Adaptive Multitorch Multipass SAW

H. S. Moon and R. J. Beattie

Abstract

This paper describes several advances in sensor and process control techniques for applications in Submerged Arc Welding (SAW), which combine to give a fully automatic system capable of controlling and adapting the overall welding process. This technology has been applied in longitudinal and spiral pipe mills and in pressure vessel production.

Key Words : Laser seam tracking, Digital potentiometer, Multitorch SAW

1. Introduction

Laser based welding sensors have been available commercially since about 1984[1]. Initially they were applied to the basic functions of seam finding and real time tracking.

From the start, it was clear that one of the main advantages of laser-based systems over the traditional tactile probes was that the laser systems could measure key weld joint parameters. These parameters could then be used for process control. An early and very successful system [2,3] included such features as adaptive fill by controlling speed or voltage/current, adaptive weave width, and adaptive weave plane. The adaptive fill algorithm was capable of filling large joints in multiple passes correctly.

This paper describes recent work that generalises the existing state of the art to deal with multiple torches welding simultaneously. This is common in Submerged Arc Welding of thick wall specimens in pipe mills, pressure vessel fabrication, shipbuilding and other similar applications. To achieve the desired results, several developments had to be completed successfully, including:

- Development of a sensor with a very large depth of field and programmable field of view
- Development of a reliable interface to existing widely used SAW equipment
- Closed loop control of existing SAW equipment
- Generalisation of existing adaptive fills algorithms to deal with the case of multiple torches and multiple passes.

Multipass SAW is generally used to weld large joints, which in some applications can be greater than 150 mm deep. Adaptive fill generally requires that the joint volume be measured accurately as a key input to the adaptive algorithm. Conventional laser welding sensors do not have a large enough depth of field to deal with these joints. For example, sensors that use a laser stripe have their horizontal and vertical resolutions linked by the sensor optics. Hence, to obtain a very large depth of field, the horizontal resolution is degraded. The solution chosen was to develop a new sensor based on a scanning spot principle. In this case, the horizontal and vertical resolutions are independent. Use of the scanning spot also gives some other benefits in dealing with a large dynamic range and in combating reflections.

While the most modern computer controlled SAW equipment has analogue or digital interfaces for easy connection to sensors, there is still a large and growing

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population of highly reliable and effective SAW equipment, which is based on analogue technology. Interfacing computer systems with this equipment has often been problematical. This paper describes two solutions to this problem.

Effective control of the welding power sources then offers the immediate possibility of closed loop control. By measuring the actual welding voltage and current, a negative feedback scheme can be used to control continuously the welding parameters to ensure that they stay at their target values.

The welding with up to five torches simultaneously is generally recognised to be challenging. It is necessary to be careful about many aspects of the design of the welding head and about the geometry of the arrangement of the torches. Precise control of the welding parameters (voltage, current and wirefeed speed) is also required to maintain stable conditions giving high quality results. It is within this overall context that the multitorch adaptive fills algorithm has to operate successfully. A range of experiments was carried out to identify an approach to varying the welding parameters that gave successful results.

2. Overall system architecture

The overall architecture of an adaptive multitorch SAW system is shown in Fig. 1. In this case, it is assumed that the system is using three torches in a DC/AC/AC configuration.

