Development of a High Speed Rotating Arc Sensor System for Tracking Complicate Curved Fillet Welding Lines

Gun-You Lee[1,#], Myung-Suck Oh[2] and Sang-Bong Kim[2]

[1] Dept. of Mechatonics Eng., College of Eng., Pukyong National University, Busan, Korea,
[2] Dept. of Mechanical Eng., College of Eng., Pukyong National University, Busan, Korea

ABSTRACT

This paper presents development of a high speed rotating arc sensor system using a microprocessor based controller with tracking function for a complicate curved fillet welding line. The welding tip connected to the torch body is eccentrically positioned from the centerline of the torch. The area during one rotating cycle is divided into 4 regions of front, rear, right and left in welding direction of the torch tip to determine the horizontal deviation between the welding seam and the torch position. The average value at each region is calculated using the regional current values and a low pass filter incorporated with the moving average method is implemented. The effectiveness of the developed system is proven through the experimental results for several kinds of complicate curved fillet welding lines.

Key Words: Arc sensor, GMAW(Gas Metal Arc Welding), Seam tracking, Welding automation

1. Introduction

Today, a welding process is being strongly encouraged to improve quality, productivity and labor conditions. In the area of shipbuilding construction, an automated welding process is ultimately necessary, since welding sites are spatially enclosed by floors and girders, and welders are exposed to hostile working conditions. So, a welding process is a difficult manufacturing process because of insufficiency of skilled workers as well as decline of productivity and requirement of continuous and stable quality control. Robotic welding is widely adapted in several fields of welding shops for improvement of welding efficiency and liberating operators from severe working environment. In order to realize more compact and convenient automatic welding under complicate welding environment, an intelligent type of welding robot with ability of welding seam tracking is required[1, 2].

Nowadays, several kinds of sensors are used for welding seam tracking. A seam tracking sensor in an automated welding system is divided into touch-type sensor and non-touch-type sensor. In a touch-type sensor, there is a method of tracking welding seam mechanically. So it is easily broken and contaminated by welding environment. In a non-touch-type sensor, there are several kinds of methods such as using vision system, dual-electromagnetic sensor, and arc sensor. The vision system and dual-electromagnetic type sensor are expensive and very complex in structure[3].

The arc sensor has the advantages of compactness requiring no detectors around the welding torch, and of being unaffected by heat and arc light. The arc sensor weaves or rotates along the welding tip at appropriate speed according to various welding conditions and uses electrical signal obtained from welding arc itself. The seam tracking is performed by using current/voltage patterns changed according to variation of the

Manuscript received : April 11, 2003;
Accepted : September 30, 2003
Corresponding Author:
Email : msi1928@hanmail.net
Tel: +82-51-620-1606; Fax: +82-51-621-1411

tip-to-workpiece distance on one weaving or rotating cycle. In spite of welding smog, arc light and spatter, the arc sensor can precisely achieve seam tracking and lead to a satisfactory welding bead. Furthermore, it does not need a special detection device attached to the torch and its production cost is comparatively very low because it is developed by software based on arc characteristics[3~6].

Because the usual weaving arc sensor always needs a weaving pattern in the welding process and cannot have a weaving frequency over several Hz and welding speed is too slow, it is difficult to apply the sensor to corner part, rotating part and thin plate welding. As conventional methods of a weaving arc sensor, there are several kinds of methods such as a method to determine current value of the torch tip by obtaining average values of currents at both sides of a groove, a method using curve fitting, and signal processing algorithm based on neural network. Consequently the range of weaving arc sensor application is limited by the shape of a welding joint, thickness of welding object, sort of metal transfer and so on. Therefore, the development of the welding seam tracking device and algorithm applicable to various welding joints and welding conditions is requested[1, 3].

