Automated TIG Welding System with Visual Sensor for Repairing Nuclear Plants

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Abstract

An automated TIG welding system has been developed. This system is to be used for repairing nuclear plants, whose work environment is highly radioactive, so should have the automatic self control function and the remote controllable function. For this purpose, the visual sensor, a TV camera and an image processor, is installed and the image processing technique is applied to the all-position TIG welding system. In this system, all controls are made with microprocessors and every necessary information is displayed on the screen of the remote control unit.

The excellent performance was obtained as the application of this system to the practical field.

KEY WORDS: (Welding Automation) (All Position Welding) (Automatic TIG Welding) (Visual Sensor) (Image Processing) (Automatic Tracking) (Remote Control)

1. Introduction

For welding under a highly radioactive environment, for example, the periodic maintenance work at nuclear power plants, it is an essential problem to reduce the workers' exposure to radioactivity by any means, one of which is the utilization of a remote control unmanned welding system.

Until now, in Babcock Hitachi Co., automatic remote control TIG welding equipments with relay sequence control have been used for this purpose. However, its operation is very difficult if the weaving control is necessary, because there is no function of groove detection and weld line tracking, and the latitudinal position adjustment for the welding torch by manual monitoring using TV is needed.

There are some experiences for development of automatic welding equipment to which microcomputers are applied, represented by the all-position circumferential automatic TIG welding equipment, in Babcock Hitachi Co. On the other hand, the visual sensors for welding automations have been researched and developed since 1970's in JWRI.[1)–8)] The development of an automated TIG welding system with the visual sensor, with which latitudinal weld line tracking suitable for remote operation became possible, especially in a practial field, was planned as a cooperative work of JWRI and Babcock Hitachi Co.

And now, the new system has been developed for repairing nuclear plants. The details are introduced as follows.

2. Automatic Remote Control TIG Welding System

2.1 System requirements

The welding system to be developed is to be used for welding nozzles and piping in the periodic maintenance work at nuclear plants. It is required not only to assure high weld quality within a fixed time schedule of work, but to be used in considerably different circumstances from other ordinary welding works, that is to say, it must be operated in a radioactive environment of high degree, and so retouching is difficult even if the defects are found out. Then, it is quite essential to secure high reliability and accuracy for this system.

The following items are, therefore, considered in the development.

(1) From the view points of usability and reliability, the system should have the same composition as the all-position circumferential automatic TIG welding system that has ever been used in Babcock Hitachi Co.
(2) The total monitoring and welding monitoring units for remote operation should be equiped with the system.
(3) The visual sensor, the so-called image processing technique, is necessary to attain the above item.
(4) The operability in such special region of high radioactivity is necessary.

2.2 Construction of the total system

The total system consists of the control unit by which

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remote operation is possible, and the welding unit by which welding work is performed. The block diagram of the total system is shown in **Fig. 1**.

The control unit consists of the welding controller, the image processor, the monitoring CRTs for various purposes, the welding power supply and the cooling water supply. The welding unit consists of the welding head, the joint box, the control box and the monitoring TV camera. The control unit and the welding unit are connected with a long cable of 20 m length which can be elongated up to 100 m.

2.3 Control system

The scheme and the appearance of the control system are shown in **Figs. 2** and **3** respectively. The 8 bit microprocessor, 6800 type, for which the authors have much experiences in practical applications is used. Good performance can be got in remote operation on the basis of

