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Automatic Control of Horizontal Narrow Gap Welding (Report II)†
–Detection and Measurement by Image Processing–

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Abstract

With the view of developing the welding device for full automatic control of the horizontal narrow gap welding, we have applied the BIP system and its algorithm to the automatic measurement of the groove width, the automatic detection of the welding start and stop positions and the weld line tracking.

The groove width and the welding start and stop positions can be measured with the accuracy of approximately 0.2 (mm), by applying the BIP system, the TV-camera, micro-computer system and the specific algorithm.

The information for the weld line tracking can also be obtained, by using the BIP system, the TV-camera, micro-computer system and the PMD system.

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

1. Introduction

The investigation, as in our first report[1], was carried out in the algorithm for the automatic selection of the optimum welding conditions to keep the bead height constant and bead configuration satisfactory even in case the groove width varies, as automatic control for the horizontal narrow gap welding.

In order to construct the automatic control system, however, the automatic measurement of the groove width variation, automatic detection of the welding start and stop positions and automatic detection of the information for the weld line tracking are needed additionally.

This report will reveal the results of our study concerning the algorithm and its characteristics in case the optical method (the application of the BIP system) is adopted as the detecting technique for various informations necessary for performing these controls. Two kinds of dtection method were investigated, one was the light projection method which used the projector as a light source, others was the directly arc observing method which used the arc as a light source. The algorithm of the directly arc observing method will be described at the next report.

2. Information Extracting Principle and Apparatus

This method is that the light through the vertical slit is projected with the projector at the part of the groove, and the slit-image is picked up by the TV camera and its image processing[2] is performed by means of the micro-computer, prior to the arc start, for various measurement and detection described the preceding chapter[3]. The concept of the principle and an example of the image on the TV monitor obtained at that time are shown in **(a)** and **(b)** of **Fig. 1** respectively. The dark part which separate the bright one corresponds to the groove part in Fig. 1 (b).

The block diagram for the detection system is shown in **Fig. 2**. What is to be detected (say, slit image) is picked up by the TV camera, converted into digital value through

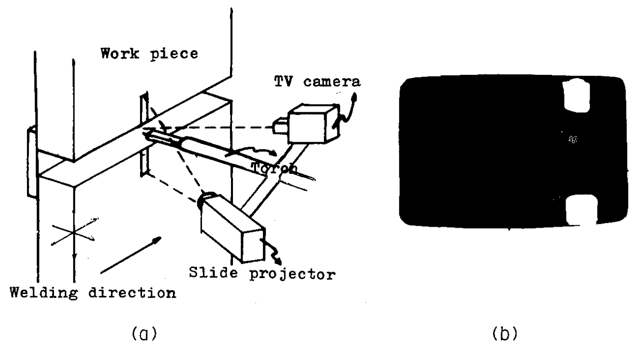

Fig. 1 Scheme of the image pickup system and one example of slit image on the TV-monitor.

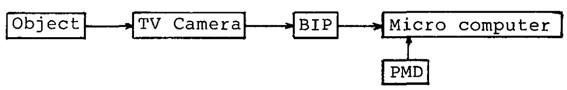

Fig. 2 Block diagram of the detection system.

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the BIP, then put in the micro-computer. After that, the necessary information of the groove shape is extracted by the image processing by means of internal operations of the micro-computer, at the same time, the information of the slit position is obtained by PMD (Position Measurement Device). The outline of BIP and the explanation of PMD are as follows.

(B I P) : Binary Image Processor[4])

The image obtained is a simple one which will fade out at the part of the groove as shown in Fig. 1 (b), So, BIP is applicable to this image.