Several rotating arc sensors have been proposed in the literature for welding seam tracking. These approaches are focused on the function of seam tracking for smooth welding lines and quality of welding beads [3~6]. Therefore, the working angle between rotating tip and fillet welding is neglected. In the case of fillet welding, the working angle is maintained to be at right angle. Also, a study for software filtering of welding current with noise has not been done. In this paper, the horizontal deviation of the welding torch and the working angle are measured by a rotating arc sensor to track a complicate curved welding line. In order to measure the correct welding current under noise and disturbance, signal processing algorithm is proposed.

In this paper, a microprocessor based high speed rotating arc sensor system tracking complicate curved fillet welding lines is presented. The torch is rotated by a gear between torch body and wire guide. The welding tip connected to the torch body is eccentrically positioned from the centerline of torch. The welding current is measured by using the current sensor. To measure the rotating position of the torch tip on the welding line, a rotating position sensor is made by using 4 photo diodes and a circular plate with 1 hole. The orbit of the torch tip is separated into 4 regions of front, rear, right and left in the welding direction of the torch tip to determine the horizontal deviation of the welding torch and the working angle. The average value at each region is calculated using the regional current values and a low pass filter incorporated with the moving average method is implemented. The developed arc sensor system is designed so as to be applied to mobile robots and welding manipulators which can perform a lot of tasks such as fillet welding, corner welding and complicate curved welding line, etc. To apply flexibly this sensor system to any types of mobile robot platforms, the system is developed as one module type including rotating torch, welding acquisition system and controller. The effectiveness of the developed system is proved through the experimental results for several kinds of complicate curved fillet welding lines.

2. Composition of high speed rotating arc sensor system

2.1 Principle of rotating arc sensor

Robotized welding of large structures is usually accomplished by the GMA(Gas Metal Arc) welding process in which carbon dioxide gas, or a mixture of argon and carbon dioxide, is used. The welding power supply is of constant voltage and the wire feed speed is constant. Under these conditions, the welding current varies with the distance between the welding tip and the workpiece. As the distance increases, the current falls almost linearly. In the GMA welding process, in which this linear relationship is utilized, variations in welding current occurring as the torch rotates over the welding seam are used as input signals to control the torch position.

In the case of horizontal fillet welding, the principle of a high speed rotating arc welding process is shown in Fig. 1. The figure shows the basic waveform(solid line) of welding current in relation to the rotating position of the torch tip. If there is a horizontal deviation($\Delta y \neq 0$) between the welding seam and the torch position, the plot of the welding current will be represented by the dotted line in Fig. 1. By dividing the waveform at C_F(front) into left and right sections, and comparing the current values of these two sections, the aiming point of the torch can be detected. The rotating arc sensor enables a remarkably quick control response and increases the detection sensitivity of torch deviation, and offers extremely accurate seam tracking.

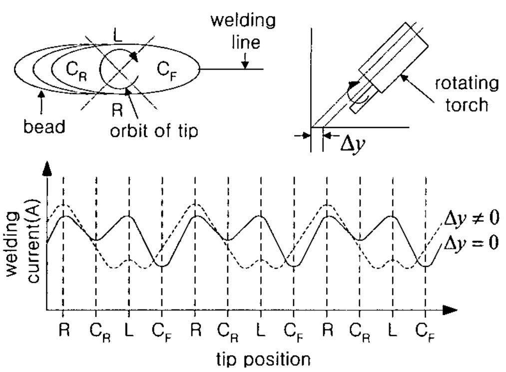


Fig. 1 Principle of seam tracking by rotating arc.

In this paper, using the principle of rotating arc, high speed rotating arc sensor system tracking a complicate curved fillet welding line is developed. It can be applied to mobile robots and manipulators for welding automation.

2.2 High speed rotating torch

In this paper, we developed a high speed rotating arc sensor rotated at about 25 ~ 50Hz using a DC motor as shown in Fig. 2. The torch is rotated by a gear between torch body and wire guide. The welding tip connected to the torch body is eccentrically positioned from the centerline of torch. The photo sensors are used for the speed control of the DC motor and the detection of rotating position. The welding current is measured by using a current sensor. In this case, because the current corresponding to a gap distance between tip and workpiece is changed, the sensor accuracy and response speed are high. It is possible for us to use this arc sensor for thin plate welding and overlap welding. We can also expect that quality of welding be improved in the welding process.