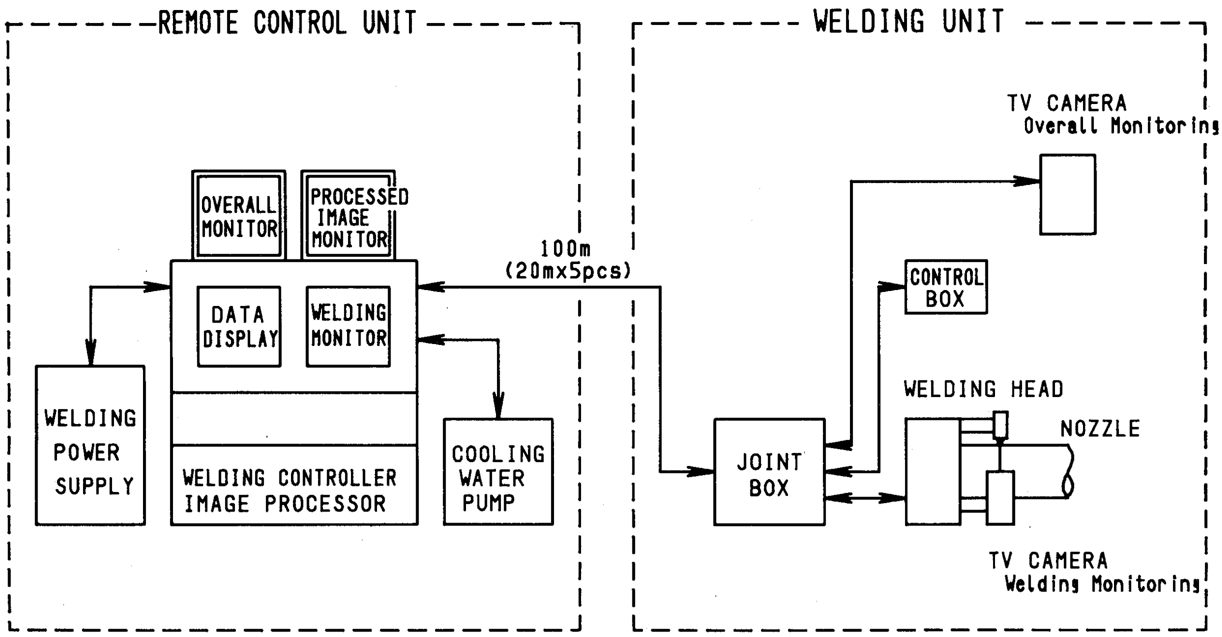


Fig. 1 Block diagram of automatic remote control TIG welding system.

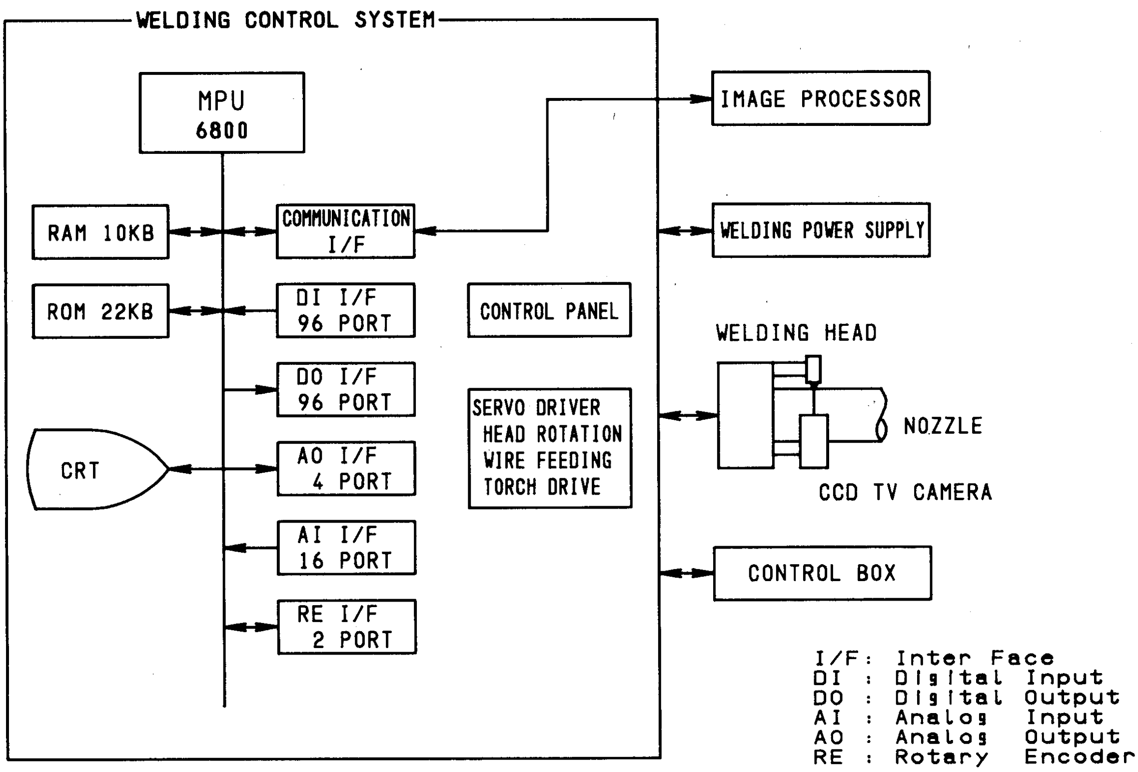


Fig. 2 Block diagram of welding control system.

Fig. 3 Appearance of control panel.

numerical control with combination of a DC servo motor and an incremental encoder. Details of its control panel can be seen in **Fig. 4**.

On the assumption that the operation is made by workers who wear strict radiation protection suits, all operations from the condition setting for the welding to the remote welding work can be made by only pushing the button switches on this panel. The display consists of 4 CRT screens; the data display, the monitor for the welding process, the total monitor and the processed image monitor which enable every condition to be continuously monitored.

