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Author(s)	Ushio, Masao
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Sensors in Arc Welding

Masao USHIO *

Abstract

Sensors used for automatic and robotic arc weldings are reviewed. Classification and full details of contact and non-contact sensors for seam tracking and adaptive control are described with some recent technical applications.

KEY WORDS : (Arc Welding) (Sensor) (Through-The-Arc Sensor) (Arc Sensor) (Adaptive Control) (Automatic Welding)

1. Introduction

Process sensing and control technology has become a commonplace as the key factor of recent welding technology, say, automatic welding and robotic welding. A wide range of sensors for joint tracking and adaptive control software in arc welding has been developed and applied in the automatic and robotic welding. However none of them satisfy all purposes and each has to be selected for the purpose it will be applied to.

Under the situation, The Technical Committee on Welding Processes of Japan Welding Society has published a welding guide book "SENSORS AND CONTROL SYSTEMS IN ARC WELDING", which includes the general review of sensors and their applications to arc welding process as well as 39 technical papers [1]. This report Will summarize the state-of-the-art review of the sensors and their applications used in arc welding.

As already stated by I. Masumoto et al., in 1982 [2], the sensors for arc welding is defined as follows; A detector, if it is capable of monitoring and controlling welding operation based on its own capacity to detect external and internal situations affecting welding results and transmit a detected value as a detection signal, is called as a sensor system (control system).

The external situations referred herein cover the presence of interfered members, change in welding groove dimensions, and welding line positions, and the presence of tack welds and its length while the internal situations cover the welding arc shape. the dimensions of molten pool, the penetration, the temperature distribution, the arc sound and so on, which are all related with welding phenomena themselves.

However the following cases are excluded from the objects for arc welding sensors here; 1) Sensors for power supplies, wire feeders and other equipment used with welding machines, 2) Sensors for welding robots, manipulators and other automatic welding machinery, 3) Sensors for welding recording, weld inspection. Therefore the objects detected by sensors are briefly described here as follows,

1) work shape errors,
2) setting errors,
3) groove shape change,
4) tack beads,
5) welding deformation,
6) jig error.

2. Classification of Sensors for Arc Welding

Generally, sensors used in arc welding are exposed to undesirable circumstances, which might disturb their stable operations. Arc light, arc heat, spatter, fume, electromagnetic field, bent or deflected electrode wires, unintended change in wire speed, wear down of contact tips, and fluctuations in welding conditions and arc shape. Sensors must be either protected from these disturbances or equipped with functions to eliminate them. The conditions that sensors must fulfill include, 1) the capability to maintain the accuracy proper to a specified welding process, 2) free from the influence of welding process-induced disturbances, 3) sufficiently durable and highly reliable, 4) inexpensive, 5) easy maintenance, 6) compact size and light weight, and 7) wide range applicability.

Welding control systems that use the sensors are classified as follows,

1) seam tracking control of weld lines,
2) adaptive control of welding conditions,

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* Professor

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3) seam tracking control and adaptive control,
4) welding monitoring.

Table 1 shows the sensors applied for many welding control systems.

3. Seam Tracking Control of Weld Line

Sensors used for seam tracking control of weld lines are mainly, contact (wire-touch) type sensor, electromagnetic sensor, through-the-arc sensor, and optical sensor, mounted in welding robot.

3.1 Contact-type Sensor

This sensor is a type which detects the change in electric current or voltage through the welding wire when it is placed into contact with a base material as illustrated in **Fig. 1**, and obtain the contact point from the coordinate of a robot or an automatic machine in service. They are generally called "wire touch sensor" or "wire earth sensor", or simply "touch sensor", A voltage ranging 300 to 600 V and 50 or 60 Hz is applied. To obtain steady contact, the tip of wire is sometimes automatically cut. And also to reduce the error comes from the misestimate of wire extension, a wire lock mechanism may be installed.

These sensor cannot be used during welding operation, and detect the welding start point.