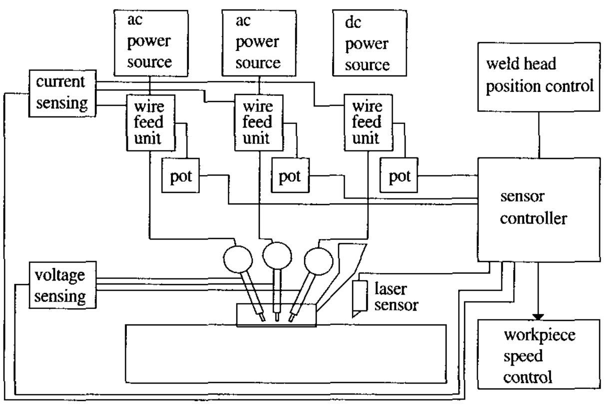

Fig. 1 Overall System Architecture

As usual, each torch is supplied by a suitable power source. In this type of application, a DC power source for stable arc, while the trailing torches are AC powered normally drives the leading torch. In DC operation, the electrode is normally connected to the positive terminal. Electrode negative (DCEN) polarity can be used to increase deposition rate but depth of penetration is reduced by between 20 and 25%. For this reason, DCEN is used for surfacing applications where parent metal dilution is important. The DC power source has a 'constant voltage' output characteristic that produces a self-regulating arc. For a given diameter of wire, welding current is controlled by wire feed speed and arc length is determined by voltage setting. AC power sources usually have a constant-current output characteristic and are therefore not self-regulating. Sensing the arc voltage and using the signal to control wire feed speed controls the arc with this type of power source. In practice, for a given welding current level, arc length is determined by wire burn-off rate, i.e. the balance between the welding current setting and wire feed speed that is under feedback control. To prevent an arc blow, main powers of two AC welding power sources are electrically connected each other to control a direction of each welding current path. In addition to the electrical connection, a torch arrangement such as horizontal distance and relative height between each torch and welding conditions play an important role in stable welding. Sometimes, an improper torch arrangement may cause open arc and bad bead appearance. To achieve a good bead appearance and qualities, an adequate combination of welding current, voltage and torch arrangement should be considered. Based on experience, it took five months to get the appropriate welding conditions and torch arrangement of multitorch system.

This multitorch system can accomplish high production speed compared with single welding torch system. In general, 30 or 40 cm/min can do welding speed of single torch system, however, welding speed of 150 cm/min can be possible in case of three welding torch system.

The laser sensor is positioned to look at the weld joint just ahead of the first torch. Ideally, it should be positioned as close to the first torch as possible but not so close, that flux will interfere with its view of the weld joint. The sensor is connected to its controller of that is normally PC based. The controller is responsible for analysing the sensor signals and controlling the position of the welding head and for controlling the process. Control of the process can be by varying the welding speed or by changing the welding parameters. It is well known and obvious that large changes in weld deposition rates can result from changing weld speed since the deposition per unit weld length is simply inversely proportional to the speed. The advantage of using the speed as the adaptive control parameter is that it is generally easy to implement and can be used with a very simple adaptive algorithm. However, it is not always desirable to change the speed outside a certain acceptable window because of possible weld defects. It is often preferable to change the weld parameters themselves. This is more complex, since it requires additional electronics to interface with the welding equipment and additional software to drive the interface and in the form of a more complex adaptive algorithm.

With the welding equipment used, two different interface systems have been developed. In each case, each wirefeeder is augmented with an electronic potentiometer as shown in figure 1. The electronic potentiometers are controlled directly by the sensor controller as described below.

The number of torches that has been controlled successfully in this manner is up to five. Figure 2 shows a three-torch head including a laser sensor.

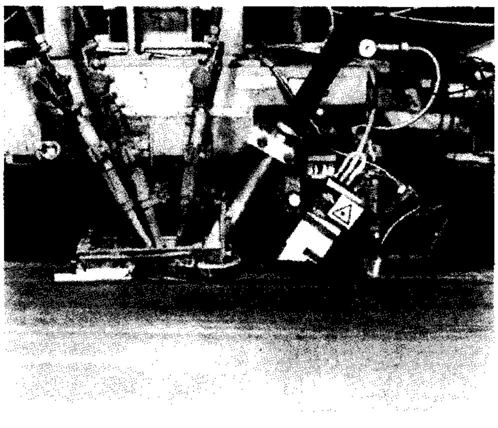

Fig. 2 Three torch head and Sensor

3. Sensor developments

While laser seam tracking sensors are becoming commonplace in a wide range of automated welding applications, the requirements of thick wall pipe and pressure vessel welding systems place particular demands on sensor performance. This section describes a new sensor that has been designed specifically for deep groove applications. The large depth of field structured light sensor and the narrow depth of field sensor are shown in Fig. 3, Fig. 4 respectively. The welding environment provides certain constraints on sensor design. The type of welding being discussed is often performed on preheated parts, and cycle times can be