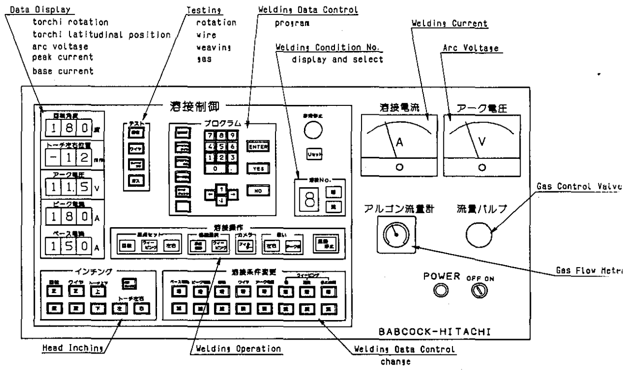


Fig. 4 Schema of control panel.

2.4 Welding head

Figure 5 shows the appearance of the welding head. It consists of the clamp unit, the rotation unit, the torch unit, the wire feeding unit and the TV camera unit. There are few restriction on this welding head as the followings.

(1) It is required to simplify the clamp mechanism to reduce the set-up time because frequently attach- and detaching of the welding head are necessary at the time of the base metal preheating. The heat resistance of up to about 200°C is required for the clamp unit.

(2) It is difficult to apply the type of the head on which halved rails are attached to the nozzle because of the weld part configuration.

The mechanism that can be clamp the end surface of

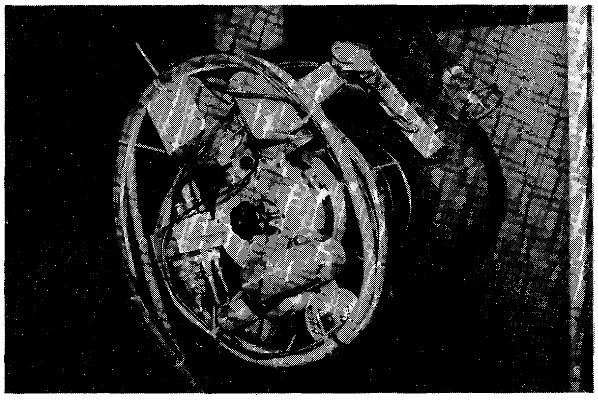


Fig. 5 Appearance of welding head.

the nozzle by one-touch action for the clamp unit is adopted. The attach- and detaching can be made without any adjustment of the latitudinal torch position by using this mechanism because the end surface is usually machine-finished.

The arc length control device and the weaving mechanism are installed on the torch unit. The incremental encoders are used to read the positions of the rotating head and the latitudinal driven torch. **Table 1** shows the specification of the welding head.

2.5 Control function

The general sequence of the welding process is shown in **Fig. 6**. The sequence is fully controlled by microprocessor. The specification of this sequence is the same as the one for the above mentioned all-position automatic TIG welding equipment.

The functions of the welding controller are shown in **Table 2.**

Each item is described below:

(1) Data input

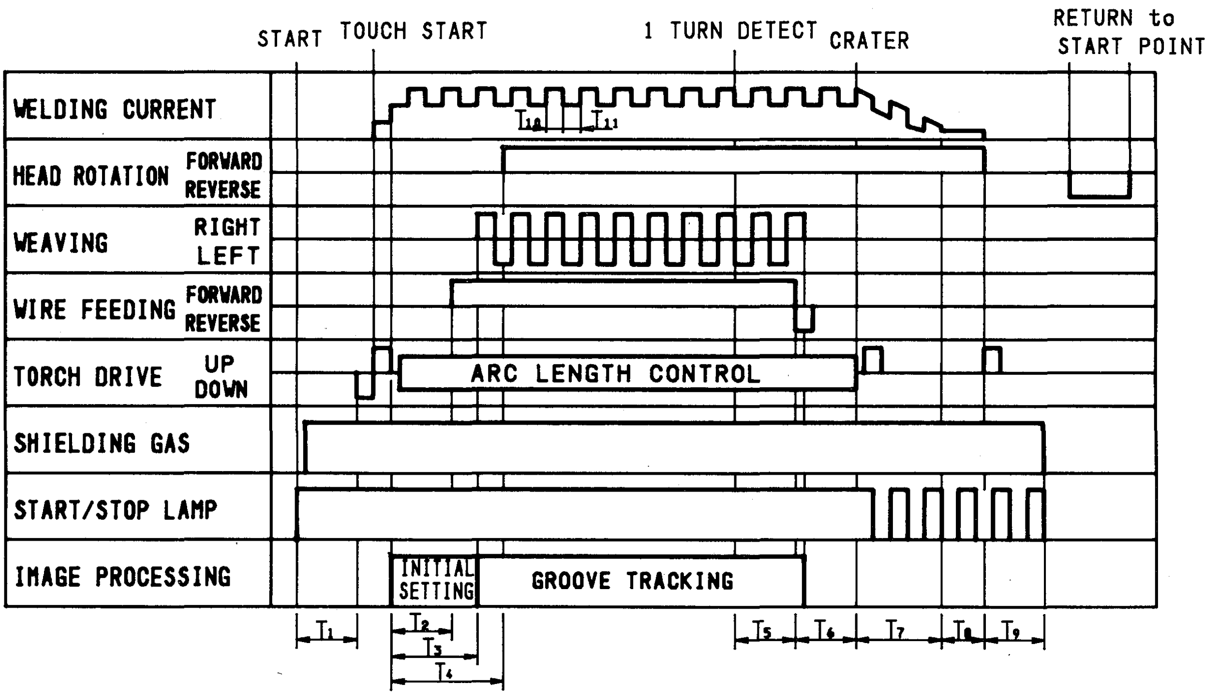
On the equipment used hitherto on which data input operation was made by digital switch setting, so there were certain problems such as bad operability and so on. Therefore, CRT display has been introduced for data control of this system. The input mode by graphic indication, which enables anyone to operate easily, is applied to the position control data operation. Examples of the CRT image plane are shown in **Figs. 7 and 8**. As for the data of the welding condition, 10 combinations can be controlled by using this display.