With this, information redundancy is reduced and real-time data input is possible. The principle, as shown in **Fig. 3**, is that the image is divided into the points of vertical 256 and horizontal 128, and the summation of

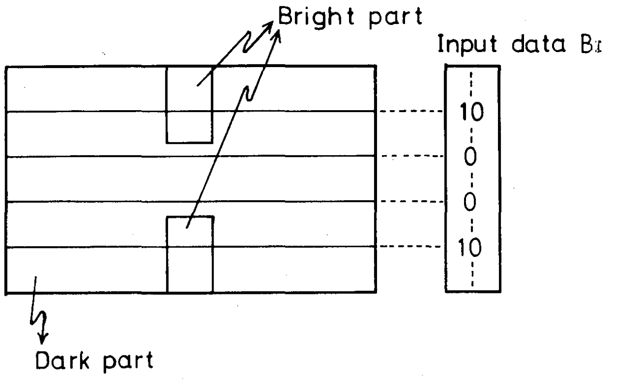

Fig. 3 Schematic explanation of the data reading method with the BIP (Binary Image Processor).

the horizontal direction for the points with brightness more than a threshold value becomes computer input data.

(P M D) : Position Measurement Device

By processing the image data obtained from Fig. 1 (b), the information of the groove part can be extracted. But, it is necessary to memorize the information of possition of slit image on the weldment as the slit image travells. **Figure 4** shows the block diagram for the position mea-

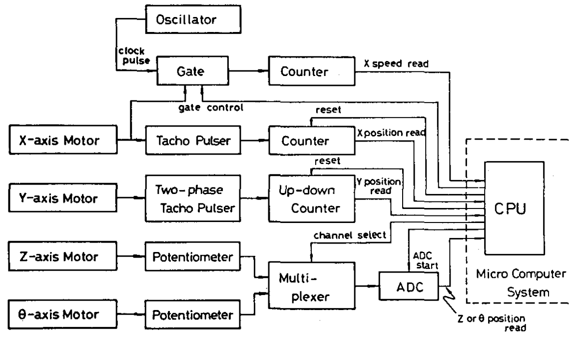

Fig. 4 Block diagram of the PMD (Position Measurement Device).

surement device. As seen in the figure, the following 4-axis positioning information is acquired; (See Fig. 1)

X direction (Weld line direction)
Y direction (Vertical direction)
Z direction (Plate thickness direction)
θ direction (Torch vertical angle)

The information on X-position can be obtained by counting the revolution of the motor shaft, and converting it into the travelling distance. The method adopted is shown as follows. The pulse generated from tacho pulser that synchronized with the X-motor is counted by the counter. Read and reset signals which control the counter gate are output from CPU, and at the latter signal, the counter is cleared. It is possible to measure the revolution number of the X-motor at the necessary time by generating these signals with computer software.

The information on Y-position can be obtained by the same principle as the X-position. Besides, the two-phase tacho pulser and up-down counter are adopted in order to measure the regular or reverse revolution of the Y-motor shaft, that is necessary in case of weld line tracking. The control method of counter gate by CPU is the same as the X-position.

The information on Z and θ positions is obtained by the device which is maked-up with the potentiometer, the multiplexer and A/D converter that are attached to the Z and θ axes. Direction selecting signal and start signal for the A/D converter are output from CPU, the indicated value of Z or θ potentiometer, which is selected by the former signal, is digitalized at the latter signal and the digital data are input to CPU at the next timing. It is possible to obtain the information on Z and θ positions at the necessary time in the same way like as X and Y positions.

The information on welding speed is necessary for controlling the welding speed. This becomes possible by applying the theory that the welding speed is in inverse proportion to the time interval of the pulse which is generated with the X-tacho pulser. The clock pulse which generated by the oscillator as a standard is input to the counter through the counter gate, which is controlled by the pulse from X-tacho pulser. The timing signal for counter gate control and the read signal of the counted value is output from CPU, so it is possible to obtain the information on the X-direction travelling and to calculate the welding speed on the basis of the counted value with computer operation.

3. Detecting Method

3.1 Method of groove width measurement and weld line detecting

The groove edge of Fig. 1 (b) image can be detected by recognizing the boundary portion of the bright and the dark parts in the vertical direction. The transition from the bright part to the dark part, corresponds to the B_I data as in **Fig. 5 (a).** In order to recognize the boundary portion from this, the differential operation which is given in Eq. (1) is applied.

