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ORIGINAL ARTICLE

Automatic seam tracking in pipeline welding with narrow groove

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Abstract Automatic welding has been used frequently on pipeline projects. Productivity and reliability are the most essential features of automatic welding system.While the mechanized GMAW process is the most widely used welding process, the carriage and band system is the most effective welding system for pipeline laying. This application-oriented paper introduces a new piece of automatic welding equipment used in the dual tandem welding process for pipeline construction. It is based on cutting-edge design and practical welding physics to maximize productivity. This paper also describes the control system that was designed and implemented for automatic welding equipment. The system has the self diagnostic function which facilitates maintenance and repairs, and also has the network function via which the welding task data can be transmitted and the welding process data can be monitored. The arc sensor was also developed for a narrow welding groove in order to achieve higher accuracy of seam tracking and fully automatic operation.

Keywords Pipeline welding · Self-diagnostic · Arc sensor · Dual tandem welding · Pulse welding · Offshore construction

1 Introduction

Automatic welding has been used frequently on offshore pipeline projects. Its productivity and reliability are the most essential features of the automatic welding system. It has been proved that the carriage-and-band system is most effective on pipeline lay barges. Currently, many pipe laying contractors rely on automatic welding by using their own proprietary equipment or renting it at a high cost.

The aim of this study is to develop a new generation of automatic pipeline welding systems based on cutting-edge design and practical welding physics. The developed system has been improved in three respects. First, the tandem pulse process has been applied to the system. The pulse welding process becomes increasingly common because it has less heat input than that of standard arc welding, while providing stable arc and superior weld quality. In order to increase weld productivity, the developed system has been applied with the dual tandem pulse welding process. Second, an arc sensor has been developed for automatic seam tracking. Since the system adopts tandem welding processes, it has more arcs than conventional systems have. Adding to arcs makes it difficult for machine operators to trace on-weld seams. Thus, an automatic seam tracking system is required.

In this study, an arc sensor is used for automatic seam tracking. Arc-based signal sensing with a weaving welding torch is now widely used for seam tracking in automated GMAW pipeline application [1]. Key factors in performance of through-arc sensing approaches are the welding processes, welding conditions and welding speed [2]. However, the reliability of an arc sensor primarily depends on groove geometry, welding position and arc sensor algorithm. The groove shape of the pipeline is mostly a narrow U-like shape. It means that the tip-to-work piece distance(CTWD) is dramatically changed at the edge of groove, whereas the CTWD is constant during the oscillation motion except the position of the end of groove. This makes it difficult to develop the reliable arc seam tracking sensor in pipeline welding. This study focuses on

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the development of signal processing methods and arc sensing algorithms which enable stable tracking in pipeline welding applications featuring out-of-position welding and narrow U-shaped grooves.

Finally, the developed system has various features needed for welding effectively. To minimize downtime caused by machine faults, a self-diagnostic function has been developed so that the system can automatically detect the fault status for each control board and cable connection. A wireless remote pendant and a database downloading system have been developed for easy use of operators. Process monitoring and job data transfer are possible using a refined software running on a Windows system via a wireless network. Also, the mechanized carriage has been designed to have a slim, ergonomic design and less weight so that the operator can handle it easily.

The developed system has realized remarkable increase of weld productivity. Detailed descriptions will follow in next section.

2 System configuration and main improvements

For offshore pipeline installation, a number of machines should be adequately considered such as line-up, welding, NDT and coating stations on a lay barge. Figure 1 shows a layout of automatic welding production line and an actual field welding environment in a lay barge. The number of welding stations depends on the thickness of a pipe and welding speeds. In the pipeline welding process, two welding carriages traveling on a guide ring are necessary to weld girth welds in the 5G position simultaneously. Each welding carriage is controlled by fully computerized control system around pipe circumference.