(2) Position control

In the case of all-position welding, the data of the condition must be changed according as the welding position. The correction values at a few divided points on the circumference are set and the welding condition is changed appropriately according to these set values at each point along one round of the welding head. However, in such method, the welding condition always starts from the initial one wherever the welding start point is, thus the

Table 1 Specifications of Welding Head

ITEMS	SPEC.	REMARKS
HEAD ROTATION		
Speed	~ 5.1 rpm	
Torque	max 240 Kg-cm	
Resolution	0.15 deg.	Pulse Encoder
TORCH MOVEMENT		
Vertical		
Stroke	40 mm	
Speed	160,320 mm/min	2 Speed Drive
Force	~ 7.2 Kg	
Traverse		6w DC-Servo Drive
Stroke	max 50 mm	
Speed	~ 780 mm/min	
Force	max 20 Kg	
Resolution	0.016 mm	Pulse Encoder
WIRE FEEDER		6w DC-Servo Drive
Feed Rate	~ 1300 mm/min	
Wire Size	ϕ 1.2 mmϕ	
Force	max 17 Kg	
TORCH		
Electrode	ϕ3.2 mmϕ	2% Th Tungsten
Capacity	300 A	
Cooling	Water	



T 1 : PRE-FLOW
T 2 : WIRE FEEDING DELAY
T 3 : WEAVING DELAY
T 4 : HEAD ROTATION DELAY
T 5 : WIRE STOP DELAY
T 6 : CRATER DELAY
T 7 : DOWN SLOPE
T 8 : CRATER TIME
T 9 : AFTER FLOW
T 10: PEAK TIME
T 11: BASE TIME

Fig. 6 General sequence of welding process.

Table 2 Functions of Welding Controller

ITEMS	FUNCTIONS
DATA CONTROL	
Input Operation	Data Key and CRT Monitor
Stored Welding Data	10 Combinations
Digital Data Display	Current, Voltage, Torch Position
WELDING CONTROL	
Low Pulsed Current	
Revised by Position	
Arc Start	Touch Start Sequence
TORCH CONTROL	
Rotation	
Traverse	Weaving Control
Vertical	Arc Length Control
AUXILIARY CONTROL	
Interlock	Gas, Water, Arc Voltage, Machine Trouble
Self Check	Tolerance of Motor Speed
	Weaving Motion

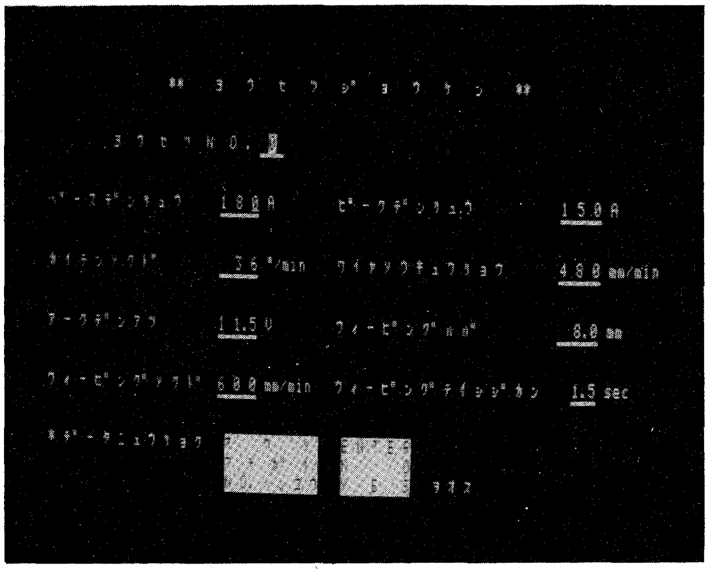


Fig. 7 Example for welding data programming.