3.2 Electromagnetic Sensor

This sensor is designed to determine the distance between torch and base metal by measuring the change in induced voltage of the detection coil due to the change in

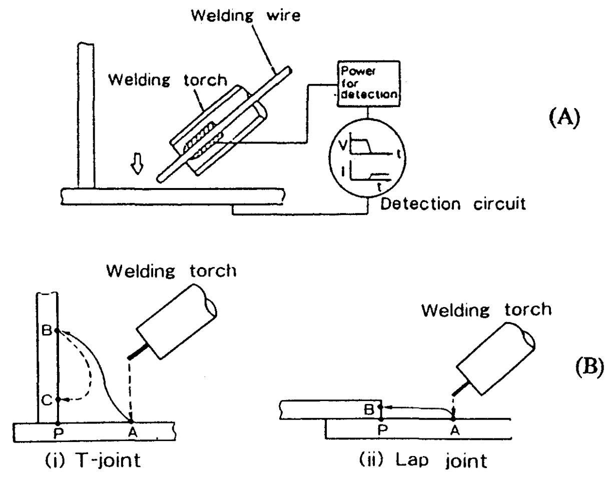

Fig. 1 Principle of contact-type sensor (A) and detecting of weld lines (B).

Eddy current effect. When the distance between a excite coil and a base metal is changed, the magnitude of the Eddy current is changed, thereby changing the impedance of the coil and consequently changing the induced voltage in detection coil.

The control system is designed to trace a welding line by laying out two electromagnetic sensors in a rectangular direction as illustrated in Fig. 2. The control system is applied to let a welding robot to trace a welding line and correct work setting error. Seam tracking control is carried out by detecting output signal changes produced when an attempt is made to oscillate the sensor as illustrated in the same figure.

Table 1 Classifications of sensors.

	Sensor type	Units in the sensor configurations
Contact	Contact probes	Micro-switches, potentiometers, and differential transformers (DTF).
	Electrode contact	Voltage and current for contact detection that is applied to the W electrode or the welding wire.
	Thermal	Thermocouples, thermistors.
Non-contact		Photo-thermometers, infrared thermometers.
	Arc characteristics	Welding current, arc voltage, wire feed speed, number of shorts, number of peak current anomalies.
	Electromagnetic	Electromagnetic eddy current detectors, magnetic detector by Hall devices.
	Optics	Point sensors (phototransistors and photodiodes), linear sensors (CCD, MOS, and PSD) and area (image) sensors (CCD, MOS, PSD and ITV).
	Sound	Variable sound pressure or ultrasonic sound pressure detector probes.

3.3 Through-the-arc Sensor

Generally, this sensor is called as "arc sensor", "ACC sensor", "AVC sensor", or "through-the-arc sensor". The principle is shown in **Fig. 3.**

When the welding torch is oscillated in the groove, the length of wire extension changes and causes the welding current to change in case of constant voltage type power source. By measuring the current change behavior, the torch position in the groove can be determined.

In the case of TIG welding, arc voltage is used, since the power source has the drooping or constant current characteristics.

Fiqure 4 shows the steady state arc characteristics of GMA welding with a mild steel wire of same feed rate, using a constant voltage power source. The welding current will increase when the distance between torch and base metal is shortened. On the other hand, the voltage between the torch and the base metal will decrease. In GMA welding, wire melting rate in equilibrium state is expressed as follows,

$$R = AI + BLI^2 \quad (1)$$

where, R:melting rate of wire, A,B: constants, L: extension, I: current. Then,

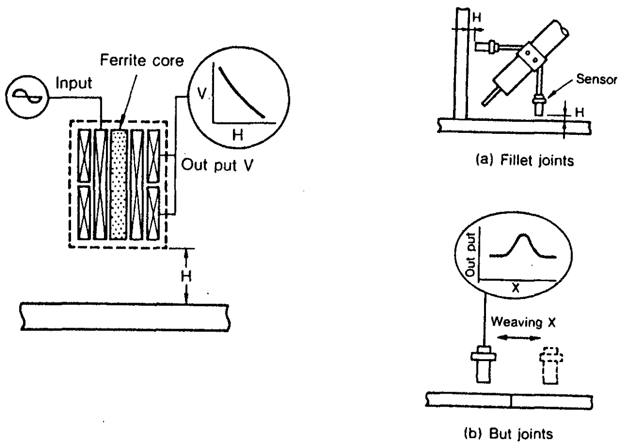

Fig. 2 Principle of electromagnetic sensor and application tp seam tracking.

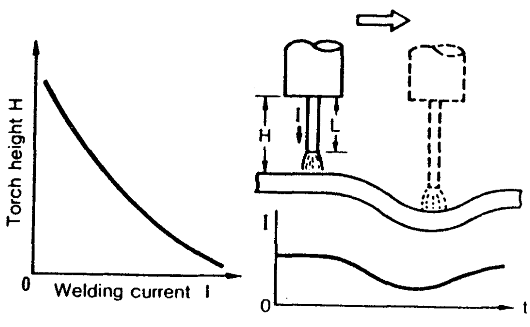

Fig. 3 Principle of through-the-arc sensor.