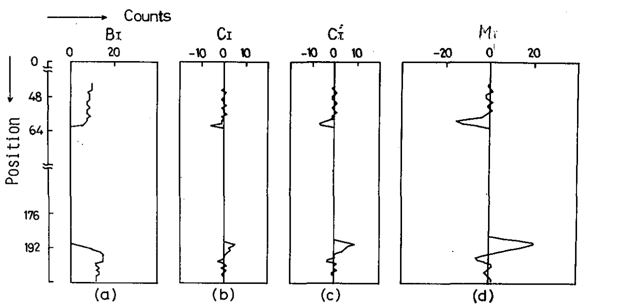

Fig. 5 Calculated result of the differential operation (C_I, C_I', M_I).

$$C_I = B_{I+1} - B_I \qquad (1)$$

The result of calculation of differential operation (C_I) is shown in **Fig. 5 (b).** In order to improve S/N ratio of the differential operation value (C_I), the operations of Eq. (2) and (3) are performed.

$$C_I' = C_I + C_{I+1} \qquad (2)$$

$$M_I = C_I' + C_I'_{+1} + C_I'_{+2} \qquad (3)$$

Equation (1) is substituted into Eq. (2) and (3), Eq. (2)' and (3)' are obtained. C_I' becomes one-step transferring spatial differentiations, and M_I becomes spatial differentiation for a minor region of before and behind.

$$C_I' = B_{I+2} - B_I \qquad (2)'$$

$$M_I = (B_{I+4} + B_{I+3}) - (B_{I+1} + B_I) \qquad (3)'$$

The results of these operations are shown in **Fig. 5 (c)** and **(d)** respectively. The S/N ratio of the data which point out the boundary portion of the bright and the dark parts is the most favorable in M_I value. The differential operation, as a result, has the maximum point of the absolute value near the groove edge in every cases, that is, the position where the absolute value becomes maximum can be stably detected as the groove edge position, by using M_I whose S/N ratio is the most favorable. The groove width can be obtained by calibrating the interval of the upper and lower edge positions with magnification of TV camera. By means of internal operation of the above-mentioned method by the computer, the upper and lower groove edge position come to be able to detect, accordingly, it is possible to measure the groove width. The weld line can be detected at the same time if the weld line is defined the center of groove. The algorithm for detecting is shown in **Fig. 6** as a flowchart. That is, this method is that algorithm has two buffers for data input, the data within the buffers are examined whether they have already processed whenever the interrupt signals enter (every 1/60 second), then new data are always stored in either data buffer. Owing to this algorithm, the time loss is reduced to zero at the time of data input. The control algorithm is shown in the left of Fig. 6, and the right

