

A Fully Automatic Adaptive Pressure Vessel Welding System

Dr HS Moon, HHI Co. Ltd & Dr RJ Beattie, ISS Ltd.

Introduction

This paper presents a new generation of system for pressure vessel welding. Typical pressure vessel weld joint preparations are either traditional vee grooves or have narrow or semi narrow gap profiles. Since the wall thickness can be up to 6" or greater, welds must be made in many layers, each layer containing several passes. The normal process is SAW and the welding time for a single complete weld can be many hours.

Although SAW is normally a mechanized process, pressure vessel welding up to now has usually been controlled by a full time operator. The operator has typically been responsible for positioning each individual weld run, for setting weld process parameters, for maintaining flux and wire levels, for removing slag and so on.

The aim of the system described here is to remove the need for the operator so that the system can run automatically for the complete multi layer weld. To achieve this, several new developments have been made and combined into a single automated system. These include:

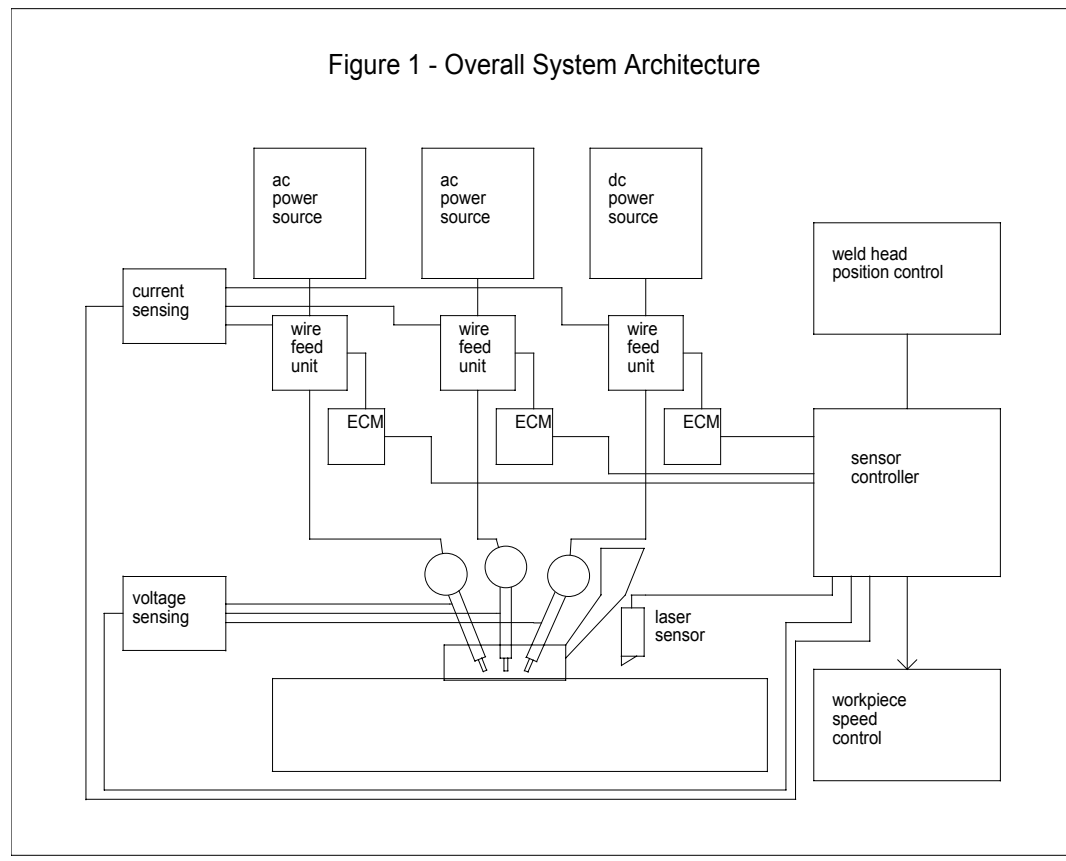
1. Design of multi torch automated machines capable of dealing with very large parts
2. Development, testing and implementation of algorithms for adaptive control of multi torch SAW which are suitable for the various stages of pressure vessel welding, i.e. root, fill, cap.
3. Special programmable scanning spot laser sensor capable of dealing with the wide range of joint sizes encountered in pressure vessel welding and able to give good signal quality in the presence of reflective components
4. Process control software capable of using the sensor signal to determine how to control the welding process. This includes the two main tasks of positioning individual weld runs (including deciding how many passes per layer) and controlling the weld parameters to achieve the desired fill levels
5. Unique remote computer interface to common proprietary (Lincoln) SAW equipment. This is a standalone Electronic Control Module (ECM) which has many applications in all types of automated welding
6. Closed Loop control of SAW equipment. The adaptive algorithms calculate the target current and voltage (or wire feed speed and voltage) for each torch. These are passed to the closed loop control systems which immediately set and control the power sources to achieve and

maintain the desired parameters. Step tests where the target values were changed by large amounts showed good results in terms of fast response times and accurate actual values.

7. Simple to use operator interface which makes the system user friendly.

The system described here has been implemented for several pressure vessel applications. It is not a research system but a full scale production system.

The importance of this system is that it meets the need to increase the productivity of pressure vessel welding systems. One operator can control several machines because the machines themselves are designed for unattended operation. The systems also reduce the required operator skill level and provide for more uniform results since the systems make the welding decisions by themselves.



Application

The system architecture of a typical system implementation is shown in figure 1.