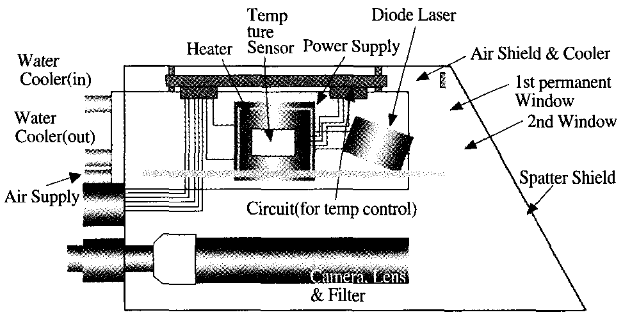

Fig. 3 Large depth of field structured light sensor

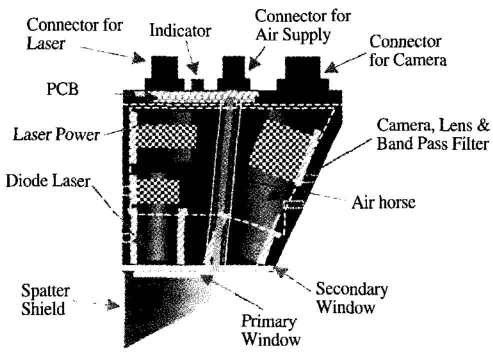

Fig. 4 Narrow depth of field structured light sensor

Table 1 Technical specification of large depth of field structured light sensor

Weight	1.2 kg
Dimension Length Width Depth	 180 mm(including spatter shield) 91 mm 51 mm
Stand Off	100 mm nominal
Acquisition Rate	30 Hz
Analysis Rate	> 15 Hz
Field Of View	55mm nominal, 75mm maximum
Depth Of Field	150 mm
Horizontal Resolution	0.1 mm
Vertical Resolution	0.3 mm
Laser	Class IIIb 690 nm 30 mW cw max

measured in days and hours instead of minutes and seconds, so the sensor must be able to withstand continuous operation in close proximity to hot surfaces.

The sensor shown in Fig. 3 has various functions such as water cooling, temperature sensing board and heating system for laser diode to maintain a constant wave length, and spatter shield and air cooling to prevent fume and spatter from damaging the sensor. The narrow depth of field sensor was to develop for laser welding of stainless steel with 0.7mm thickness. In this case, the welding speed is so fast that heat transfer from preheated parts can be negligible. For this reason, a cooling system was not adopted. The sensor specifications are shown in Table 1 and Table 2.

Table 2 Technical specification of narrow depth of field structured light sensor

Weight	800 g
Dimension Length Width Depth	 135 mm(including spatter shield) 69 mm 50 mm
Stand Off	70 mm nominal
Acquisition Rate	30 Hz
Analysis Rate	> 20 Hz
Field Of View	6.4 mm nominal
Depth Of Field	7 mm
Horizontal Resolution	0.01 mm
Vertical Resolution	0.016 mm
Laser	Class IIIb 670 nm 20 mW cw max

4. Welding power source interface

There are two main reasons for wanting to provide remote control of SAW welding equipment:

1. For closed loop control of the welding parameters
2. For adaptive fill by varying parameters.
   Some modern SAW power sources are well equipped with analogue or digital remote interfaces that simplify external control by a sophisticated process control system. However, the most popular SAW equipment in use does not have a remote interface. Two methods of controlling this equipment have been developed. These are:
3. Servo Potentiometer
4. Digital Potentiometer.

The principle behind a servo potentiometer ("servopot") for controlling power sources by a computer controlled remote potentiometer that is also fully isolated electrically from the welding equipment is shown in Fig. 5. The servopot mainly consists of a through shaft motor with a potentiometer mounted on each end of the motor shaft. The potentiometers are chosen to be very similar. The basic idea is that when the motor turns and adjust the position of the potentiometer wipers, both pots are changed in the same way. One pot is used to provide the feedback loop in a conventional negative feedback control system while the other pot is connected to the welding equipment in place of the usual manual control potentiometer.