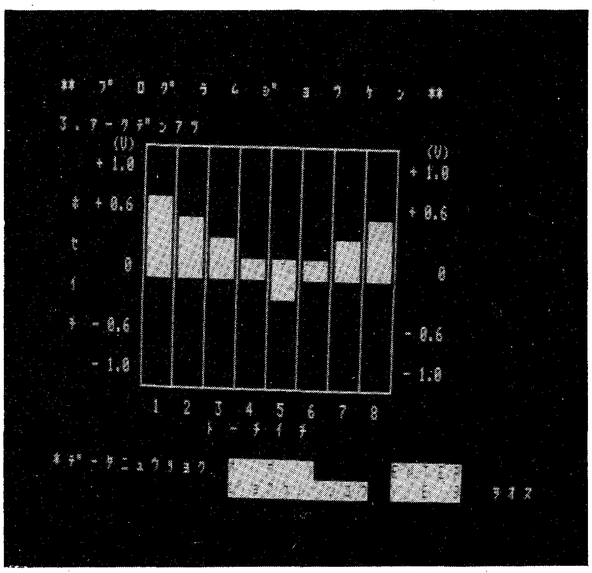


Fig. 8 Example for position control data input by graphic operation.

proper condition can not be necessarily given.

On this system, the correction values for the welding condition are set at 8 divided points on the circumference and the torch position is sensed precisely with the incremental encoder, further more, linear interporation is applied between the divided points so that the conditions can be changed continuously, as the result, the welding condition can always set suitably and the welding process can be maintained in a proper condition wherever point the welding starts from. That is to say, the welding current, the wire feeding rate, and the arc length are controlled properly according to the information of the position of the welding head.

(3) Rotation and weaving control

An orthodox servo control method using a tacho-generator is adopted by the reason that this system is required for wide range speed control and handling heavy load including cables, etc. Accurate numerical control can also be made on using the information of the incremental encoder.

(4) Other control

The welding condition such as the peak and the base arc current, the arc voltage, the circumferential and latitudinal torch position are monitored and indicated in digital. Every condition can be changed with a panel switch during welding. Furthermore, the cooling water, the shield gas (argon), the arc voltage and others are always monitored continuously, and in case the abnormal state occurs, the monitoring system ensures that the whole system is stopped following the pre-arranged sequence and the trouble cause is indicated on the display.

3. Groove Detection and Weldline Tracking Control

3.1 Image processing system

The image processing system consists of the TV camera with which the arc image is picked up and the computer with which the video signal from the TV camera is processed. The construction and the specifications of the used device in this system are shown in **Fig. 9** and **Table 3** respectively.

Each item is described below;

(1) TV camera

Two practical systems can be considered as a pick-up device for the arc image, one is the system in which the image is picked up directly by a TV camera, the other is the system in which the image is transmitted by a fiber system consists of a scope and an image guide. The latter can be more compact as an image pick-up head than the former, but it was not adopted by the reason of the following faults;

a) Less number of pixels, so lower resolution.
b) In the case of quartz fiber, the arc image becomes indistinct.
c) The image becomes dark due to various losses in the fiber guide.
d) Fragile.
e) Expensive.

The camera unit used in the system is shown in **Fig. 10.** It has the following features;

a) A clear arc image can be obtained by combination of

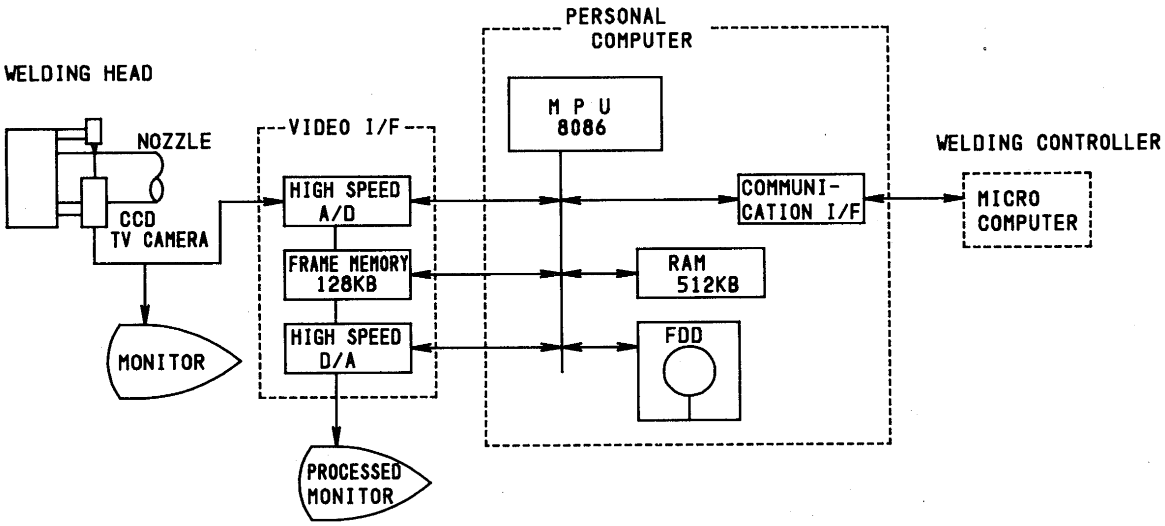


Fig. 9 Block diagram of image processing system.