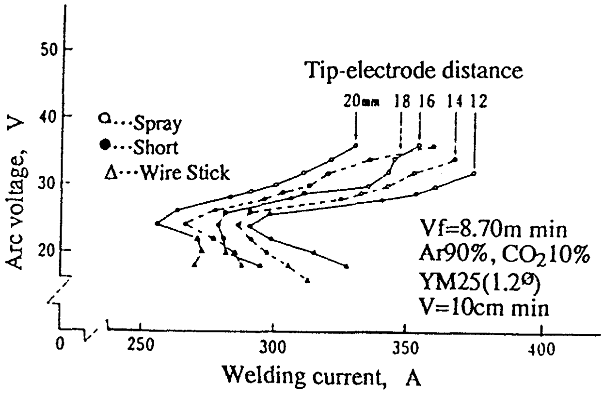

Fig. 4 GMA welding arc characteristics (wire feed rate: constant).

$$dI/dL = -BI^2/(A + 2BLI) \quad (2)$$

This equation clearly indicates that the current change rate increases with increases in welding current and wire feed rate (= wire melting rate in steady state) and also with decreases in wire extension and wire diameter (B is related with wire resistance and therefore wire diameter).

By the torch oscillation in the groove, current waveform changes as shown in **Fig. 5.** In this case, c denotes the center of torch oscillation width. As shown in the figure, when the oscillation center is not coincide with the groove center, the current waveform in the left half-cycle is not the same as the one of the right half-cycle. By moving the oscillation center so as to obtain the equivalent current in both half cycles, tracking of groove center could be carried out.

Many systems have been developed that uses the basic concept of arc sensor and some of them are show in **Fig. 6.** In almost cases, the torch is oscillated mechanically, but the torch may also placed in a place and the arc may be oscillated by electromagnetic force or gas blow,

These arc sensors are also applicable to short circuit transferred arc welding, which is most advantageous. However, because the detected signal is very noisy, some new data processing methed are being developed that comparing the averaged data sampled from left and right, or comparing the data from very near right and left edges.

By detecting the welding current, voltage, wire feed speed, the distance between contact tip and the base metal, can be calculated. In this case the applicability might be wide, because the symmetrical waveform of current is not necessary to determine the position of torch with respect to the groove.

3.4 Optical Sensor

Many control systems have been developed that use optical sensors. Different sensors are used in different ways as shown in **Fig. 7.**

Figure 7(a) shows that the point sensor which is

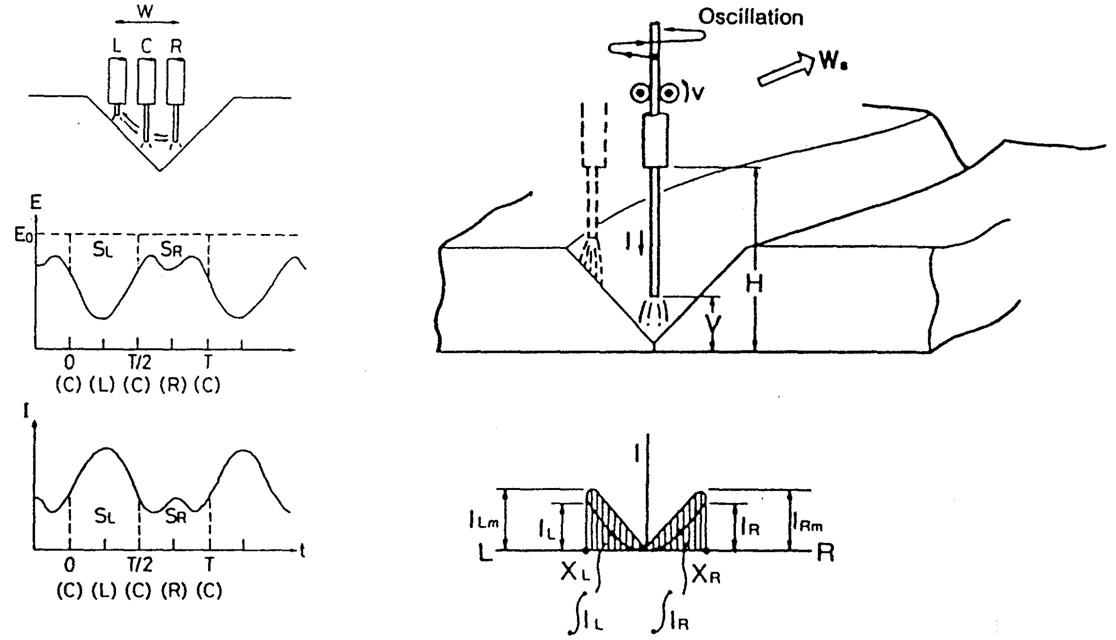

Fig. 5 Current waveform of oscillating arc and seam tracking by arc sensor.

