Title	Automatic Control of Horizontal Narrow Gap Welding (Report III) : The Total Control System and the Wire Position Control Method by Arc Observation(Welding Physics, Processes & Instruments)
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Citation	Transactions of JWRI. 1980, 9(2), p. 151-156
Version Type	VoR
URL	https://doi.org/10.18910/7120
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Automatic Control of Horizontal Narrow Gap Welding (Report III)†
— The Total Control System and the Wire Position Control Method by Arc Observation —

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Abstract

The development of the automatic control system was made to detect change in the groove width and the welding start and stop positions, to control the weld line tracking, and to set up the optimum welding conditions corresponding to the change in the groove width, for the purpose of the automatic control of the horizontal narrow gap welding.

In this report, the principle and the algorithm of direct arc observing method which improves the reliability of weld line tracking, and the synthetical control algorithm to realize the full automatic control are described.

The results obtained are summarized as follows:

(1) The weld line and the wire position can be detected stably within the accuracy of 0.5(mm) with the direct arc ovserving method.

(2) The welding apparatus and the algorithm for synthetically controlling were manufactured as a trial.

(3) As the experimental result of automatic control, the control apparatus and the algorithm were certified to be used practically.

KEY WORDS: (Automatic Control) (Measurement) (Television) (Computers) (Guidance System) (MIG Welding) (Narrow Gap Welding)

1. Introduction

With the view of developing the welding apparatus for the full automatic control of horizontal narrow gap welding, it was previously reported[1),2)] that the automatic measurement of the groove width, the automatic selection of the optimum welding conditions corresponding to change of the groove width, the automatic detection of the welding start and stop positions, and the weld line tracking were carried out by using the light projection method. It is possible that the full automatic welding is made by putting together these measurement and detection, that is, the arc start and stop, the selection of welding conditions and the weld line tracking are automatically carried out.

In order to improve the reliability of weld line tracking, the direct arc observing method was also adopted. This report will reveal the principle and the algorithm of that method, and the experimental result with the full automatic control system mentioned above.

2. Method of Weld Line Tracking by Direct Arc Observing

2-1. Principle of detection

The light projection method, described previously[2)], has enough performance to carry out weld line tracking control succesfully, however, more reliable control will be possible if the direct arc observing method is used at the same time, especially in case thermal deflection of base metal or distortion of electrode wire is caused during welding.

The principle of the direct arc observing method, where the arc welding process progressing part is directly observed obliquely with a TV camera from the front of welding direction, as shown in **Fig. 1 (a)**, was described in the reference[3)]. An example of the picked up image is shown in **Fig. 1 (b)**. The bright part shows the arc in the groove. The upper and lower boundaries of dark and bright part correspond to both edges of the groove, and the concave on the left side of the bright part is the image of the electrode wire. By processing the image data and detecting the groove edge and the wire position, the wire position in the groove can be controlled in real time during welding.

† Received on September 24, 1980

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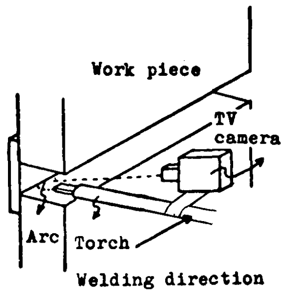
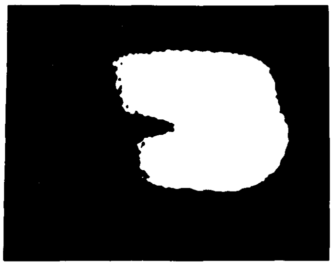
** Katayama Iron Works, Ltd.