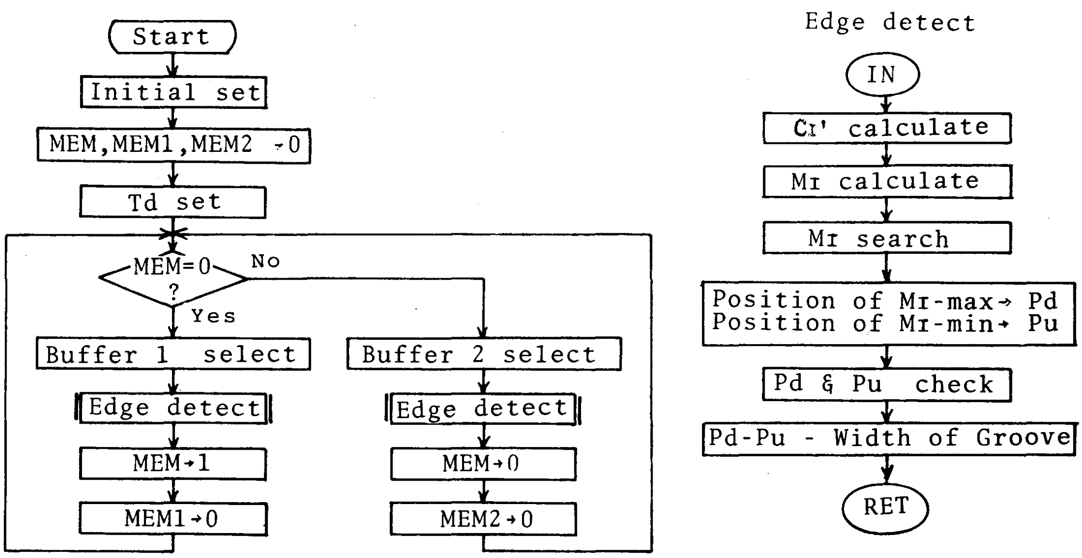

Fig. 6 Flowchart of algorithm for the groove width detection.

shows the groove width detecting routine.

According to this method, in case the resolving power of detecting system is 1/12 (mm), we have made sure that the groove width can be detected with the accuracy of approximately 0.2 (mm) by employing the standard test piece (processing accuracy 0.05 (mm)). The time required for looping in the flowchart is about 40 (msec).

In **Fig. 7**, the results that this detection technique is applied to practical weld material of gas cutting groove is

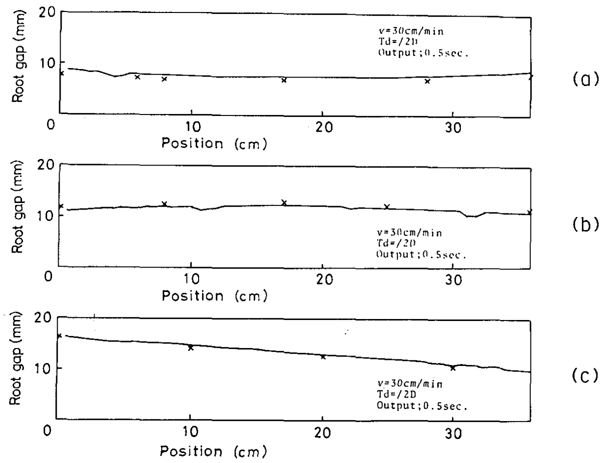

Fig. 7 Results of the groove width detection made for the test piece of practical material.

shown. In this figure, the result of detection is shown in (a) for the test piece with the groove width of approximately 8 (mm), the result of detection is shown in (b) for the test piece of approximately 12 (mm) and the result of detection is shown in (c) for the test piece whose groove width varies linearlly from about 15 (mm) to 9 (mm). The mark x in the figure is the result of manual measurement with an ordinary measure. From this results, it can be safely said that, by using this system, the groove width is detected with remarkable precision for the material put to practical use, and with high speed. In addition to that, we believe this system will be applied to various use as other measurement technique than welding engineering.

3.2 Welding start and stop positions detecing method

The start and stop positions of the weldment can be detected by supplementing a little more algorithm as groove width detecting algorithm. When the projecting slit image gets to the stop position on the weldment, its width is gradually reduced as **Fig. 8 (A),** untill it comes to null. The transition at the start position is quite the reverse of the above situation. In this way, the start and stop positions on the weldment can be detected by recognizing the transition pattern of the slit image. This image transition corresponds to the variation of M_I value