To measure the rotating position of the torch tip on the welding line, a rotating position sensor shown in Fig. 3 is made by using 4 photo diodes and a circular plate with 1 hole. The seam tracking algorithm is proposed by using the average current values at each interval section.

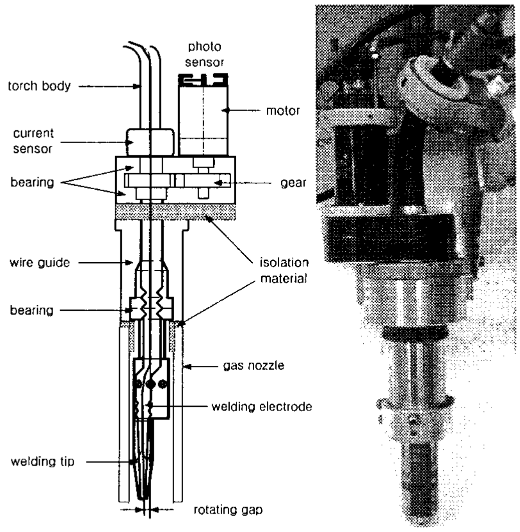


Fig. 2 Schematic diagram of high speed rotating arc sensor

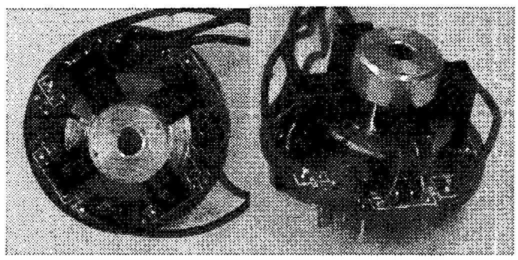


Fig. 3 Developed rotating position sensor

The developed arc sensor system is designed so as to be used in mobile robots and manipulators which can perform a lot of tasks such as fillet welding, corner welding, and gap welding, etc. To apply flexibly this sensor system to any types of mobile robot platforms, the system is developed as one module type including rotating torch, welding acquisition system and controller.

2.3 Hardware construction of arc sensor controller

The high speed rotating arc sensor system is composed of a microprocessor of Intel 80c196kc. The block diagram of the arc sensor system and welding mobile robot is shown in Fig. 4.

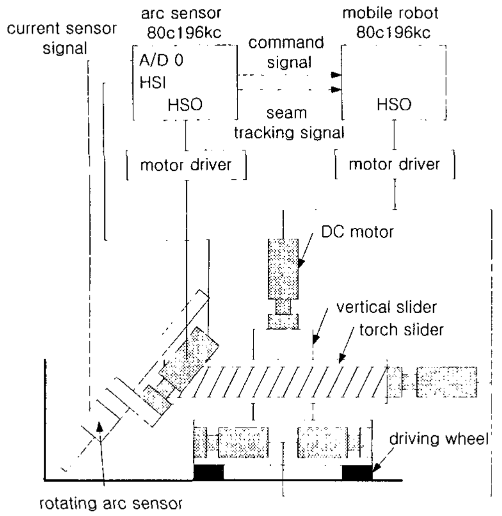


Fig. 4 Block diagram of high speed rotating arc sensor system and welding mobile robot

The microprocessor in the arc sensor system generates PWM(Pulse Width Modulation) waves for the DC motor by HSO(High Speed Output) function. The microprocessor measures the voltage value as the output signal of the current sensor with a 10-bit A/D converter, performs signal processing and realizes welding seam tracking algorithm. The signals detected from 4 photo diodes are put into HSI(High Speed Input) port of the microprocessor. The rotating positions are divided into 4 positions and each position is recognized by matching between hole position in a circular plate and position of the welding tip.