In general, most of the commercial welding carriage systems adopt dual single torch or single torch mechanism—one welding wire for one welding torch – because of easy implementation and stable welding arc phenomena in the welding groove. The developed welding system in this paper adopted the dual tandem welding torch mechanism—two

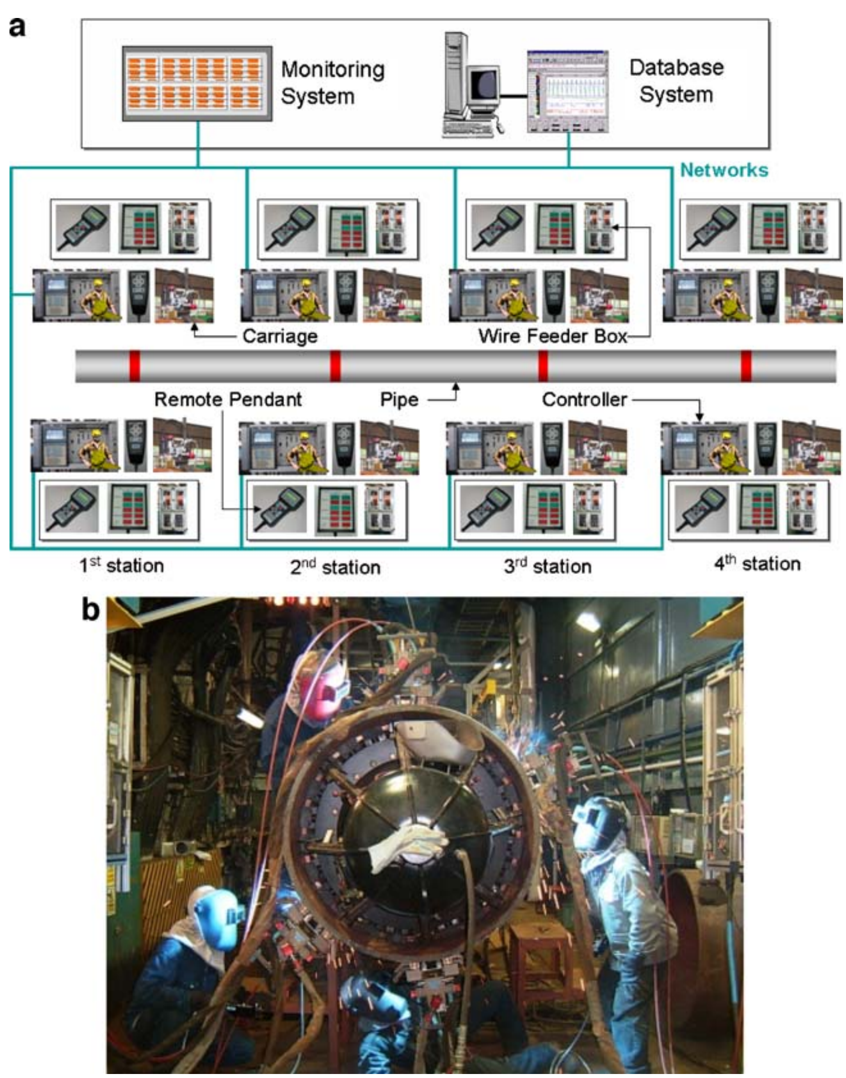


Fig. 1 Layout of automatic welding production line on a lay barge (**a**, **b**)

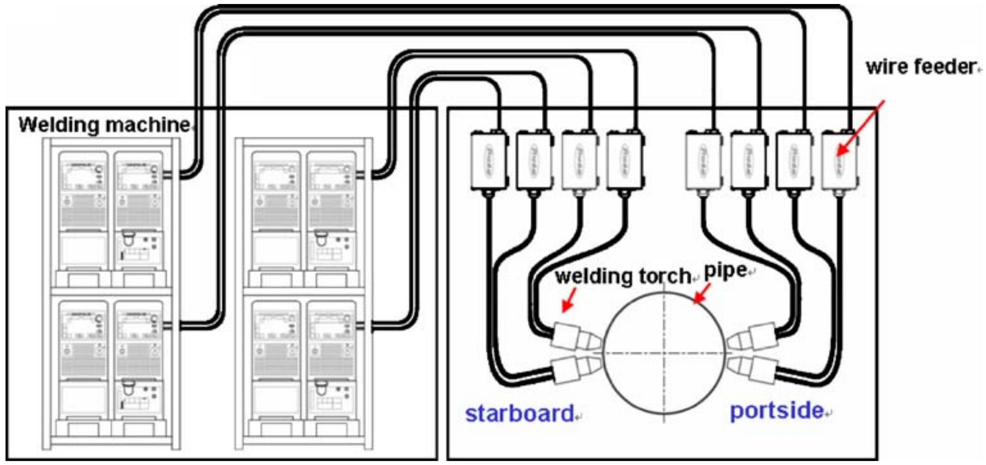


Fig. 2 Configuration of developed system

welding wires for one welding torch—to increase the welding production rate.