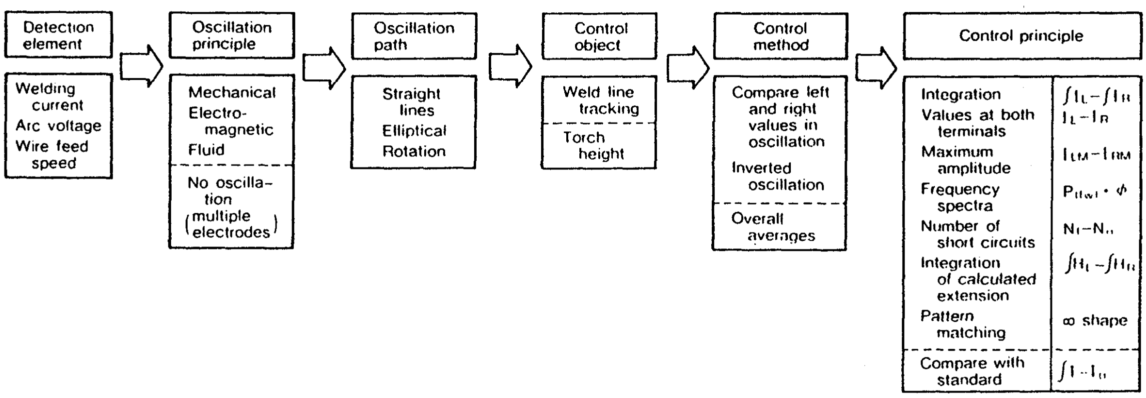

Fig. 6 Tracking control systems by arc sensor.

oscillated or rotated so that it moves laterally across the weld line. The quantity of light received and the sensor positions (coordinates) at that time are placed in two dimensions. The gap and groove position are detected and tracking is controlled.

Figure 7(b) shows a method in which a semiconductor laser or other point light source irradiates the base metal, a linear sensor detects the light positioned at fixed angle, and the emitted and received light are unitized. The changes in distance ΔH from the base metal is corresponding to the changes in the receiving position of the linear sensor by the quantity Δh.

This sensor comprises a system which controls the height of a torch for a constant value and a system which detects the variation of height of a base metal (lap joint and groove) by oscillating or rotating a detection unit and traces a welding line.

An area sensor comprises a system which receives slit light irradiated tom a base metal, processes an image, and hence judges a welding position, as shown in **Fig. 7(c),** and a system which processes an image near the arc and hence determines the position of the groove and welding wire, and the size of welding bead.

4. Adaptive and Tracking Control

The adaptive control is intended for a system which controls welding results (welding quality) in real time based on the information obtained from sensors. Recently, various research activities and development have been reported.

The object of control includes **(a)** welding bead shape (height and width), **(b)** back bead shape, **(c)** penetration depth, **(d)** deposit amount, and also the shape of molten pool or arc state (configuration and sound) are included.

Control elements comprise welding current, arc voltage, welding speed, arc position, AC polarity ratio, wire feed rate and so on. Various kinds of control technologies are introduced to perform adaptive control: they cover PI control, digital control, fuzzy control, modern control theory, and artificial intelligence.

4.1 Adaptive control with Temperature Sensor

This is a recently developed control system which controls welding parameters, such as peak current of pulse arc welding, DC arc current, and welding speed, by measuring the temperature of the surface of a base metal near weld beads or the temperature, thermal image ad luminance distribution of molten pool in order to control the penetration depth (width of back bead) of TIG weld (Stainless steel). **Figure 9** shows an example of control system which controls the shape of back beads of stainless pipe, using an infrared thermometer.