The controller of welding mobile robot generates 4 PWM waves for DC motors and receives the command signal and seam tracking signal, and control two sliders and welding speed. Fig. 5 shows the developed welding mobile robot.

3. Signal processing algorithm

3.1 Signal processing for software filter

For accurate seam tracking under noise and disturbance, the correct welding current signal is required. In generally, a hardware filter is used to reduce the effect of noise. In this paper, a software filter is implemented in the microprocessor. In order to improve the performance of the filter, a normal moving average method and a exponential smoothing method are used in the signal processing[1].

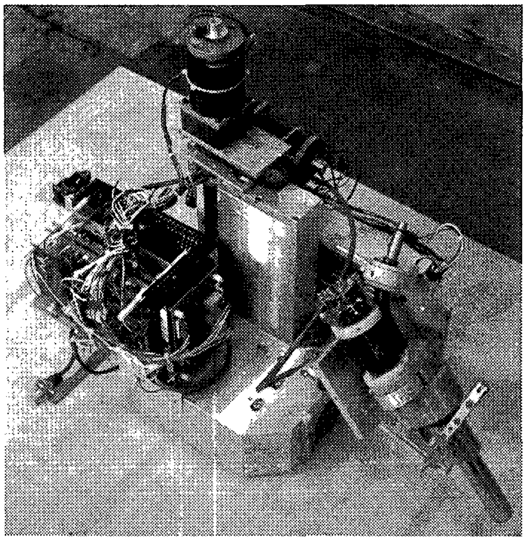


Fig. 5 Developed welding mobile robot and arc sensor system

As shown in Fig. 1, the welding zone in one cycle rotation of the torch tip is divided into 4 sections. One section is defined as a radial section around one point of C_F(front), R(right), C_R(rear) and L(left) in progressing direction of welding. In order to distinguish the current signals at the 4 sections, a rotating position sensor is used. The average value at each section is calculated.

We developed a new good performance software filter that uses moving average processing and section average processing. This signal processing can be summarized in the following:

[Step 1] Normal moving average method

The effect of the normal moving average method is similar to that of the low pass filter. The moving average is obtained by the average value of the current values sampled by A/D converter during m-th sampling time.

$$I_n = \frac{i_n + i_{n-1} + \cdots + i_{n-(m-1)}}{m} = \frac{\sum_{k=n-(m-1)}^{n} i_k}{m} \quad (1)$$

where,

i_n : nth sampling current,

I_n : nth moving average,

m : the number of sampling current.

[Step 2] Calculate section average value

To calculate the section average values, the moving average in [Step 1] is averaged as the following 4 values.

$$IC_F^d = \frac{I_{cd+1} + I_{cd+2} + \cdots + I_{cd+e}}{e}$$
$$IR^d = \frac{I_{cd+e+1} + I_{cd+e+2} + \cdots + I_{cd+2e}}{e}$$
$$IC_R^d = \frac{I_{cd+2e+1} + I_{cd+2e+2} + \cdots + I_{cd+3e}}{e}$$
$$IL^d = \frac{I_{cd+3e+1} + I_{cd+3e+2} + \cdots + I_{cd+4e}}{e} \quad (2)$$

where, IC_F^d, IR^d, IC_R^d and IL^d are average current values in the 4 sections corresponding to front, right, rear and left regions; c is a data number of one rotating, $d = n/c$ is the number of tip rotations and $e = c/4$.

Since the moving average method is operated to the welding current, signal processing for section average currents with welding noise is needed. In this paper, the exponential smoothing method is used for section average currents.