The system consists of dual tandem welding torches, four pulse welding power sources, a mechanized carriage with five axes, a guide ring, a main control unit and two wire feeder boxes. The overall architecture of the automatic pipeline welding system is shown in Fig. 2.

The system has various features to make a weld effectively. The system offers the self-diagnostic function, a wireless remote pendant and a wireless database downloading function and the mechanized carriage designed to have a slim, ergonomic design and less weight. Figure 3 shows the developed welding system.

The production rate depends on not only the welding process but also the downtime caused by the automatic welding system. Every system may cause some problems because of operation error, hardware malfunction, etc. The downtime can be minimized if a system can provide the information of system error and solutions of it to operators.

The developed self-diagnosis function of the system monitors faults of hardware operation. The fault diagnosis should guarantee the normal operation of the system. So the self-diagnosis function can judge faults of hardware and operation. Each control board of the main controller has its own fault diagnosis function. The VME Bus Controller shown in Fig. 4 collects various faults from each control board and displays alarm messages on a touch screen. Figure 4 shows the multi processor system for the main controller shown in Fig. 3.

Many problems would occur in a lay barge if a remote pendant and a database downloading system with cables were used. Because cables can be affected by magnetic field induced noise between lines and damaged by welding spatter or external environments. The solution chosen was

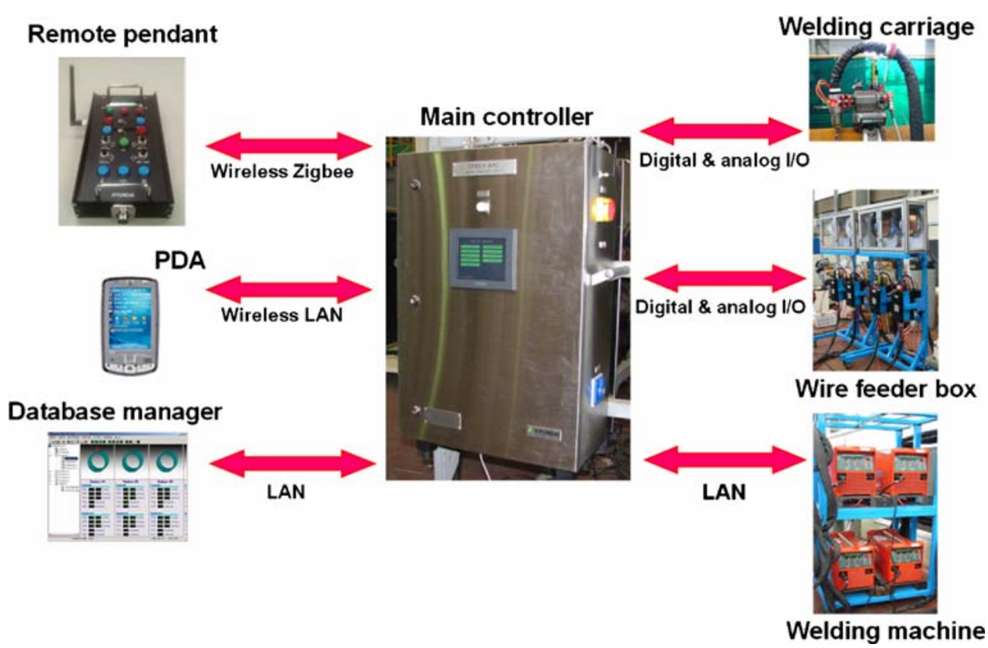


Fig. 3 Developed welding system for dual tandem pulse welding process

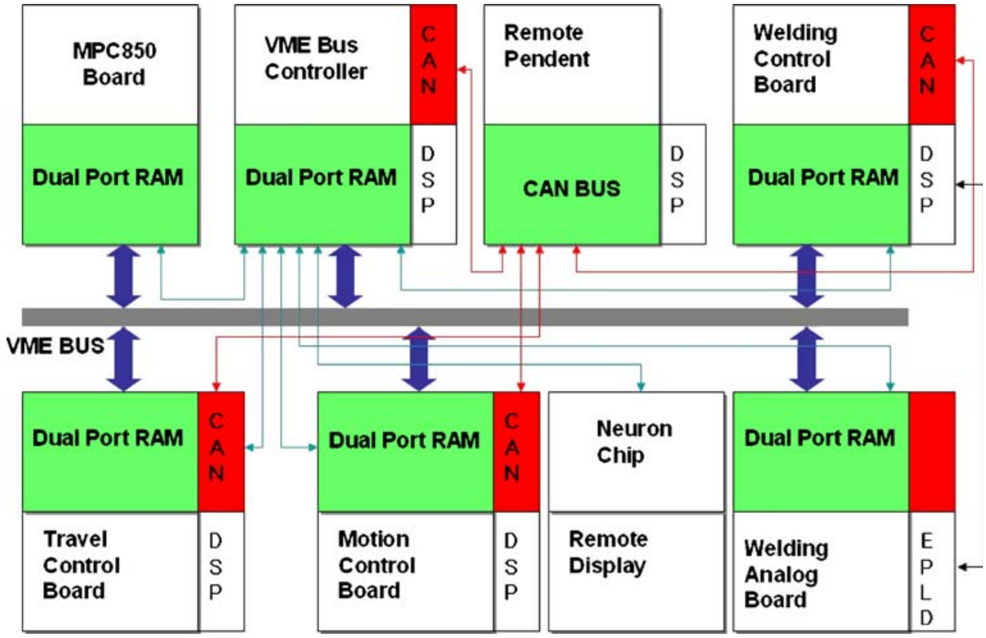


Fig. 4 Multi Processor system for automatic welding control system

to develop a new wireless remote pendant and a wireless database downloading system. Wireless communication control with up to a minimum of eight main controllers—a lay barge consists of minimum eight main controllers—simultaneously is generally recognized to be challenging. It is necessary to be careful about many aspects of the communication strategy. In this study, a wireless Zigbee and local area network (LAN) were implemented for wireless communication control.

The feature of the developed automatic welding system is outlined in Table 1.

3 Automatic seam tracking algorithm

The pulse welding process can be classified into constant current and modified constant current mode, which stands for mixed constant current and constant voltage.

Table 1 Feature of the automatic welding system

Characteristics	Specification
Pipe size(diameter)	Above 8 inch to 66 inch
Welding process	Standard MIG or pulse
Type of torch	Twin tandem (two torches) (two wire for each welding torch)
Seam tracking	Automatic seam tracking
Oscillation speed	Adjustable
Oscillation width	0 to 50 mm
Torch up/down stroke	50 mm
Welding position control	1 degree
Carriage weight	About 15 Kg

The waveforms of the mean welding current and voltage in the constant current mode and modified current mode are shown in Fig. 5. In the constant current mode, although the