Table 3 Specifications of Image Processing System

ITEMS	SPECIFICATION	
TV CAMERA		
Optical Parts	Heat Absorbing Filter	
	IR Absorbing Filter	
	Shielding Grass	
	Close Up Lens	
	Lens 16 mm F1.4	View 90 × 67 at 210 mm
Body	CCD Solid Camera	Pixel 384 × 491
COMPUTER		
CPU	MPU 8086 (8 MHz)	
	RAM 512 KB	
	ROM 96 KB	
Video Sampling	Pixel	256 × 256 monochrome
Unit	Sampling Time	1/60 sec
	Tone	6 BIT
	Frame Memory	64 KB × 2
Communication	Parallel 10 Bit × 2	Isolated
Software	o. s. MS-DOS	
	Language Assembler	

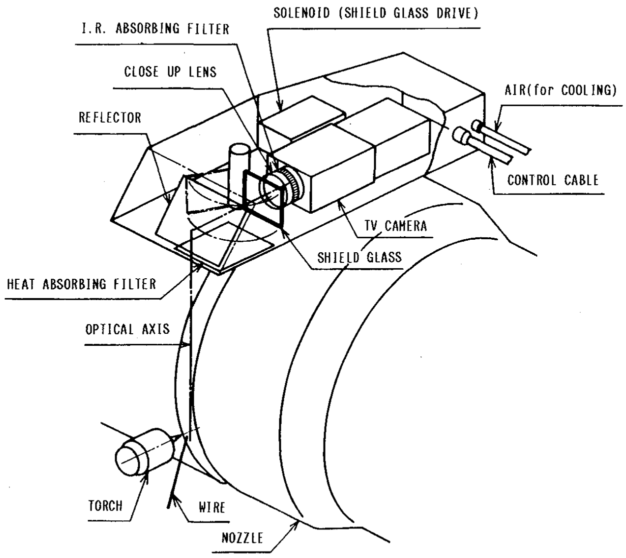


Fig. 10 Schema of TV camera unit.

the heat absorbing filter, the shield glass and the I.R. absorbing filter. An example of the image picked up with the camera unit is shown in **Fig. 11**.

b) A temperature rise is prevented not only by applying insulation material onto the weld side of the camera unit, but by the air-cooling inside the unit.

c) The shield glass is opened or closed by the solenoid operated by the remote control which makes it possible to observe and adjust the position of the tungsten electrode before welding and also to check the appearance of the weld bead after the work.

A small size CCD camera is used. It has the following excellent features compared with the vidicon type camera used until now;

a) Small size and light weight.
b) Resistive to electromagnetic noise.
c) Resistive to a shock.
d) No seizure phenomenon.

(2) Image processor

The image processor is composed of the personal computer and its commercially available interfaces.

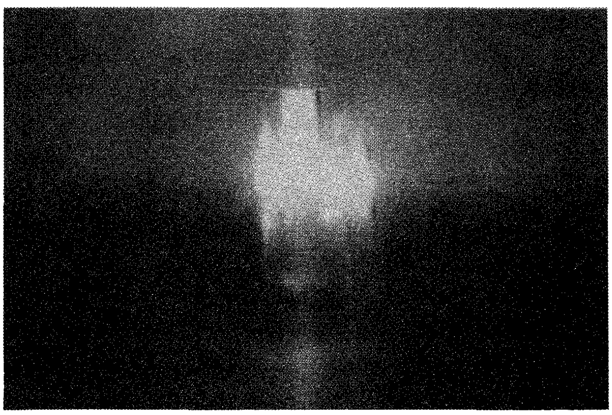


Fig. 11 Example of image nearby welding arc.

Although there are some problems in reliability to this combination, it is used by the following reason;

a) The work is limited only to the short term.
b) The allowed term for the development is also short.
c) The device is to be used only one time.

The processed result is transmitted to the microprocessor on the welding controller through 10 bits X 2 signal lines and the processed image can be seen on the screen for confirmation.

3.2 Image processing method

The image processing algorithm for this system is shown in **Fig. 12** as flowchart about which is explained below;

(1) The image of the place near by the arc is sampled to the video frame memory after AD conversion of the video signal from the TV camera by synchronizing with the start signal from the (personal) computer.

(2) The image data are processed by setting a window in the image frame. The window setting is made so as to include the image near by the arc within the window and then the grey level histogram, shown in **Fig. 13**, for the pixels in this window is prepared to determine the threshold level for discriminating the image of the joint configuration including the arc from the background.