[Step 3] Exponential smoothing method

Using the exponential smoothing method, the section current values can be written as follows:

$$C_F^d = \sigma_1 IC_F^d + (1-\sigma_1) C_F^{d-1}$$
$$R^d = \sigma_2 IR^d + (1-\sigma_2) R^{d-1}$$
$$C_R^d = \sigma_3 IC_R^d + (1-\sigma_3) C_R^{d-1} \quad (3)$$
$$L^d = \sigma_4 IL^d + (1-\sigma_4) L^{d-1}$$

where, $\sigma_i < 1 (i = 1,2,3,4)$ is a weighting factor. ∎

The result of the signal processing is shown in Fig. 6. In this case, the rotating speed of the arc sensor is 50Hz, and sampling frequency of welding current is 5kHz. The welding speed is 40cm/min. The distance between welding seam and center of rotating arc sensor is 4mm. While the welding tip rotates, the measured welding current(solid line) is filtered by moving average method(dash dot line) and the section current values(dotted line) are calculated.

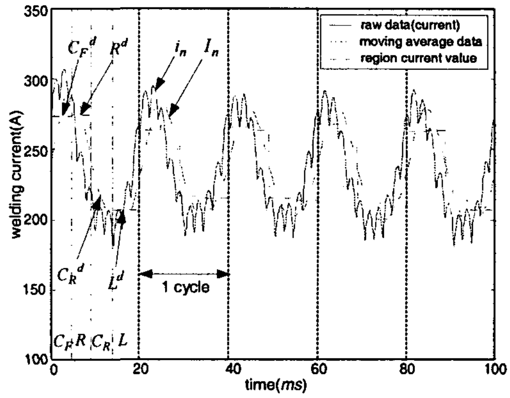


Fig. 6 Result of signal processing

3.2 Algorithm of seam tracking

In the case of general seam tracking with an arc sensor, the modeling relation of welding current is used. But the application range of the arc sensor using the modeling is limited by variation of welding condition. Therefore, it was difficult to track a welding seam by the modeling method of welding current.

In this paper, in order to solve such problems, the difference between left section current value(L^d) and right section current value(R^d) is used for the horizontal deviation error of the torch position. Also, after calculating the difference between center front section current(C_F^d) and center rear section current (C_R^d), the vertical deviation error of the torch position is calculated. The vertical current difference is represented as the working angle. The horizontal current difference($D_h = L^d - R^d$) and vertical current difference($D_v = C_F^d - C_R^d$) for Fig. 4 are shown in Fig. 5. In this case, the average welding current is 245A and the horizontal deviation error is 50A.

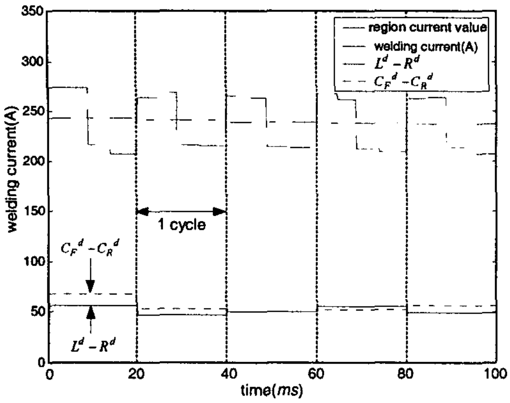


Fig. 7 Difference of area average data

To control the torch slider for seam tracking, a PID control method is used. The tracking error for the seam tracking sensor is defined as follows:

$$\begin{aligned} e_h &= C_H D_h \\ &= C_H(L^d - R^d) \end{aligned} \tag{4}$$

where C_H is constant. The control input for the torch slider is designed by using the PID controller:

$$u_s = K_P e_h + K_I \int e_h dt + K_D \dot{e}_h \tag{5}$$

The tracking algorithm is started after 0.5sec which seems sufficient to obtain some desired stable arc condition because high current is suddenly flowing as soon as the welding start switch is on. Even though the rotating arc is accurately adjusted on the center of a welding seam, the current signals measured at left and right sections are different from each other. So, an appropriate permission value for obtaining good welding bead must be selected according to the welding condition.

4. Experimental Results

The experiments were done to verify the performance of the developed system. The welding conditions used in the experiment are shown in Table 1.