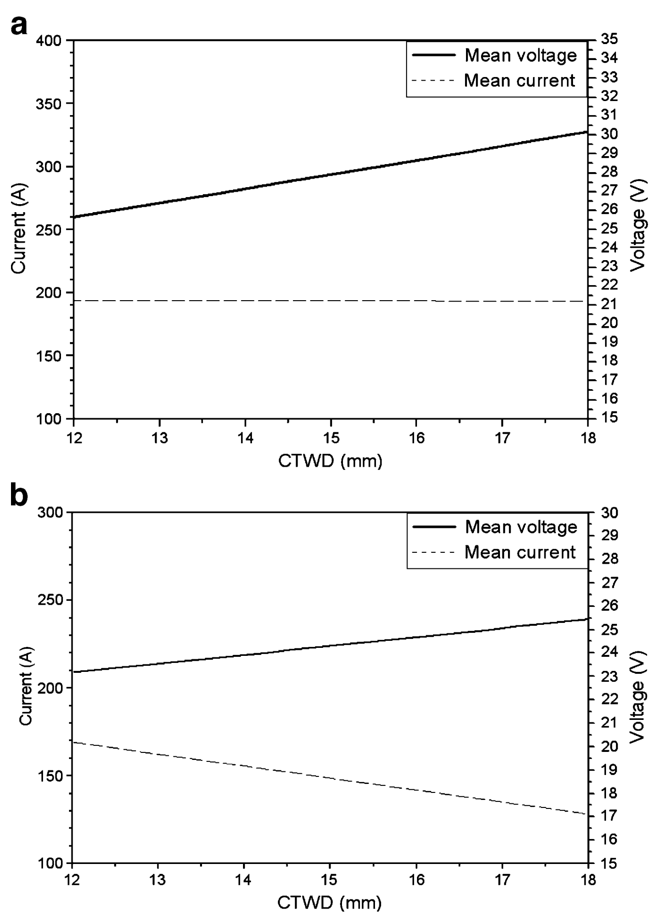


Fig. 5 Waveforms of mean welding signal by CTWD

CTWD is increased from 12 mm to 18 mm, the mean current is always constant, regardless of changes of CTWD. On the other hands, the waveforms of mean current in the modified constant current mode show a different way to keep the constant arc length.

As shown Fig. 6, the sensitivities of the measured signal (especially for the arc voltage) to arc length changes in the constant current mode and the modified constant current mode show a little difference. The sensitivity of the constant current mode is higher than that of the modified mode, where the current and voltage of the modified constant current mode should be changed to keep the constant arc length. The major reason for selecting the constant current mode in weld seam tracking system is sensitivity of the voltage signal. It is well known that the arc voltage increases or decreases as the CTWD increases or decreases. Therefore, the constant current mode is better than the modified mode to develop the arc sensor from the viewpoint of the sensitivity.

In this study, the constant current mode was adopted for the lead wire to track the weld seam line, and modified constant current mode was adopted for the trail wire to enhance the arc stability and weld qualities by keeping the constant arc length. The arc voltage signal for the through-the-arc sensor was measured and processed during oscillation and dwell time, respectively.

While through-the-arc weld seam tracking sensors are becoming commonplace in a wide range of automated welding applications, the requirements of pipeline welding systems place particular demands on sensor performance especially for the tandem pulse welding.

The welding environment provides certain constraints on sensor design. The welding being discussed is performed in a narrow U-shaped groove, and cycle times can be measured in seconds instead of hours and days. Therefore the sensor must be able to adapt to various situations which change at every second.

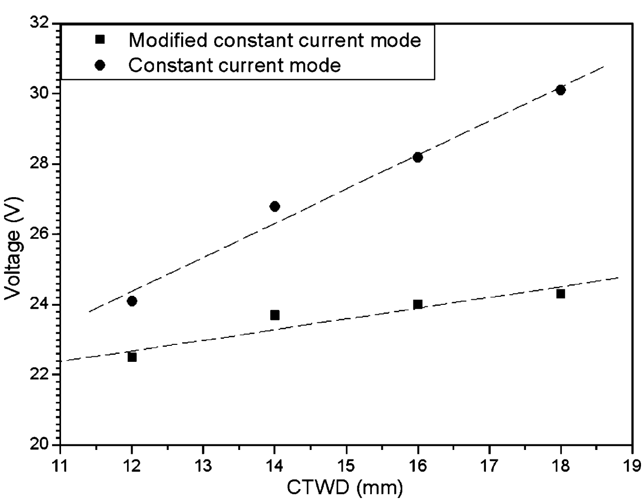


Fig. 6 Sensitivity of arc sensor by current mode

Various types of signal processing algorithms have been developed up to now such as curve fitting, integral method, moving average, etc. [2, 3, 4]. The first requirement for effective seam tracking algorithm is accurate measurement of the welding signal and determination of the geometry offset deviated from weld seam center line. To ensure reliable operation in pipeline welding with a narrow groove, a modified moving average algorithm was developed in this study.

The first step for seam tracking is to calculate a weaving time. If the measured weaving time between dwell left and dwell right is W_t, the sampling time(=S_t) is:

$$S_t = W_t/n \tag{1}$$

Where n is a fixed total sampling number.

Assuming that arc voltage is proportional to the CTWD, and a tandem pulse welding system is being used, one can represent the total deviated distance from the weld seam center line as follows.

$$Offset\ distance = \left\{ \begin{matrix} (V[1] + V[2] + \ldots + V[n/2]) - \\ (V[n/2+1] + V[n/2+2] + \ldots + V[n]) \end{matrix} \right\} * 2/n * k \tag{2}$$

where

V	the measured arc voltage signal
k	the gain between the measured voltage signal and the tip-to-workpiece distance.
n	fixed total sampling number during full weaving
$n/2$	sampling number during half weaving

The left and right side of Eq. 2 means the mean value of measured voltage signals for half weaving at left and half weaving at right respectively.