Welding of thick wall components is a key process in several important manufacturing areas, including pressure vessel fabrication, production of offshore structures and the nuclear industry. More recently, manufacture of piles and columns to support wind turbines has grown significantly in importance.

The welding process for these applications is normally Submerged Arc Welding (SAW). Typically the overall process is split into three phases – root, fill and cap. Each phase puts different requirements on the control of the process.

Root welding is especially critical in ensuring a defect free weld. For the automation system, this means that positioning of the electrodes relative to the actual root face of the joint is particularly important. Additionally, control of the welding parameters must be accurate and stable to make sure penetration is consistent and predictable. Closed Loop Control of the welding parameters ensures stable, constant and accurate values. Normally, adaptive control of the welding parameters is not used during the root pass to ensure consistent penetration. Due to the critical nature of the root pass, one concession from fully automated operation is that an operator can be assumed to be present during the root run only. One implication of this, for example, is that if a problem arises during the root pass, the system can issue a warning rather than stop which would be necessary if no operator was present.

Fill welding represents the major part of the process in terms of weld time. Fill welding is normally considered in terms of a number of layers, with each layer itself consisting of a number of individual passes. Several factors are important in carrying out this phase efficiently. As usual, positioning of the individual passes must be accurate and relative to the current state of the welded joint. This means that the image analysis of the sensor signal must be capable of recognizing reliably the key features of the partly filled joint, especially the points on the joint sidewall where the previous passes are located. Any adaptive control of the welding process must be carried out during the fill phase. This has two main functions:

1. To compensate for mismatch **across** the joint
2. To compensate for variations in joint volume **along** the joint.

Compensating for mismatch across the joint means recognizing that the joint area is larger on one side than the other and perhaps also that the height of the joint preparation is larger on one side than the other, and then changing the weld parameters on each side of the joint accordingly.

Compensating for variations in the joint along the welding direction, means adjusting the travel speed and/or voltage/current/wire feed speed to fill the joint to the correct level. For example, a large tubular component may have been formed such that the joint volume on one side is much larger than on the other side. From the point of view of production efficiency, the whole joint should be filled in the same number of passes. Hence, the deposition rate must be continuously adjusted so that the proportion of the joint filled is constant. If a multi head machine is being used where several tubular components are being joined at the same time, then an additional constraint is that the speed must be the same for each weld (obviously) and all welds should be completed in the same number of runs.

Cap welding must be carried out in a way which gives a good cosmetic appearance to the joint in addition to the other normal welding requirements. Because the joint may be full during cap welding, use of a laser sensor alone is not normally considered reliable enough at this stage. In a linear welding machine, one solution is to instrument the machine such that the position of the joint edges can be memorized during fill welding. The required positions of the cap passes can then be calculated from and controlled using the joint memory. Circumferential cap welding requires a different solution which can be based on the use of a line marked on the surface a fixed distance from the root of the weld or on the use of independent measurement of the horizontal position of the part combined with memorization. The independent part measurement may be part of an antidrift system.

Large Field of View Sensor

The special requirements of the application mean that the laser sensor must have high performance in certain areas, including:

- Large field of view in width and depth
- Ability to “see” steep joint sidewalls
- Ability to cope with a wide range of surface conditions ranging from freshly machined to black scale
- Immunity to reflections from shiny vee preparations

A new sensor was designed specially for this range of applications. It uses a scanning spot instead of a laser stripe. Although this increases the complexity of the sensor, it gives several important performance benefits:

- Decoupling of vertical field of view from horizontal field of view
- Immunity to reflections

- Capability to deal with a large range of surface conditions, even within a single scan.

The particular sensor designed, called A700, is programmable. This means that the scan width, scan frequency and number of individual points per scan can be selected to match the application. For example, narrow gap joints require a large depth of field but a relatively small width of field. Joints with traditional vee preparations require large horizontal and vertical fields of view. By making the sensor programmable, the same sensor can be used for both joint types.

Sensor Control System

The sensor control system is based on an industrial PC running Windows NT. The PC gives high performance and rugged durability at low cost. Selecting Windows NT as the PC operating system gives access to a wide variety of development tools and software modules. It also makes it easily possible to produce a highly attractive and informative graphical display. This means that the system status and performance can be seen easily by glancing at the system display screen.

Weld Process Control

There is a large installed base of SAW equipment which was not designed for computer control (Lincoln NA3/4). Although the design of this equipment does not use the latest digital technology, it performs well and is known to be reliable. To allow the computerized adaptive control system described here to be combined with this analogue equipment, a new interface was designed. Effectively this uses a novel electronic control module to control the equipment through the original operator interface. The module contains a computer interface combined with a fully isolated pair of digital potentiometers. The process control computer continuously measures the actual welding parameters and uses the module to adjust the power source to maintain a target value.

Use of the module means that two new important functions are added to the existing equipment:

1. Closed loop control
2. Adaptive fill.

By measuring the actual voltage and current several times a second and adjusting the potentiometers to maintain the required target value, closed loop control of the welding process is achieved. This means that the selected welding parameters are essentially guaranteed to be achieved. For example, if there are wide fluctuations in the plant power supply to the welding

equipment, these will not affect the welding parameters because closed loop control will detect small errors from the set values and compensate accordingly.

Since the electronic control modules have a computer interface, adaptive control becomes possible. The process control system works out target values for voltage and current (or wire feed speed) based on the sensor signal and adaptive control algorithms. These target values are then sent to the control modules where they then represent the new target value setpoints.

Conclusion

A new generation of automated SAW systems for thick wall applications has been produced by combining advances in several areas. The new systems offer significant benefits in productivity and quality.