Table 1 Welding conditions

Welding voltage	30V
Welding speed	40㎝/min
Sheld gas	CO2 gas
Electrode wire	Φ1.4㎜ solid wire
Base metal	Mild steel
Thickness of base metal	6㎜

In the case of experiment 1 ~ 3, the welding mobile robot is moved directly. The seam tracking is performed by the torch slider. In experiment 4, when the welding mobile robot rotating at the center of the robot, the welding speed is maintained at a constant value as shown in Fig. 8[2].

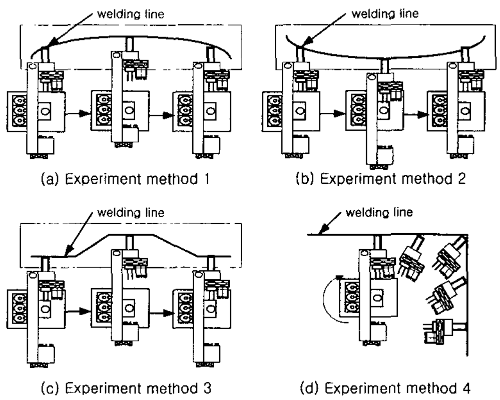
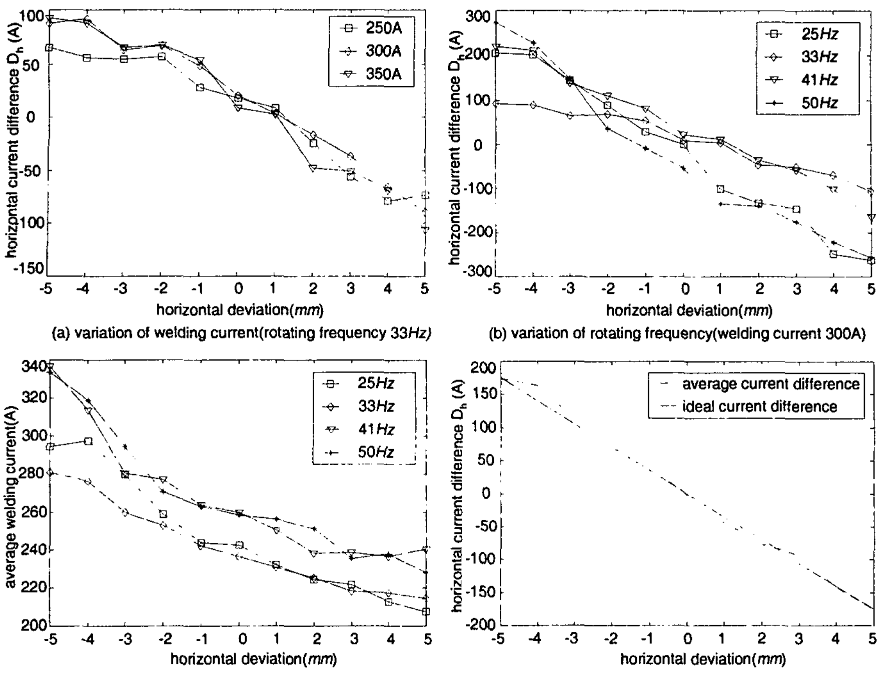