In the real situation, the welding signals have fluctuations due to the various factors such as metal transfer, molten pool behavior and so on. For acquiring the information of the exact torch position from the arc voltage or welding current signals, many researchers [3, 4] usually used a moving averaged method.

Moving average method has been used over the past years in various applications. The moving average method can be represented as follows:

$$\mathrm{value_a(k)} = \{(\mathrm{factor} - 1) * \mathrm{value_a(k-1)} + \mathrm{value_m(k)}\}/\mathrm{factor} \tag{3}$$

where

$\mathrm{value_a(k)}$	averaged value at k step
$\mathrm{value_a(k\text{-}1)}$	averaged value at k-1 step
$\mathrm{value_m(k)}$	measured signal value at k step

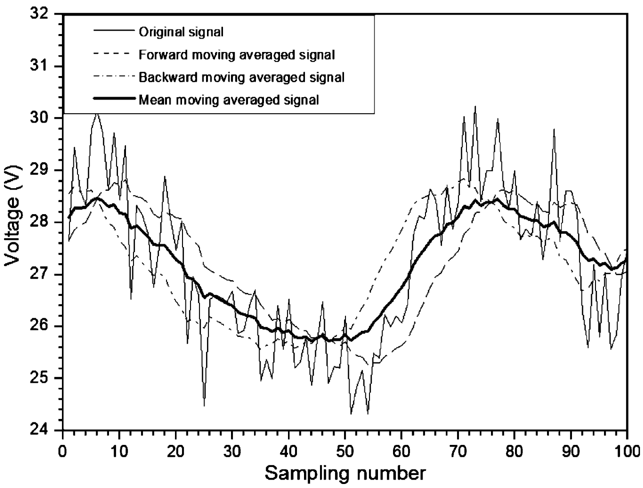


Fig. 7 Characteristic of modified moving average method

factor moving averaging factor (positive number), same as k

This is a kind of digital low pass filtering method. Because this moving averaging method has the advantage of easy determination for the cutoff frequency by changing the factor, it can be effectively used together with a hardware low pass filter which has a variable cutoff frequency. In this paper, a digital low pass filter with 50 Hz cutoff frequency for signal processing was used.

Figure 7 shows the results of each moving average method such as forward, backward and mean moving average method. The forward moving average method is based on the Eq. 3 and starts calculation from the sampling number 1 to 100 (total sampling number during weaving). The backward method starts moving average processing from backward, that is, 100 to 1.

$$\mathrm{Value_{forward}}(k)_{k=1\sim100} = \{(\mathrm{factor}-1)*\mathrm{value_a}(k-1)+\mathrm{value_m}(k)\}/\mathrm{factor} \quad (4)$$

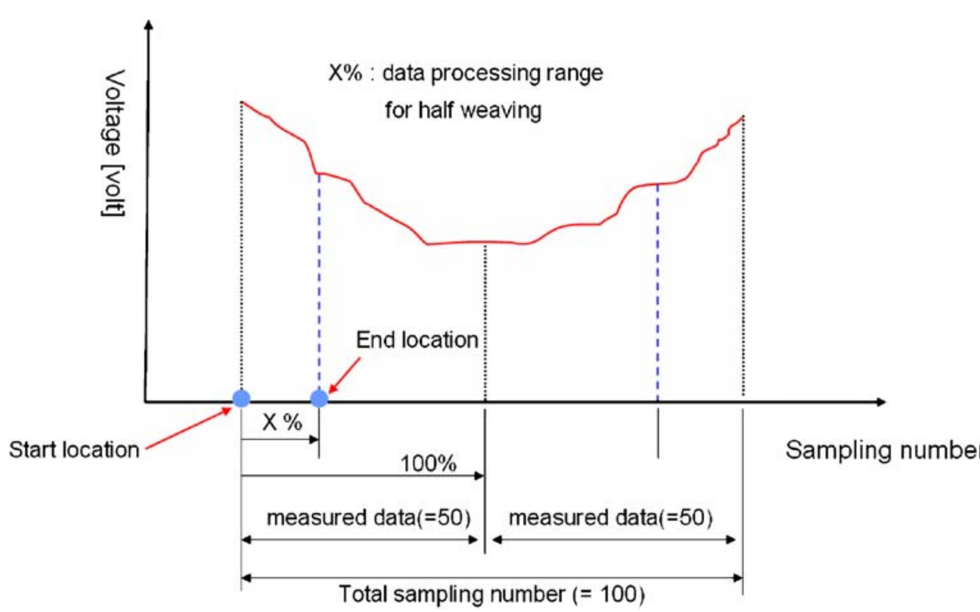
$$\mathrm{Value_{backward}}(k)_{k=100\sim1} = \{(\mathrm{factor}-1)*\mathrm{value_a}(k)+\mathrm{value_m}(k-1)\}/\mathrm{factor} \quad (5)$$