Transactions of JWRI is published by Welding Research Institute of Osaka University, Suita, Osaka, Japan



(a)



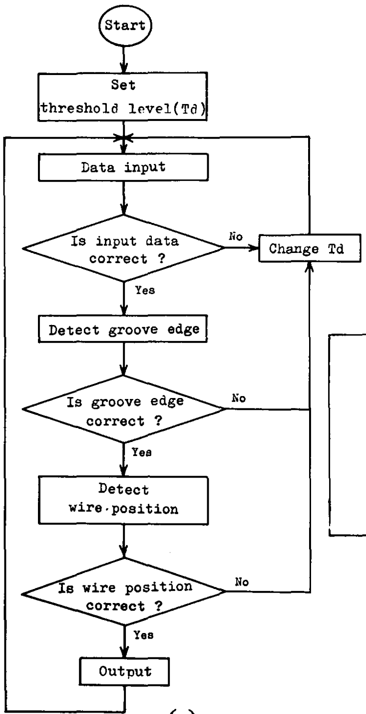
(b)

Fig. 1 Principle of direct arc observing method and example of obtained image.

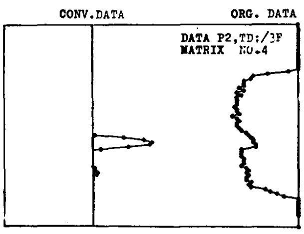
2-2. Detection of groove and wire position

The image data of **Fig. 1 (b)** are converted into digital values, which are plotted on the right side of **Fig. 2 (b)**, with the BIP[4]. The pattern of the plotted data has also the concave corresponding to the wire image, and the wire position can be detected by recognizing this concave. In order to do this, we adopted one dimentional convolution operation which is considerably high detective reliability. By Eq. (1), the value W_I is calculated, where B_I is the datum of the I'th horizontal scanning.

$$W_I = 2B_{I-5} + 2B_{I-4} + B_{I-3} - 2B_{I-1} - 3B_I - 3B_{I+1} - 2B_{I+2} + B_{I+4} + 2B_{I+5} + 2B_{I+6} \quad (1)$$



(a)



(b)

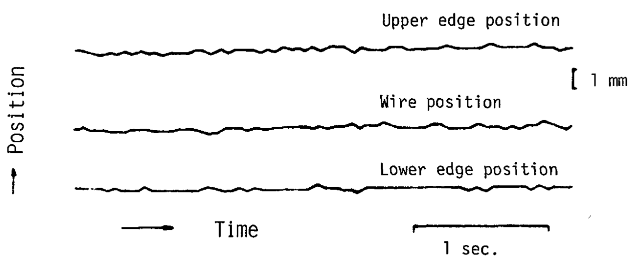
Fig. 2 Distribution of data and algorithm for detection of wire position.

Coefficient of each term of the right side of Eq. (1) is employed on considering a pattern matching method[5]. The calculated W_I is shown in the left side of **Fig. 2(b)**. It is shown that the large W_I value is obtained at the wire image, and we can define the position of the maximum W_I value as the wire position. We can also get the information on the groove edge as the points where B_I changes from zero to a certain value and vice versa. This algorithm is almost the same as the measurement for the groove width in the light projection method[2].

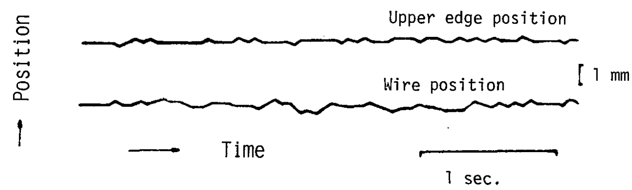
Fig. 2 (a) shows the algorithm to detect the groove width and the wire position in real time. This algorithm is characterized by having an image data checking routine and an automatic threshold value control routine for the BIP. These are necessary when we process the image, which changes as time passes, in real time during welding.

Figure 3 shows the result of the detection of the weld line and the wire position in real time during welding, which is of high peak pulsed MIG arc. The upper graph in this figure is the detection result of the groove edges whose width is of 8 (mm) in one pass in one layer welding. The weld line and the wire position are detected constantly within the accuracy of 0.5 (mm). **Figure 3 (b)** is the result of the upper weld of two passes in one layer welding at the groove width of 12 (mm). The lower edge of the groove is not detected because of the insufficiency of arc light, but the upper edge and the wire position are detected stably.