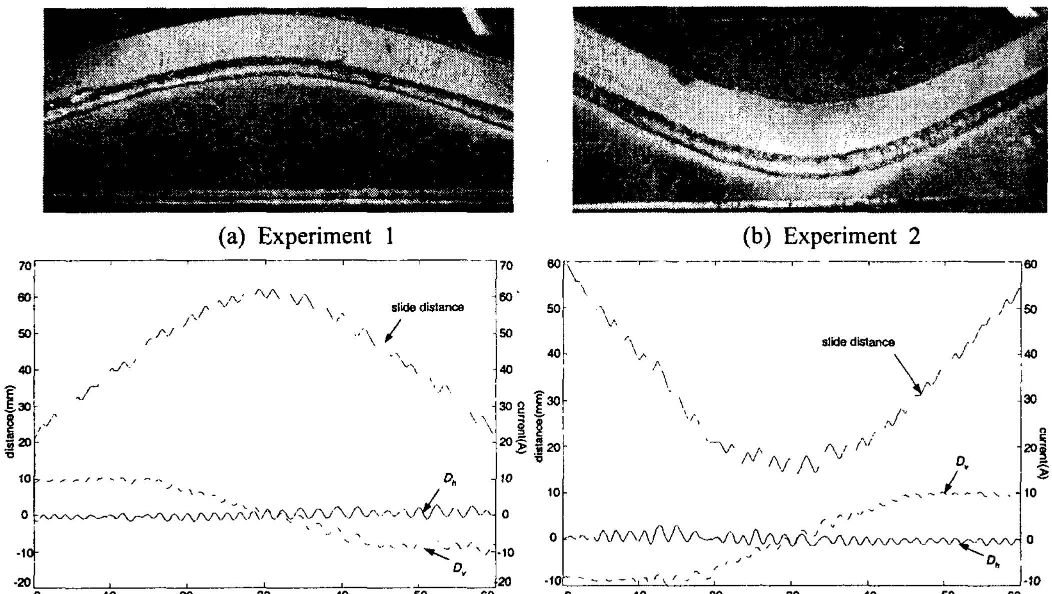
Fig. 8 Experiment methods

When welding conditions are changed, the relationships between horizontal deviation(Δy) and horizontal current difference(D_h) are shown in Fig. 9. In the case that the welding current varies, a decreasing rate of horizontal current difference is almost constant as shown in Fig. 9(a). But, the decreasing ratio varies according to the rotating frequency as shown in Fig. 9(b). Fig. 9(c) shows the average welding current for variation of the rotating frequency. The ideal current difference for horizontal deviation is shown in Fig. 9(d). Using this relationship, the correlation constant(C_H) in Eq. (4) is found to be -1/35.04(㎜/A).



(a) variation of welding current(rotating frequency 33Hz)
(b) variation of rotating frequency(welding current 300A)
(c) variation of rotating frequency(welding current 300A)
(d) average and ideal current difference

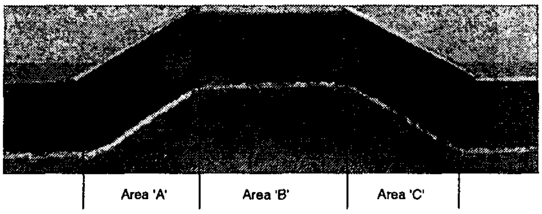
Fig. 9 Relationship between a horizontal deviation and horizontal current difference



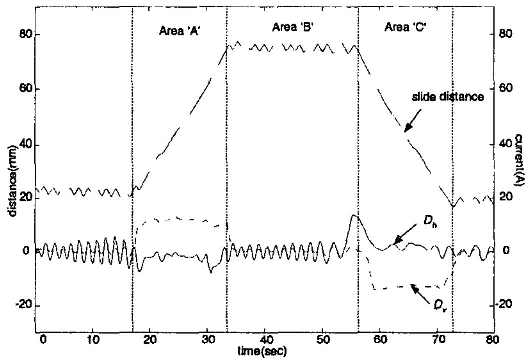
(a) Experiment 1
(b) Experiment 2
(c) Seam tracking result of Experiment 1
(d) Seam tracking result of Experiment 2

Fig. 10 Experimental results for curved type welding line

The experimental results for a curved welding line are shown in Fig. 10. The shape of the curved line and the result of seam tracking are shown in Fig. 10(a) and (b). In Fig. 10(c), (d), the slide distance, horizontal current difference(D_h) and vertical current difference (D_v) are shown. In this case, the vertical current difference is varied for the angle between rotating arc sensor and base metal. Therefore, the working angle between welding mobile robot and welding line can be measured.