$$\mathrm{Value_{mean}}(k)_{k=1\sim100} = \{\mathrm{Value_{forward}}(k)+\mathrm{Value_{backward}}(k)\}/2 \quad (6)$$

One important point in this figure is that the forward and backward methods cannot represent the original signals exactly and may cause some errors when determining the accurate offset distance of the Eq. 2. The mean moving average method is a very straightforward method of signal processing for a special case of this study. As indicated in the word, the mean moving average method uses the sum of forward and backward moving averaged values to adopt good features of these methods respectively.

To enhance the reliability of the deviated distance described Eq. 2, a modified signal processing method was proposed. The signals measured near the center of groove sometimes show a flat, because the groove shape at the center position is similar to a bead on a plate. The flat position cannot guarantee the reliability of the arc sensor because the signal measured at this position shows same values. It means that the sensor cannot detect the signal difference between the left and right side of weaving. So

Fig. 8 Definition of start and end location for summing the averaged signals



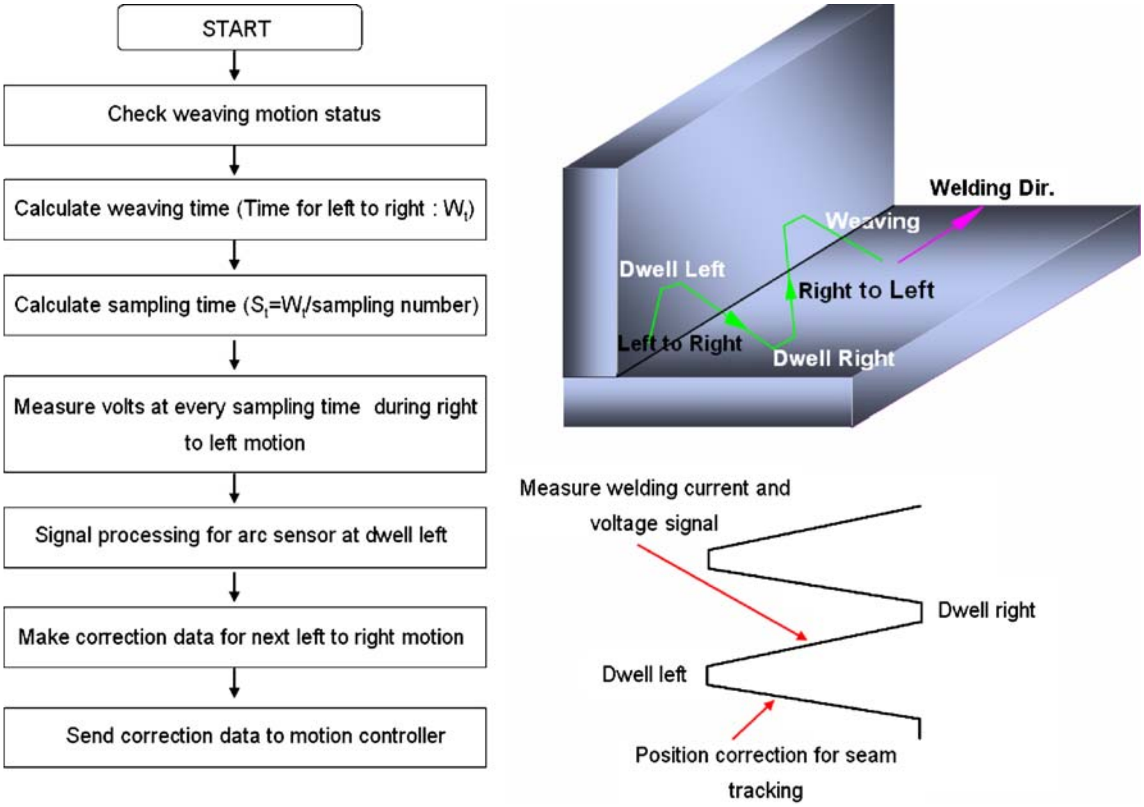
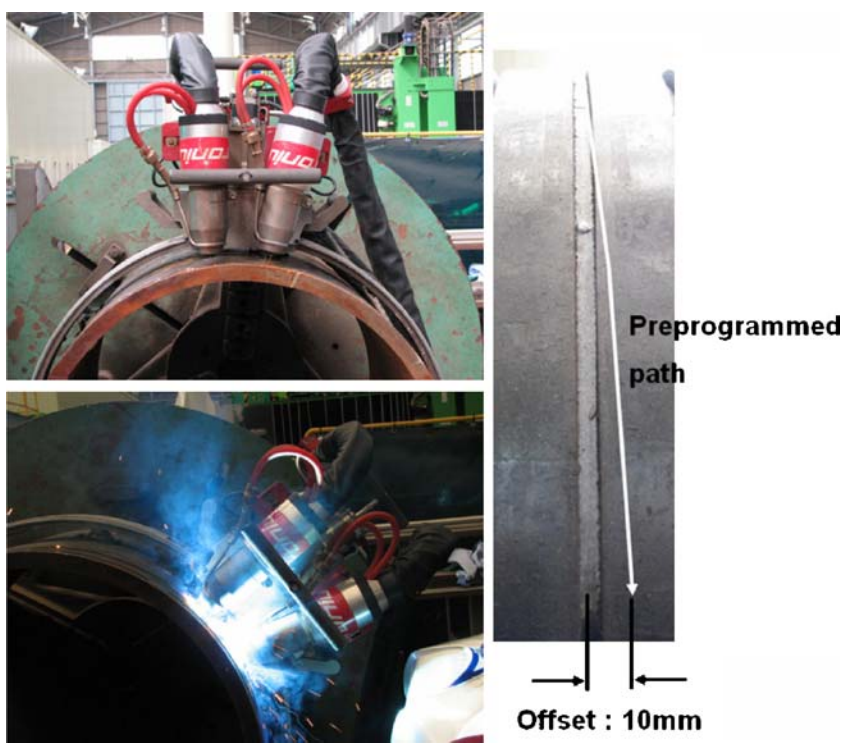


Fig. 9 Sequence for seam tracking and definition of weaving motions

Fig. 10 Photograph of result of seam tracking



the ratio of measuring interval plays an important role in sensitivity and reliability of the seam tracking sensor. Figure 8 shows how to select the start and end location for signal processing at every half weaving motion.