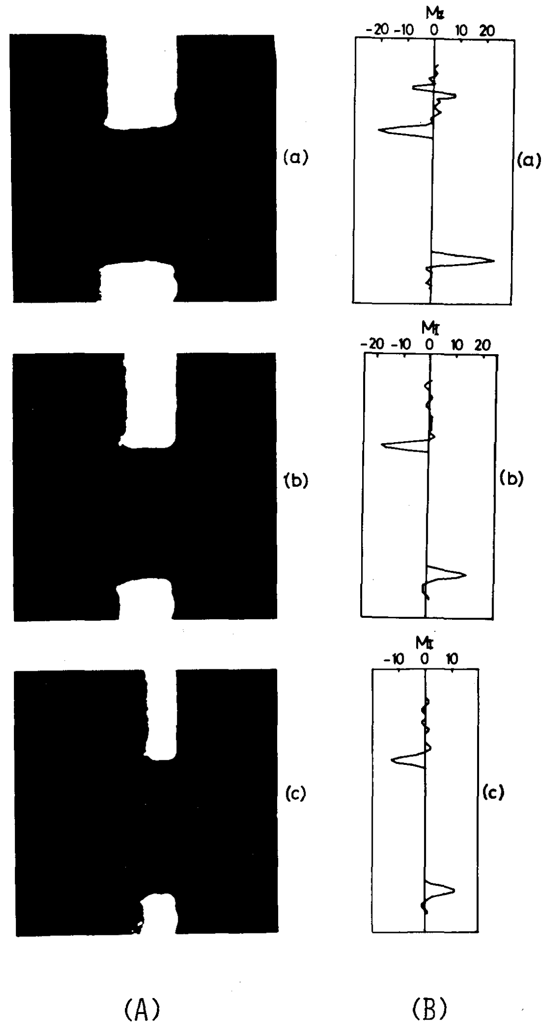

Fig. 8 Transition of the slit image and the differential operation (M_I) at the end part of the weld line.

as calculated in Eq. (3). (See **Fig. 8 (B)**). The automatic detection of the welding start and stop positions is possible according to recognize the variation for M_I value.

The algorithm for detecting the welding start and stop positions is shown in **Fig. 9** as a flowchart. In case M_I value of the slit image is calculated in real-time and it is continuously less than a certain value, the position of the slit image is measured with the device shown in Fig. 4 and is memorized as the end part of the weldment.

3.3 Processing for reduction of error due to noise

In the image processing performed by this detection method, error in detection due to sporadic noises can be eliminated by exerting the ingenuity in software. The technique is shown in **Fig. 10** as a flowchart. This technique is that the error in detection is eleiminated by the examination in which the present result is compared with the average value of the past three results and is regared as the error due to sporadic noise if the large difference as