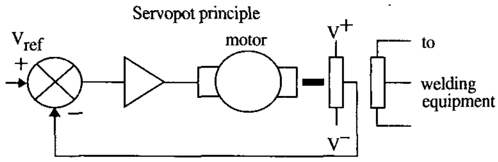

Fig. 5 Servopot principle

A straightforward calibration procedure is used to calibrate each pot within the sensor control system. When the sensor system then desires to make a change in the voltage or current of a particular torch, it uses the calibration procedure to determine the required resistance setting on the appropriate pot. From this it determines the required voltage setpoint (V_{ref}) on an analogue output. This provides the setpoint that is compared with the reference voltage fed back from the feedback potentiometer.

A photograph of a dual servopot assembly is shown in Fig. 6. This subsystem contains two servopots, one is used to control current, and the other is used to control voltage. The potentiometer, which is connected to the welding equipment, is completely isolated from the control system since the control is effectively provided by the mechanical link through the common motor shaft to the feedback pot. These systems have been found to

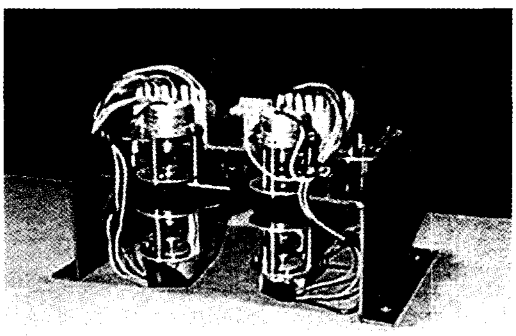
Fig. 6 Dual Servopot Assembly

work reliably. However, in the spirit of continuous improvement a second-generation interface has been developed using a digital solution.

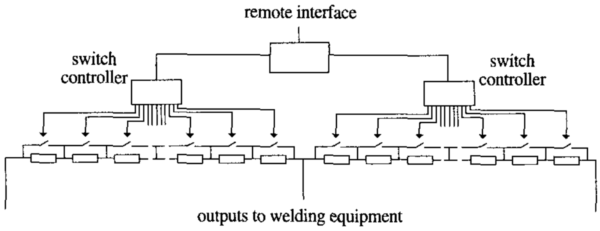

Fig. 7 Digitpot principle

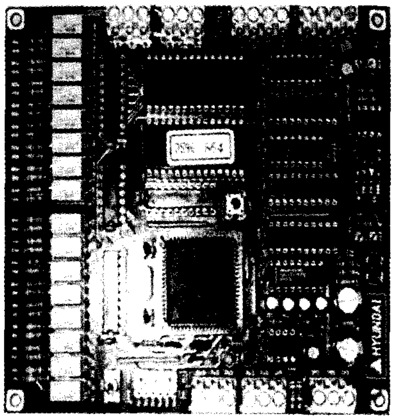

Fig. 8 Picture of digipot developed

The principle behind a digital potentiometer ("digipot") for controlling power sources by a computer controlled digital potentiometer that is fully isolated electrically from the welding equipment is shown in Fig. 7. In this case, there are no moving parts. The manual control potentiometers in the welding equipment are again effectively replaced by alternative potentiometers. However, in this case a digital circuit replaces each manual pot. The digital circuit uses a network of switch capable resistors under control of a programmable logic device to replicate the potentiometer function. The number and values of the resistors in the chains making up the digipot are carefully selected to provide the required range and precision.

To ensure reliable operation, the digital potentiometer input and output signals are optically isolated, while the power supply is transformer coupled. In this way, the digipot is, like the servopot, completely isolated from the welding equipment. The principle of the digipot has found use in another welding application. A photograph of a digipot is shown in Fig. 8.

5. Multitorch multipass adaptive fill

Adaptive fill has been used over the past 15 years in single torch applications. This section describes how adaptive fill has been extended for use on multitorch heads with up to five torches. In addition to dealing with multiple torches, the adaptive algorithm can also deal with multiple passes and layers.