Sufficient information for control of weld line tracking is obtained by either the light projection method or the direct arc observing method, but the system in which both methods are combined together improves the reliability, because one makes up for another weak points.



(a) One pass in one layer (Groove width 8(mm))



(b) Two passes in one layer (Groove width 12(mm))

Fig. 3 Detection results of the groove edge and wire position during welding in real time.

3. Automatic Control Apparatus

Appearance of an apparatus to carry out automatic control, which is manufactured as a trial, is shown in **Fig. 4**. It is divided into four main systems as i) an image pickup system, ii) a processing system, iii) an electrical system and iv) a mechanical system. Co-relation of each system is shown in **Fig. 5**. The image data are sent from the image pickup system to the processing system. Control signals output from the processing system are amplified and drive the mechanical system through the electrical system. The function of each system is outlined as follows.

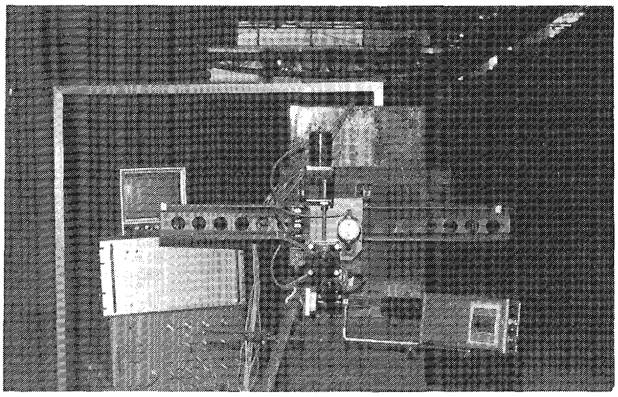


Fig. 4 Appearance of automatic control system which is manufactured as a trial.

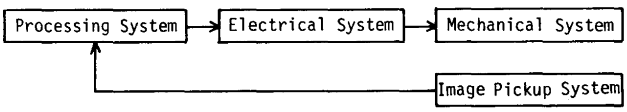


Fig. 5 Block diagram of control system

(Image pickup system)

A TV camera with vidicon of antimony trisulfide (Sb_2S_3) is used as a image pickup device and a small projector as an external light source. In direct arc observing method, N/D filter and infrared rays filter are used for the reduction of arc light.

(Processing system)

The processing system consists of CPU, memory and I/O interface. Intel 8080A is used as CPU, Intel 1702A (2K bytes) as ROM and Intel 2102 (1K bytes) as RAM. The I/O interface mainly consists of BIP and PMD, which is reported previously, and it has also D/A converter to output for control signal. The whole device is controlled by this processing system.

(Electrical system)

The electrical system mainly consists of servo-amplifiers which amplify the control signals output from the processing system, for each axis in the co-ordinate system. Each axis can be controlled independently and it can also be operated manually.

(Mechanical system)

In the mechanical system, torch driving is carried out. Movable axes are X, Y, Z and θ, where X-axis is for the motion of weld direction, Y-axis for the weld line tracking perpendicular to the weld direction, Z-axis for the plate thickness direction and θ-axis for the torch vertical angle. Each axis has a sensor for the position measurement.

A block diagram of more detailed co-relation among systems is shown in **Fig. 6**.