(3) Using this level, binarization is made by vertically scanning the image data as is seen in **Fig. 14**, followed

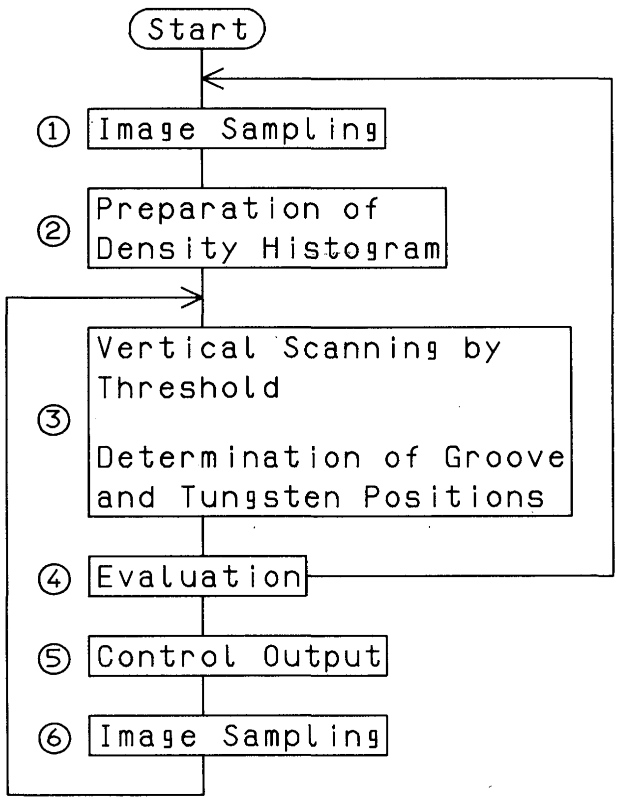


Fig. 12 Flowchart for image processing.

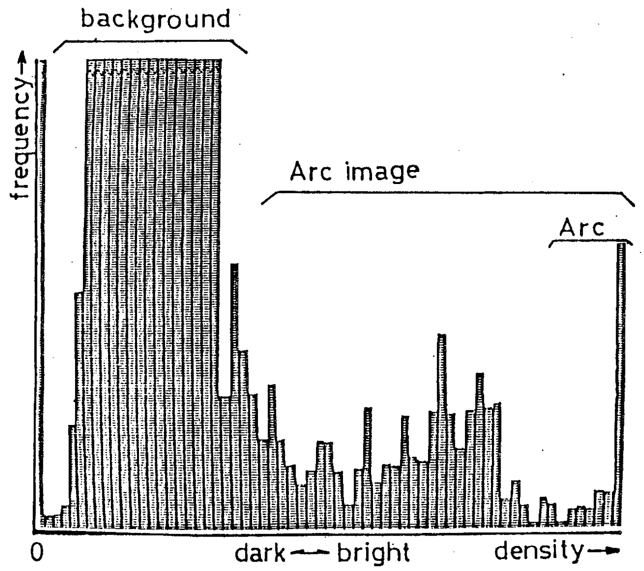


Fig. 13 Grey level histogram of image data to determine threshold.

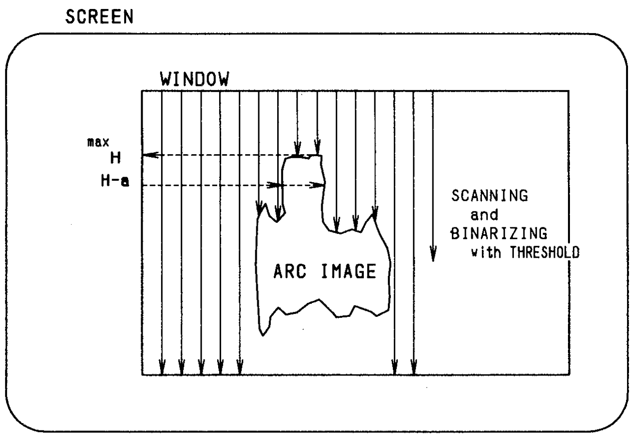


Fig. 14 Illustration of edge detection for image nearby arc.

by detecting the upper edge of the arc image. The maximum value "H" in Fig. 14 which corresponds to the edge of the tungsten electrode is obtained by searching the binary processed data. Next, binarization is made by horizontally scanning at a few line lower than the point of the "H", followed by detecting both side edges of the tungsten electrode. As detection for the edges of the groove, the same processing as above mentioned is applied.

(4) The deviation of the tungsten electrode from the groove center, the weld line, is calculated from the information of their relative position. At this calculation, the distance and the positional relation between the edges of the groove and the electrode are checked and reprocessing is made from step (1) if any error is found in the result.