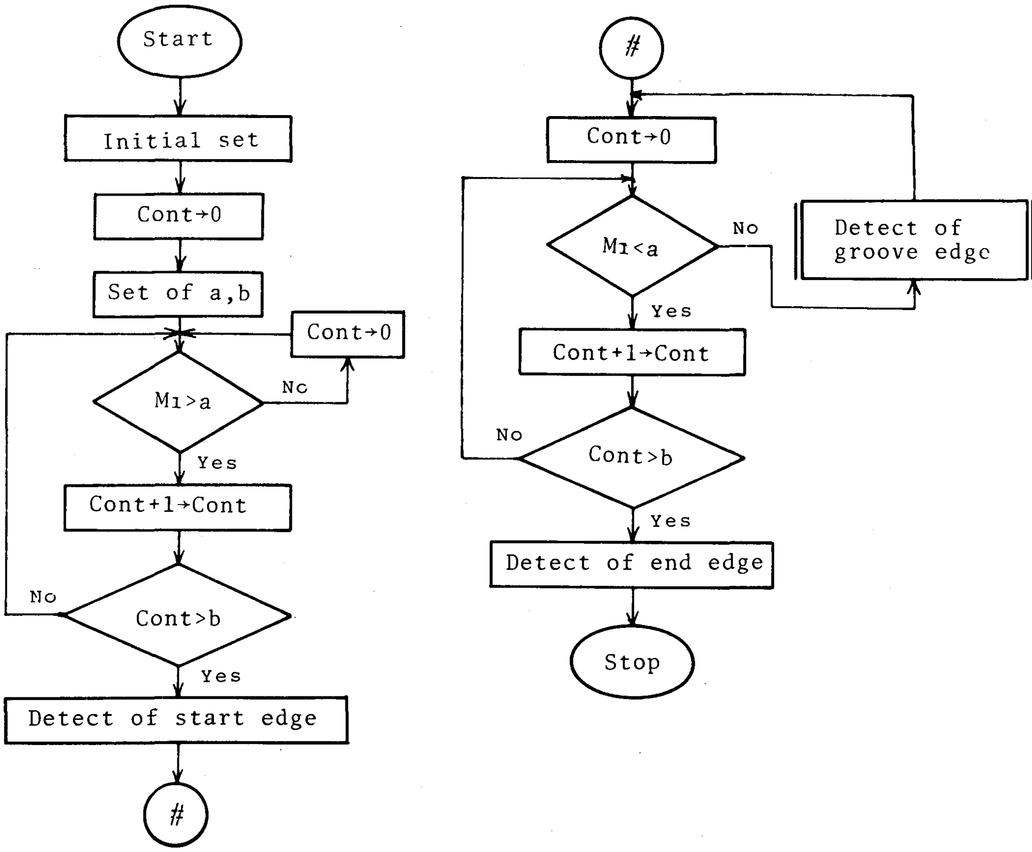

Fig. 9 Flowchart for detection of welding start and stop positions.

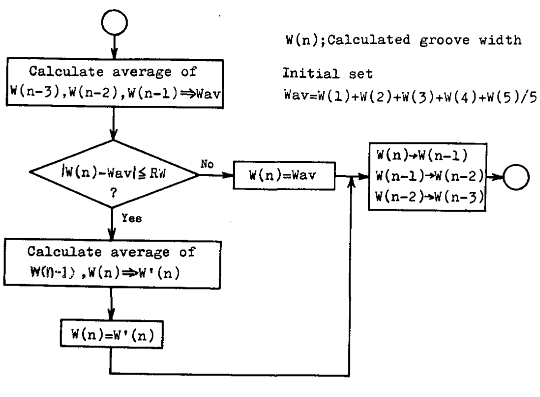

Fig. 10 Flowchart of operation for elimination of error in the groove width measurement.

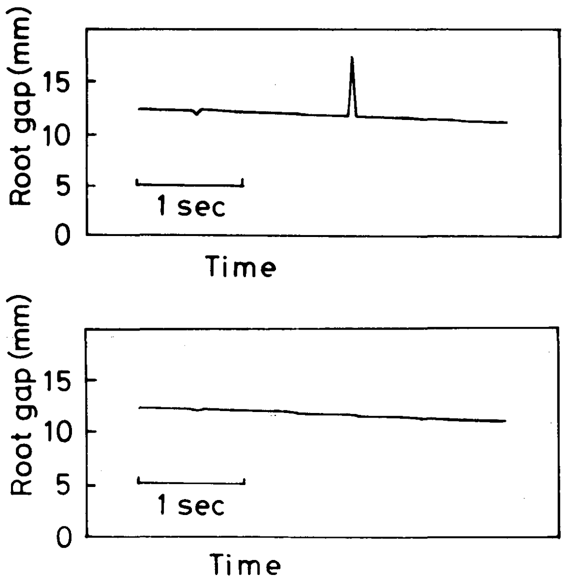

Fig. 11 Result of elimination of error in the groove width measurement.

beyond allowable limit is noticed between them.

Figure 11 shows the result of error elimination, it obtained favorable result. The result shown in Fig. 7 is also processed in the same way. It can be safely said that various examination routines utilizing such continuity are one of the features for our method.

3.4 Method for obtaining information on weld line tracking

If the control in Y direction is practiced, so as to keep the slit image position always constant in Y direction, the slit is tracking the weld line. Therefore, information for weld line tracking can be obtained, the position measurement system as shown in Fig. 4 is actuated and positioning information in X and Y directions are read with the computer and stored in the memory. Reading and storing the position information are practiced at regular intervals which can set at will in software. In this setting, if the interval is too little, the elaborate information can be obtained, so can extract the shape of object accurately, but memory capacity which store their information is increased, the other way, if too large, the little memory capacity is enough to store the information, but only rough information can be obtained. Experimentally, we get the result that interval length from 2.5 to 5 (mm) is proper for welding control. Practically speaking, the start and stop positions and groove width are measured with the control of Y direction being performed, and they are stored in the memory in sequence, corresponding to X and Y positions at that time. According to this method, two-dimensional information of the groove part is to be obtained. Its algorithm is shown by a flowchart in **Fig. 12.**

