the joint positions to be welded with high accuracy, even when the groove shapes change as the welding proceeds (**Figure 7**) In the detection logic, two dimensional point arrays in cross sectional shape data are grouped into line segments, and adjoining line segments are grouped together to determine roughly the welding line. Noise, due to unnecessary portions, arc light and such, is eliminated in the process of the detection logic and rough welding lines are narrowed down. From the narrowed down rough welding lines, optimal welding lines are deduced through judgment of other factors, such as tack welding portions and groove shapes.

The new method enables judgment of provisional welding portion, stable positioning even for the joints having gaps caused by provisional assembly errors and countermeasures against noise ,such as sputter, and has achieved a detection rate higher than

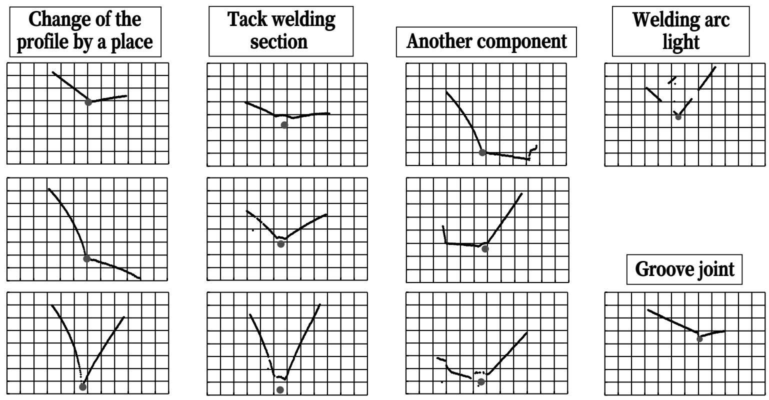

Fig. 8 Example of welding line profile on a saddle type part

95% on actual work (**Figure 8**).

2.4 Welding line tracking capability with high reliability

In the conventional methods, in which welding torches follow the positions detected by sensors, linear corrections are made for undetected portions, in which lines cannot be tracked by the sensors due, for example, to tack welding, or to surface conditions. The linear corrections are not applicable to joints between pipes because the joints have large curvatures. For this reason the conventional method cannot be adopted for the welding of pipes. A new tracking method (**Figure 9**) was developed, in which teaching data are used more effectively. The concept is as follows:

(1) If the sensor detects a displacement, the tip position is corrected and the original teaching data are shifted.
(2) If the sensor is unable to detect the displacement, use the teaching data shifted according to (1) immediately before the undetectable occasion.

The developed system tracks the undetectable portions, such as tack-welded portions which are undetectable by the laser sensor, rather well without much deviation. This is because the system shifts the tracking data, immediately before, to the undetectable portions which are usually rather short.

As described above, the developed method switches the locus control of the robot tip depending on the detection status of the sensor. Such hybrid control enables tracking of lines without deviating from the welding lines even when the sensor is unable to detect portions of the lines.

3. Welding result

Welding tip tracking accuracies of 0.5 mm or better were demonstrated as a result of the combined effects as described in section 2. **Photo 1** shows the appearance of the welding bead automatically welded by the present system.

Conclusions

No detection method has been available to track the three dimensional saddle-shaped lines with groove shape which keeps changing as the welding proceeds. We have developed a control system having capabilities of welding position detection and welding line tracking by using a laser sensor,

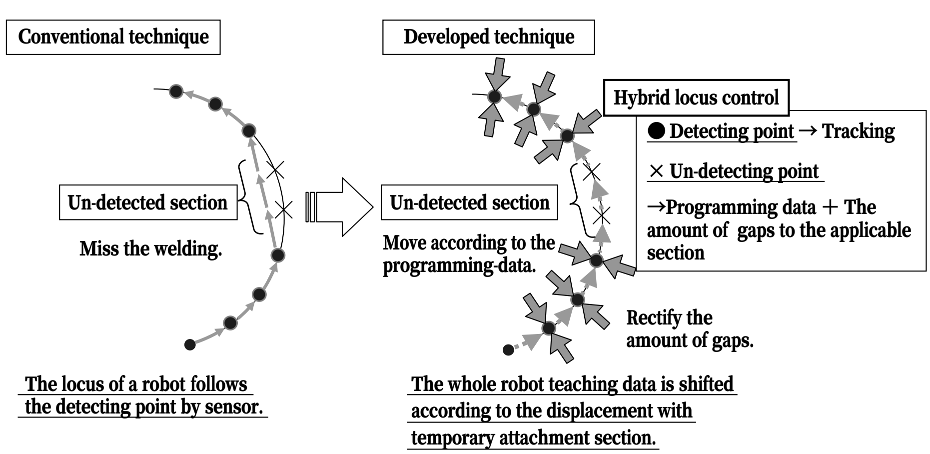

Fig. 9 High-reliable tracking method

Photo 1 Appearance of welding bead

taking into considerations the practicality and future expandability. The welding line detection technology developed at this time can automatically accommodate the changes in groove shapes and is applicable to the detection of tack welding portions and to multi-layered welding. A high welding quality was achieved as a result of effectively utilizing the information obtained by the new welding line tacking capability based on teaching data.

The newly developed system shortens the teaching time, one of the most important features, based on the off-line teaching system, an innovation of KSL, and allows teaching of saddle shaped contours by utilizing the teaching data stored in the DB according to the work shapes and fully utilizes the skills of well experienced operators.

The present development was made possible as a result of the combination of high level technological expertise, such as robotic control and image processing. In addition, the needs of the production engineers at job sites, such as cost, operating procedures and quality, were indispensable in converting the development results into practice. Close relationship among engineers enabled the development and practical application of the present system.

References

1) Kiyohara, et. al.: *Preprints of the national meeting of JWS*, Vol.61 (1997).
2) *Kawasaki Technical Review*, Vol 132, p.78 (1997).
3) J. P. Boillot: *Proceedings International Symposium on Automotive Technology & Automation*, p.61 (1998).
4) Hara et.al.: *R&D Kobe Steel Engineering Reports*, Vol.54, No.2, p.96 (2004).