4.2 Adaptive Control with Through-the-arc Sensor

As illustrated in **Fig. 10,** this control system is capable of tracing a welding groove and detecting groove width by moving a welding torch in a groove under a constant

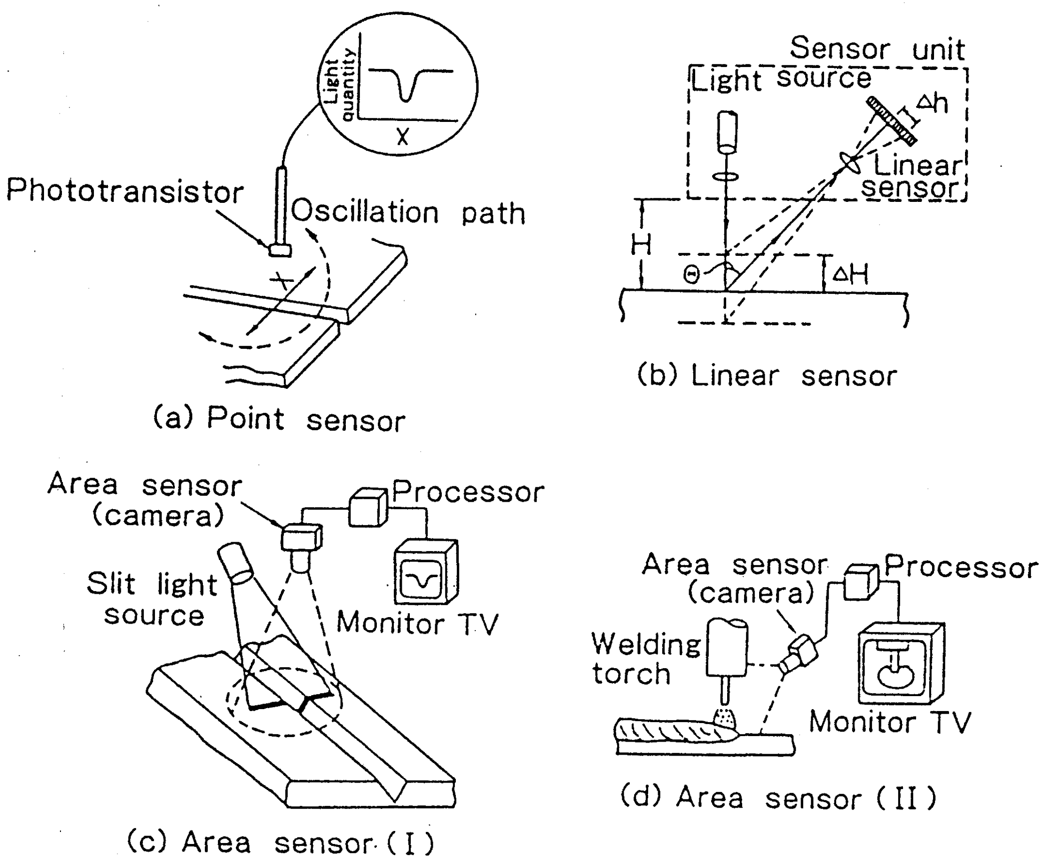

Fig. 7 Seam tracking control by optical sensor.

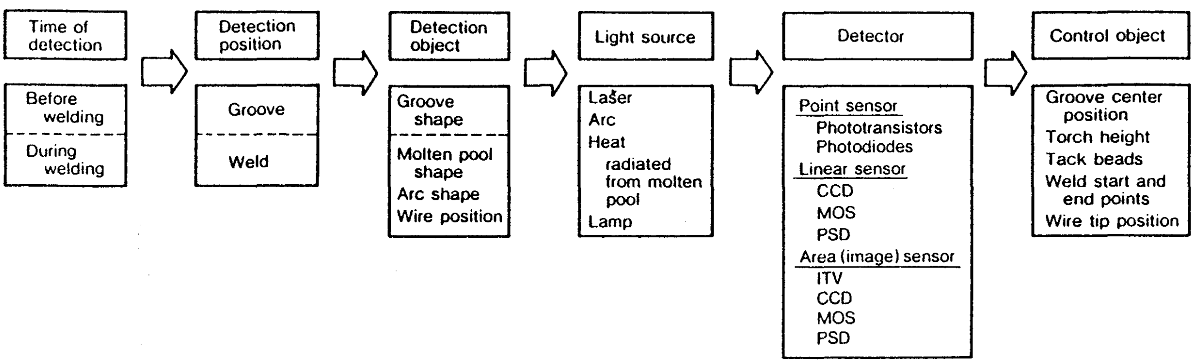

Fig. 8 Seam tracking control systems by optical sensor.