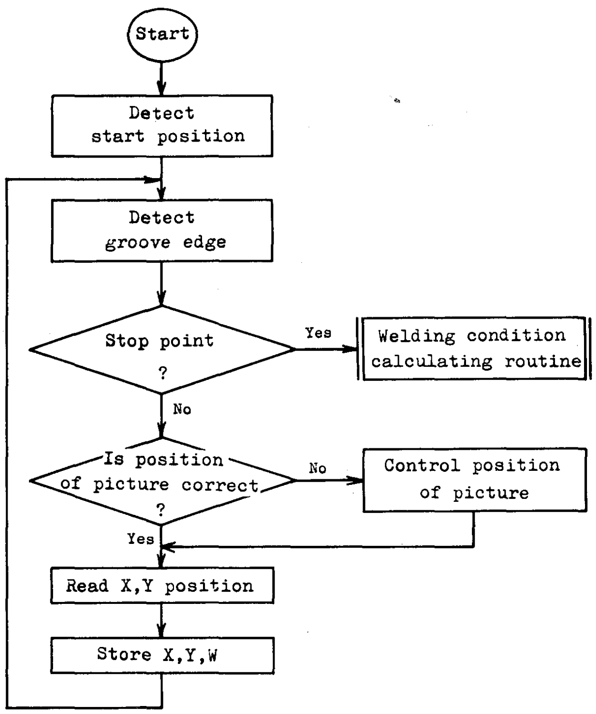

Fig. 12 Flowchart of algorithm for the weld line detection and the groove width measurement.

The result of measurement for the test piece which is maked up of the practical material and its groove width varies linearlly from 15 mm to 9 mm, and which is set on the slant by about 4 mm to the vertical direction is shown in **Fig. 13.** This is a result when interval length is set to 5 (mm). The two lines varying like stairs denote the vertical position of the groove edges, and the portion sandwiched in between them corresponds to the groove width. In the way, two-dimensional information is obtained stably.

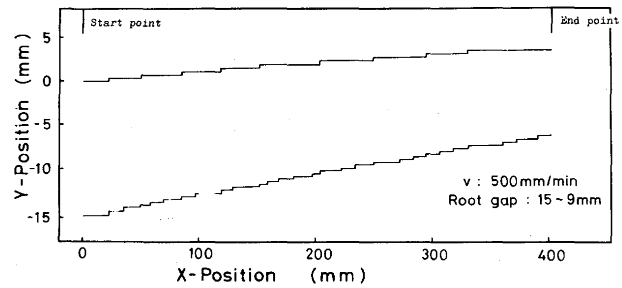

Fig. 13 Result of the groove width measurement for the test piece whose groove width varies linearly from 15 to 9 (mm).

4. Conclusion

With the object of developing the full-automatic control system of the horizontal narrow gap welding, we have made a through study of detecting technique for various kinds of information necessary for the controlling through the optical method. (application of micro computer).

Following is our concise summary of the results we have obtained by our systematic and searching investigations of the system;

(1) The groove width can be detected with the accuracy of about 0.2 (mm) by applying the specific algorithm to TV camera system, the BIP system and the micro computer system.
(2) The welding start and stop positions can be detected at the same time by supplementing some more algorithm to the groove width detecting algorithm.
(3) The information on the weld line tracking (movement in Y direction) can be obtained by making use of the TV camera system, the BIP system, the micro computer system and the PMD (Position Measurement Device) system.
(4) The intergration of the above-mentioned (1) to (3) algorithm enables the control to detect the welding start and stop positions, groove width and tracking information with a series of operations.

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