

# Advanced Technologies for Tandem SAW Narrow Groove Applications

*Automation technology takes on the challenges of the tandem narrow groove submerged arc welding process*

BY DON SCHWEMMER, BOB BEATTIE, AND PATRICK WAHLEN



*The use of narrow, deep joints reduces the number of passes as well as the time and materials it takes to build pressure vessels such as the one shown above.*

As the section thickness of vessels for the nuclear and petroleum industry increase, the desire for reduced weld time and material consumption has driven the joints on these vessels to become narrower and deeper. Narrow joints significantly reduce the number of passes, time, and materials needed to complete each weld. Whenever the needed material and specification allow, the submerged arc welding (SAW) process — ideally, the tandem process using two torches — is preferred

due to its ability to provide higher deposition rates and to produce high-quality, reliable weldments.

To achieve the desired weld properties, these joints are typically produced by depositing one or more root passes and then making two passes per layer until the joint is filled — Fig. 1. The two passes per layer method minimizes undercut, trapped or mechanically locked slag, and concave weld profiles. This method requires the ability to swing the weld wire nozzles from side to side as each pass is made. The process may also require changing the mode of the power supplies from DC to AC as the weld transitions from the root passes to the fill passes to achieve the greater deposition associated with AC SAW. In some cases, the use of AC-only welding may be necessary due to arc blow in a deep narrow joint.

Consider looking down 12 in. inside the 1.5-in.-wide weld joint of a thick-section reactor vessel, 16 ft in diameter, 40 ft long, weighing more than 500 tons, that's sitting on turning rolls, and is preheated to greater than 250°C, while trying to control the vertical and horizontal position of two SAW torches to maintain exactly 0.110 in. off the moving side wall for more than 24 h. Don't forget that you also need to smoothly switch to the other sidewall every 360 deg. These are only a few of the important requirements of this process.

Tandem narrow groove SAW is among the most challenging welding processes to

perform and automate. Consistent performance is a balance between wire position from the sidewall and the deposition rate. For a given deposition rate, if the wire is too close to the side, undercutting and underfilling will likely occur; if too far, the bead becomes more concave and incomplete fusion and flux entrapment can occur. Successful automation of this process requires critically accurate control of the wire position with respect to the joint sidewall as well as the power delivered to each weld wire. However, the latest technologies are now being applied to make this demanding process more automated, manageable, and successful.

There are four areas in which significant advances have been applied to this application: 1) Rigid and precise servo-controlled weld heads; 2) scanning spot laser tracking systems; 3) accurate digitally controlled power supplies; and 4) totally integrated digital control and process monitoring systems.

## Narrow Groove Weld Heads

Successful narrow groove welding must begin with the head — Fig. 2. A narrow groove head needs to be relatively long and thin to reach into these joints, and it must also be designed to be rigid and to maintain dimensional stability at high temperatures for long periods of time. Designs and materials are optimized for the long, thin profiles while providing

*DON SCHWEMMER (don@ametinc.com) is with AMET, Inc., Rexberg, Idaho. BOB BEATTIE is with Meta Vision Systems, Eynsham, Oxfordshire, UK. PATRICK WAHLEN is with The Lincoln Electric Co., Cleveland, Ohio.*

as massive a frame as possible for rigidity, current transfer, and heat dissipation. The latest heads are a composite of materials to provide structural integrity, thermal stability, and electrical conductivity, as well as isolation and contamination protection from potential contact with the sidewall of the part in these “tight” joints.

The deep, narrow profile of these joints, especially beyond 6 in., prohibits actually tilting of the whole head from side to side as the joint fills, so the head must have articulating nozzles that allow the weld tips to be angled into each sidewall. After each pass, the nozzles must swing to the other side to provide the appropriate entry angle. This also has to be coordinated with the head cross-seam slide as the entire head will need to move slightly to maintain the same sidewall offset with this entry angle as the joint widens and is filled.

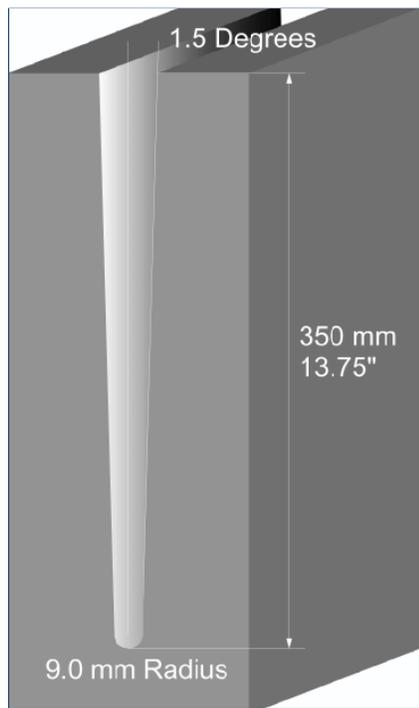
Although torch angle articulation has been historically performed pneumatically or with relatively simple mechanical devices, new generations of heads are utilizing precision servomotor- and encoder-based systems to be able to move under programmable control. This provides several significant advantages including the ability to vary the entry angle as the weld progresses, to have different angles for each torch nozzle (lead or trail torch), and the ability to control the speed or smoothness of the transition from one sidewall to the next after completion of each pass. Servo-encoder-based control of the torch angle as well as the cross-seam and height position slides allows for the coordination of all of these positioning devices to better ensure the desired position of the weld wire.

The overall narrow groove torch heads have now, appropriately, become massive rigid structures with heavy-duty precision slide assemblies, redundant wire straighteners, integrated video cameras, laser sensors, and flux delivery/recovery systems — Fig. 3. This is all to ensure the accuracy and repeatability of this process.