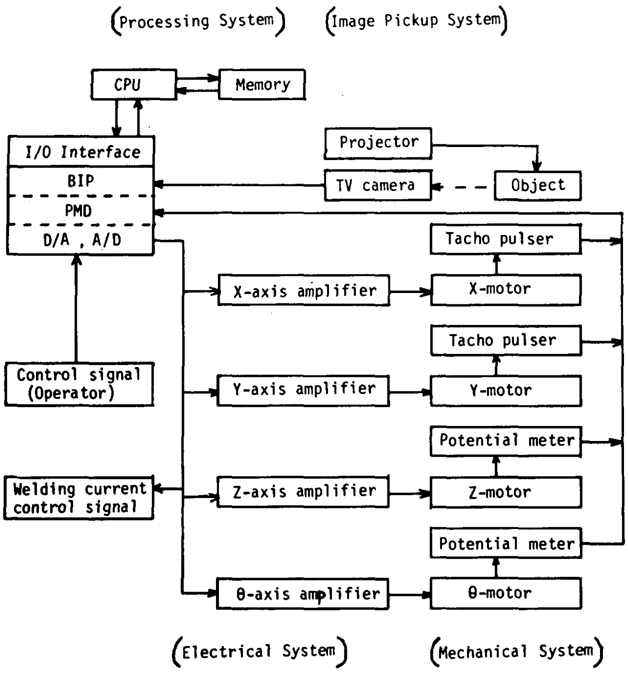


Fig. 6 Block diagram of image pickup, processing, electrical and mechanical systems.

4. Algorithm for System Control and Control Results

4-1. Algorithm for system control

In order to realize the full automatic control, the algorithm for controlling the above total systems synthetically becomes necessary. The outline of trial algorithm is shown in **Fig. 7**, here, this algorithm is composed of the four routines which are explained as follows. As shown in **Fig. 7**, in this algorithm, the flow of control can shift to every routine from wait state independently, and so an operator can select an optional routine by manual switching operation.

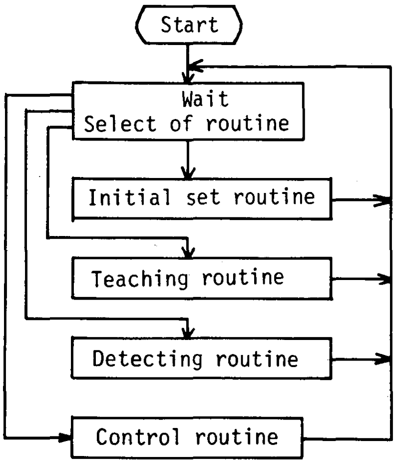


Fig. 7 Outline of algorithm which controls the welding system synthetically.

(Initial Set Routine)

When the operation is transfered in this routine, the controller waits the switching operation by an operator. The operator sets up the following items and switch on the controller, the setting up items are stored in the memory.

Pass number for one layer welding: Selection of one pass in one layer, or two passes in one layer.

Total pass number: Setting a number of passes per one job.

The control is repeated as the settings so long as they are not changed.

(Teaching Routine)

This routine is for the initial settings of torch vertical angle (θ) and wire position (Wp). (See **Fig. 8**). The control flow shifts to this routine after it passes through the initial set routine at least one time during the operation. Otherwise, a caution lamp signals and no operation is done. In this manner, each device is protected from upset. When the operator switches on after setting torch angle and wire position, the digital value of the torch position is memorized. In the case of two passes in one layer welding, this operation should be repeated two times for the two positions. So long as the setting is not changed, the control is repeated as follows.

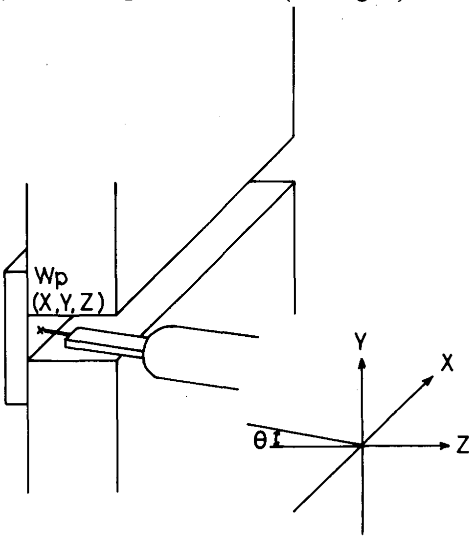


Fig. 8 Illustration for explanation of torch angle (θ) and wire position (Wp).