Figure 9 shows the sequence of seam tracking used for this study. The first step is to calculate of the exact weaving time during the weaving motion of "left-to-right". After calculating the weaving time, the sampling time for signal measurement is determined. Next, the voltage signals are consecutively measured during the "right-to-left" weaving motion. The "right-to-left" weaving motion has a fixed weaving width to avoid the abrupt weaving motion which can be caused by the arc sensor. Then, the signal processing is executed to determine the correction data for seam tracking. Finally, the correction data for a new weaving width is transmitted to the next "left-to-right" weaving motion to track the weld line.

Figure 10 shows a photograph of actual seam tracking result. For pipe welding with 28 inches in diameter, the weld path which was set with 10 mm offset. The result showed that the welding torch traced well along the weld center line by using the developed seam tracking sensor.

4 Conclusions

This paper has described a new generation pipeline welding system based on cutting edge design and practical welding technology. Key components of the system include the dual tandem welding equipment, the new automatic seam tracking algorithm for a narrow welding groove and the wireless remote pendant. The system has a self-diagnostic function which facilitates maintenance and repairs, and also has a network function via which the welding task data can be transmitted and the welding process data can be monitored. A combination of advanced electronics and software and practical and theoretical welding experience were all required in the developed system. While the system described is highly innovative, it is also extremely practical and reliable. The developed welding system in this study was successfully applied to the pipeline welding.

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