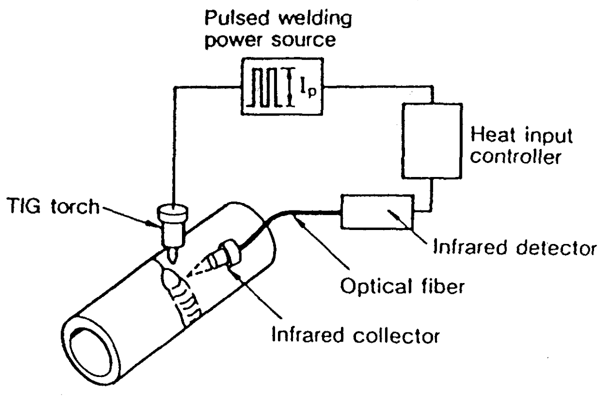

Fig. 9 Penetration control by pulsed arc.

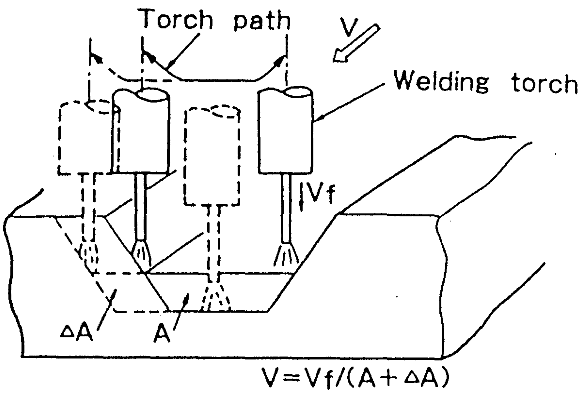

Fig. 10 Control of metal deposition.

extension control and turning round its movement direction when the height of the torch reaches a specified height. It is also capable of computing a deposit cross sectional area A from a detected groove width. Therefore, when the groove width changes, the variation A of the cross sectional area can be computed, which makes it possible to compute welding speed V at which a constant bead height can be obtained under control.

For other example, the adaptive control systems inciude **(a)** a system which controls welding speed and obtain a constant height of back beads since the frequency of short circuiting is associated with the shape of back beads in the route weld pass, and **(b)** a system which detects anomalies of welding current waveform and controls the welding speed so that the shape of back beads may be kept constant, and **(c)** a system which keeps constant width of back beads by controlling the welding current with detecting the voltage between a base material and a backing copper plate in one side SAW.

4.3 Adaptive Control Based on Optical Sensor

A control system is available which controls the width of back beads and the height of weld beads based on the application of a point sensor. This control system adopts four CdS sensors which detect an arc light quantity of SAW (submerged arc welding) penetrated into the back side of the plate, and controls constant width of back beads by controlling the welding current so that a constant amount of arc light may be obtained. Furthermore, in this system, an attempt is made to control filler wire amounts correlated to the welding current and obtain a constant height of weld bead.

The previous figure 7 shows an example of an image-processing adaptive control system based on the application of an area sensor which covers **(a)** to detect groove width, and keeps constant depth of penetration and the height of beads (deposit quantity) under the control of welding current and welding speed, **(b)** to detect groove width and keeps constant the width of weld beads and back beads under the control of polarity ratio of AC pulsed MIG arc current, and **(c)** to detect the width of molten pool and keeps constant the depth of penetration under the control of welding current.

4.4 Seam Tracking Control and Adaptive Control

Recently a welding control system has been developed which can perform simultaneously both seam tracking control of welding line and adaptive control of welding conditions based on the information obtained from a single sensor or combined sensors.

In the case of a single sensor, **(a)** seam tracking and the amount of deposit are controlled by an image processing of eight or heat distribution, by using an optical area sensor (See **Fig. 7(d)**).

In the case of hybrid sensors, seam tracking and bead shape are controlled based on **(a)** a combination of arc sensor and a optical linear sensor and **(b)** a combination of arc sensor and area (image) sensor.

5. Conclusions

Many types of sensor, tracking control and adaptive control technologies are now being developed. Future research and development will bring improvements in general purpose use and practicality of these technologies.

A survey by the Japan Welding Engineering Society on the situation of arc welding robot in 1987 showed that 73 percent of those robots were equipped with sensors, but only about half of them are performing to satisfaction. A survey by the Japan Welding Society's Welding Process Committee on sensors used in arc welding during fiscal 1981 and 1989 shows problems with sensors in terms of accuracy, repeatability, spatter protection, durability, size, shape and cost. Seventy to eighty percent of these sensors are used for tracking control; these is still little use of them for adaptive control.

The Japanese welding environment will change greatly in the future in terms of its shortage of trained welder personnel, reduction in work hours, growth in the electronics industry and in internationalization. Progress in welding will require greater used of robots and computerization.

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