In case of one pass in one layer: The torch vertical angle and the wire position are set up again to the initial each position after one pass weld. In this case, the wire position takes the initial value in X-Y coordinates and shifts in Z coordinate by the value of one pass bead height which can be calculated by a simple equation. (See the reference[1])

In case of two passes in one layer: The torch vertical angle and the wire position are set up alternately in initial two positions after each one pass weld. The wire position shifts in Z coordinate in the above mentioned way after each one layer.

(Detecting Routine)

This routine is for the automatic detection of various kinds of information and the automatic selection of the optimum welding conditions according as change of the groove width. The control flow shifts to this routine after passing through the teaching routine at least one time during the operation.

When the flow shifts to this routine, the torch begins to run automatically, start point of the weldment is detected, its position is memorized, and then groove widths are measured and stored in memories with the information on weld line tracking continuously until the stop point is detected. This is done by the method in which the weldment is devided at a certain regular intervals in X direction (the weld direction), and at each divided point, the measured values of groove width and Y coordinate of the groove edge are memorized. After the detection and memorization of the stop point, the optimum welding condition corresponding to the measured values of groove width is selected automatically and memorized according to the algorithm reported previously.

When these operations are finished, the torch returns to the start point and the flow also returns to the wait state. The operations mentioned above are shown in **Fig. 9** as a flowchart.

(Control Routine)

Through the routines mentioned above, all of the necessary information for welding control is stored in memories. In this routine, welding control is carried out on the basis of this information. (Automatic start and stop, weld line tracking, automatic selection of welding conditions and etc.) The control flow does not shift to this routine until it passes through the detecting routine at least one time during operation. The algorithm for weld-

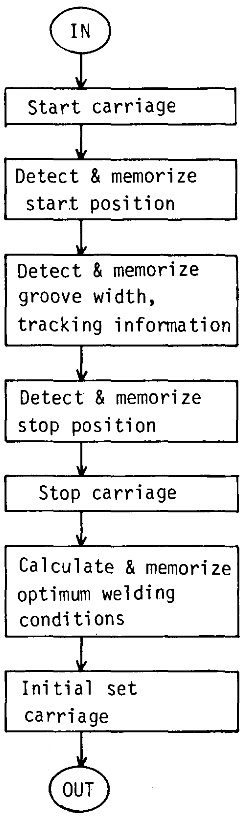


Fig. 9 Flowchart for detection routine.

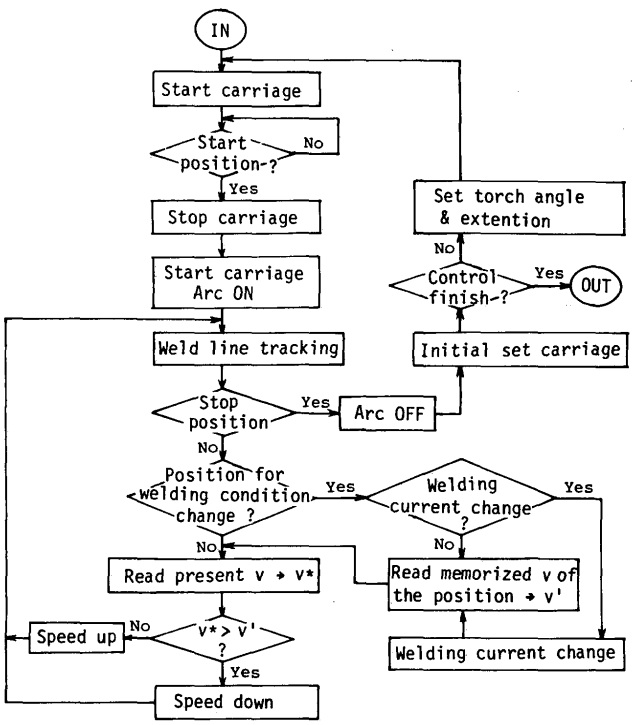


Fig. 10 Flowchart for control routine.

ing control is shown in **Fig. 10**.