The first requirement for effective adaptive fill control is accurate measurement of the joint volume. One important point in this is that the total area within the joint must be computed by a numerical integration based on the actual joint profile, not one based on any idealised profile or template. This makes accurate sensor calibration a prerequisite for accurate area measurement.

For instance, in addition to measuring the joint volume between the top corner points of a groove, the area procedure must also take into an account of the desired profile in the capping bead(s) as in calculating the total area for any variation in the width of the top of the joint will have an impact on the cap area.

The next step in adaptive fill is to compare the actual joint volume with the target volume. In multipass applications, it is necessary to use the target volume at the appropriate point in the overall welding process. These "nominal" areas are often available because of the calculations performed by the welding engineer in determining the nominal welding schedule. In some cases they clearly delineate the remaining joint area at every stage in the welding process, in other cases with very many passes, there are expressed in the form of layer areas.

With a multitorch system, it is important to decide how to allocate the required increases or decreases in deposition among the various torches. Penetration is normally the main function of the first (DC) torch. This can be varied according to variations in particular joint parameters to achieve specific penetration targets. More normally, however, the first torch is not adjusted as part of the adaptive fill procedure to maintain constant penetration.

The ratio of currents and voltages in multitorch systems is normally carefully chosen to achieve specific welding results. One way to allocate the deposition changes is to compare with the nominal deposition rates (nominal fill area). In other words, keep constant the percentage of the total deposition being applied by each torch (except the leading torch)[3]. The adaptive fill algorithm changes the voltage and current to try to achieve the correct fill. Normal practice is expected to be that the first (dc) torch will not be adjusted but that all of the ac torches will be. The first step is to calculate an area ratio. If the measured area (including the cap area) at time I is A_{wi} ratio is [3]

$$\Delta A_i = A_{wi} / \Sigma A_{fi} \qquad (1)$$

Hereafter, the (Afi is the sum of the nominal fill areas for all the passes still to be welded including the current pass.

If, deposition is proportional to current, and that all three torches are being used, the total setpoint current for the current layer is

$$\Sigma I_S = I_{S1} + I_{S2} + I_{S3} \qquad (2)$$

Therefore, the total new current required is:

$$I_{REQDi} = \Delta A_i * \Sigma I_S \qquad (3)$$

But torch 1 will not be adapted and remains at its database value, so the total adaptive current required from the two AC torches is:

$$I_{AREQDi} = I_{REQDi} - I_{S1} \qquad (4)$$

Now the AC currents are adjusted in proportion to their original setpoints. First, the total adaptive current at the setpoint is found:

$$\Sigma I_A = I_{S2} + I_{S3} \qquad (5)$$

Now the adaptive setpoints for each of the AC torches is calculated as:

$$I_{S2Ai} = I_{S2} * I_{AREQDi} / \Sigma I_A \qquad (6)$$

At present, the voltages are not adjusted as part of this procedure. However, a straightforward extension is to adjust each voltage setpoint as a function of each current setpoint change. Therefore, for example, if the current on a particular torch changes by Δ I, then the voltage change would be:

$$\Delta V = dV/dI * / \Delta I \qquad (7)$$

This can be violated when a torch reaches a limit. The limit can result from the equipment, e.g. maximum deliverable current, or from the process, e.g. maximum allowed current from that torch.

In deciding which torches should be constant and which should be adaptive, it is not normally desirable to have constant torches after adaptive torches, so one constraint applied is that the adaptive torches must all come after the constant torches. So for example, in a five-torch system, the first two torches might be constant and the last three adaptive. In fact, the algorithm used is flexible in allowing the welding engineer to specify in a weld database that torches be allowed to be used adaptively and which ones are to be kept constant.

6. Conclusion

This paper has given a detailed overview of a fully adaptive automatic welding system that has been applied in several real world systems. Key components of the system include the laser sensor, the welding equipment interface systems and the adaptive fill algorithms. A combination of advanced electronics, optics, software and practical and theoretical welding experience was all required in the development programme. While the system described is highly innovative, it is also extremely practical and reliable.

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