(5) The above result is coded in 6 bit data and transmitted to the welding controller, by which the position adjustment is made for the electrode. The result of the image processing is displayed on the monitor screen as shown in **Fig. 15** for confirmation by the operator.

(6) For sampling the next image, the processing is repeated from step (3) by using the threshold level of the preceding time. This is repeated at certain prefixed times.

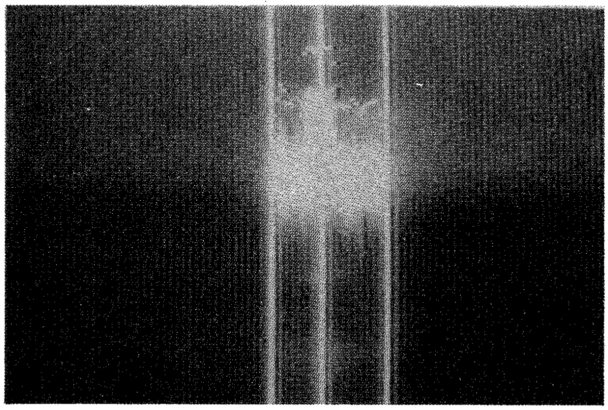


Fig. 15 Example for image processing result.

3.3 Communication in the welding system

The communication with the welding controller is made by each parallel 10 bits for input and output, 20 bits in total. Control information is transmitted by coded 6 bit data, where the least significant bit and the dynamic range correspond to 0.4 mm and from −12.8 to +12.4 mm respectively. The processing start signal from the welding controller is generated at the time of low pulse current of welding arc as well as the time when the latitudinal torch position is in the center of the weaving so as to enable the similar processing to be done at a constant threshold level.

The communication between the welding controller and the image processor is schematically shown in **Fig. 16** and described below;

(1) The arc start signal is sent to the iamge processor from the welding controller immediately after the arc ignition. The sampling and the image processing are made in the image processor on the receipt of this signal.

(2) The welding controller also transmits the signal at the moment when the electrode traverses the weaving center in the weaving action during welding process to the image processor. The image processor also makes sampling and processing on synchronizing this

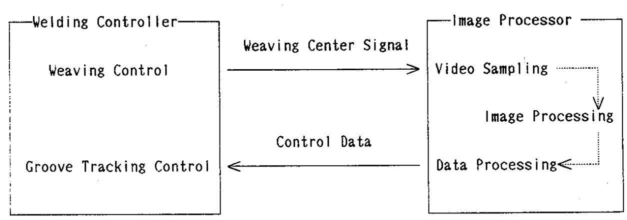


Fig. 16 Schema of data communication between welding controller and iamge processor.

signal.

(3) The processing result, if it is validated, is transmitted to the welding controller as control information by which the groove tracking control is performed with the servo mechanism.

3.4 Tracking control function

The response, so to say the processing time, is the most important factor in the application of image processing to real time control such as a weld line tracking. The comparatively fast response of about 0.3 sec per 1 frame of the image can be achieved in this system because the processing is rather simple. It is fast enough for the servo control of this system. That is verified as follows. The sampling time of a image is 1/60 sec, and the maximum waiting time for the scanning start of TV is also 1/60 sec, so maximum time of 1/30 sec is required to complete sampling. On the other hand, the welding torch which has a maximum weaving speed of 600 mm/min moves 0.3 mm in this period of time, that is less than the resolution of the control data described previously. Furthermore, from the view point of the requirement of the practical field of welding, the accuracy for the electrode position is about 0.5 mm which is rather larger than above value.

It is pointed out that the detection of both edges of the groove becomes difficult when the depth of the groove becomes shallow and their image becomes vague. That is a common problem to this kind of sensing method, but will be compensated by well using the information of the clear image during the preceeding welding, or corrected by the improvement of the image pick-up method.

4. Application

This system was applied to actual jobs after the mock-up test, the qualification test, and the training of welding operators in the factory of Babcock Hitachi Co. and the following results were obtained;

(1) Unmanned remote control welding could be achieved as expected at the beginning, expecting the case of the initial set-up, the exchange of the electrode when it is consumed, etc.

(2) The amount of radioactive exposure to workers could be reduced to 1/10 or less compared with the manual system used hitherto,.

(3) All welded parts satisfied the specific requirements after the radiographic test and the dimensional inspection, etc.

(4) The welding could be completed without depending on workers skill by using various functions such as the weld line tracking control, the arc length control and so on.

(5) The control of welding distortion could be made easily by the functions of this system such as the accurate circumferential positioning, etc.

(6) It was estimated that man-hours could be reduced by 1/3 by the total function described above.

5. Conclusion

The all-position automatic remote control TIG welding system with the visual sensor has been developed and applied for practical use. It is the next problem to improve this technology, to expand its application fields and to make the image processing in welding more excellent as a sensor for automation and unmanned operation of welding process.

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