When the flow shifts to this routine, the torch moves to the arc start point and stops there. On the indication of the arc start, the welding is carried out with line tracking and wire position control, under the optimum condition which has been already set up automatically.

The line tracking is made by the way that the torch position in the Y direction is compared with the stored one and the control signal is output by the difference between them. The control of welding condition is made on giving priority to change in welding speed. That is to say, the control is carried out by comparing actual travelling speed of the welding torch at a point with the stored one, the control signal is output and the actual speed is adjusted by the difference. In case the control of welding current becomes necessary, the control signal is output from memory corresponding to the torch position.

When the torch reaches at the stop point, the arc is put off, the crater filler is done if necessary. In the next step, checking whether the number of indicated passes is finished or not, the apparatus stops and outputs the signal of completion, or otherwise continues to weld the next pass after changing the vertical angle, the wire position, and the welding conditions.

In this manner, the horizontal narrow gap welding can be done with full automatic control.

4-2. Experiment and result

An apparatus to carry out automatic control is manufactured as a trial. As weld line tracking, light projection method and direct arc observing method were used together. The appearance of the test piece used in the experiment is shown in **Fig. 11**. Pulsed MIG arc method

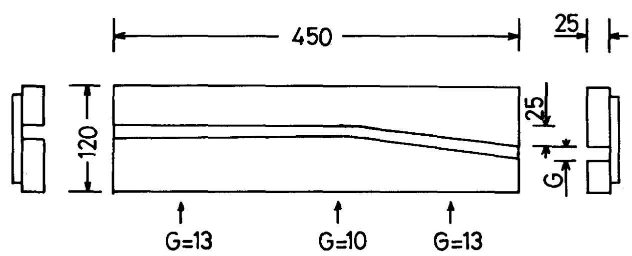


Fig. 11 Specimen for automatic control experiment.

was used at two passes in one layer welding. The result of the experiment to 4 passes in 2 layers is shown in **Fig. 12**. The control was stably made, the bead height is kept constant and the bead configuration is maintained well as the welding result. The control of the welding condition was made to the speed which varied from 30 to 40 (cm/min.) at constant welding current of 200 (A). These results prove the effectiveness of the developed system.

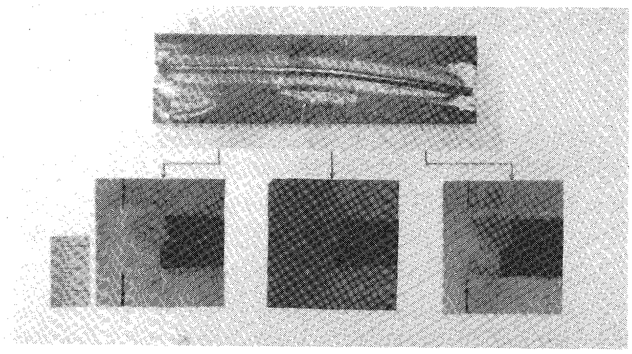


Fig. 12 Bead appearance and cross sections of the weldment which is automatically controlled.

5. Conclusion

On developing the welding apparatus for full automatic control of horizontal narrow gap welding, direct arc observing method was applied to improve the reliability of weld line tracking. Furthermore, the system made use of micro computer was manufactured as a trial and the experiment was done to show the good results.

The results in the report are summarized as follows:

(1) The weld line and the wire position can be detected stably within the accuracy of 0.5 (mm) with the direct arc observing method.

(2) An apparatus manufactured as a trial is divided into four main systems as an image pickup system, a processing system, an electrical system and a mechanical system.

(3) In order to realize the full automatic control, an algorithm which controls the apparatus was made. It is composed of four routines, that is, an initial set routine, a teaching routine, a detecting routine, and a control routine.

(4) The control experiments with the apparatus and the algorithm were carried out. Pulsed MIG arc method was used, and light projection method and direct arc observing method were used together, as weld line tracking. These results proved the effectiveness of the developed system.

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