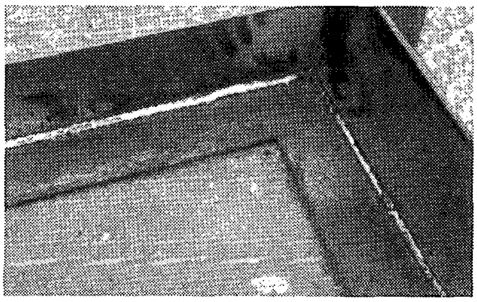
(a) Experiment 3



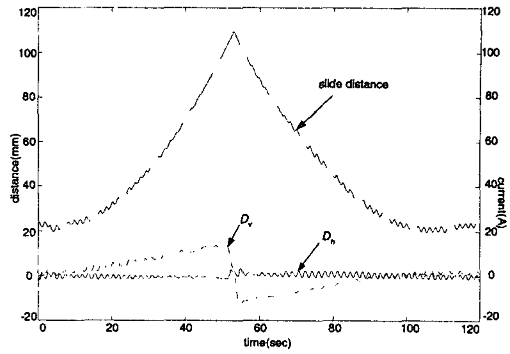
(b) Seam tracking result of Experiment 3

Fig. 11 Experimental results for trapezoid type welding line

The experimental results for a trapezoid welding line are shown in Fig. 11. The result of seam tracking is shown in Fig. 11(a). The slide distance and current differences(D_h, D_v) are illustrated in Fig. 11(b).



(a) Experiment 4



(b) Seam tracking result of Experiment 4

Fig. 12 Experimental results for lattice type welding line

The experimental results for lattice type welding line are shown in Fig. 12. The result of seam tracking is shown in Fig. 12(a). In Fig. 12(b), the slide distance and current differences are shown.

5. Conclusions

In this paper, a microprocessor based high speed rotating arc sensor system tracking a complicate curved fillet welding line is developed. The torch is rotated by a gear between torch body and wire guide. The welding tip connected to the torch body is eccentrically positioned from the centerline of torch. To measure the rotating position of the torch tip on welding line, a rotating position sensor is made by using 4 photo diodes and a circular plate with 1 hole. The orbit of the torch tip is separated into 4 regions of center front, center rear, right and left to decide the horizontal deviation of welding torch and the working angle. The average value at each region is calculated using the regional current values and a low pass filter incorporated with the moving average methods is implemented. The developed arc sensor system is designed so as be used in a mobile robot and manipulator which can perform a lot of tasks such as fillet welding, corner welding and complicate curved welding line, etc. To apply flexibly this sensor system to any type of mobile robot platform, the system is developed as one module type including rotating torch, welding acquisition system and controller. According to the experimental results, the effectiveness of the system is proved. We can see that the developed system can be applied to almost any types of welding robots.

Acknowledgement

This work was supported by the Brain Korea 21 Project in 2000.

References

1. Jeong S. K., Lee G. Y., Lee W. K. and Kim S. B., "Development of High Speed Rotating Arc Sensor and Seam Tracking Controller for Welding Robots," ISIE 2001, IEEE, Vol. 2, pp. 845-850, 2001.
2. Jeon Y. B., Kim S. B. and Park S. S., "Modeling and Motion Control of Mobile Robot for Lattice Type Welding," KSME, Vol. 16, No. 1, pp. 83-93, 2002.
3. Nomura H., "Sensors and Control Systems in Arc Welding," Chapman & Hall, 1994.
4. Nomura H., Sugitani Y. and Murayama Y., "Development of Automatic Fillet Welding Process with High Speed Rotating Arc," NKK, No. 112, pp. 75-80, 1986.
5. Sugitani Y., Murayama M. and Takano Y., "Development of Articulated Arc Welding Robot with High Speed Rotating Arc Process," NKK, No. 127, pp. 138-144, 1989.
6. Sugitani Y., Murayama M. and Tamaoki N., "Lattice Welding Robot with Arc Sensing Control," NKK, No. 153, pp. 66-71, 1996.