## Scanning Spot Laser Tracking Systems

As important as accurately placing the wires is, having the ability to precisely know where to place them is equally crucial. Thus, being able to determine the joint profile in real time is vital.

Mechanical tracking with probes has been a common and reliable method of tracking joints to accommodate for movement of the part, or variations in the part or weld geometries. However, mechanical tracking systems must contact the part and can only give position information where the probe is in contact. Also, unless there is a probe on both sidewalls,



transitioning from one side to the other can be difficult and usually requires the process to stop and be reset for the opposite sidewall. When there are two probes for the sidewalls and one for the base of the joint, the amount of equipment inside the joint becomes significant and cumbersome.

Laser tracking would be an ideal solution as it is noncontact (located away from the joint) and could provide a complete profile of the joint. However, as joints became deeper and narrower, the reliability of conventional laser tracking systems to “see” these joints became more and more of a problem. Fortunately, an unconventional approach to laser tracking provides a viable solution.

There are two main approaches to laser-based weld joint tracking: one uses a laser stripe and the other a laser spot. The simpler, more common approach to laser tracking is to project a laser stripe onto the part and then image the complete stripe with an area detector (camera). However, there are potential image quality problems with this approach for narrow groove joints. Since the entire laser stripe is always on and the entire image is always illuminated, shiny surfaces, typical of narrow groove joints, create secondary reflections, which may return more light to the sensing camera than the primary surface of interest. This results in difficulty analyzing the image to determine the actual weld profile. Due to the steep and long sidewalls of these joints, significant secondary reflections can be present, thus reducing the reliability of the system to accurately track and characterize the joint.



Fig. 1 — Typical narrow groove profile (top left) and cross section of a weld.

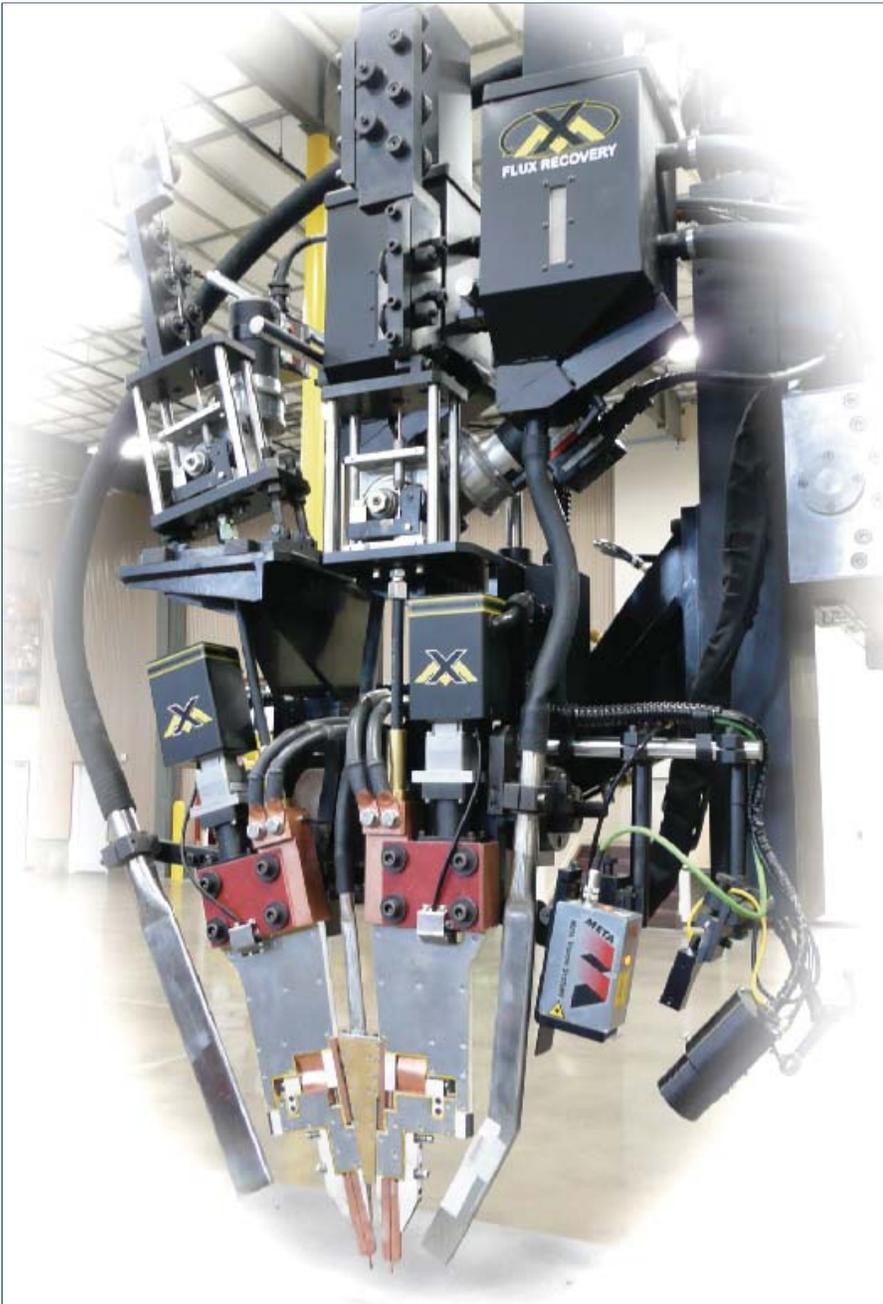


Fig. 2 — Integrated narrow groove weld head assembly.

A laser spot scanner uses a laser spot instead of a laser stripe. The spot scanner makes only a single point measurement at any one time and thereby requires a scanning mechanism (Galvo Scanner) to sweep the spot (and linear detector) across the weld joint. This principle is illustrated conceptually in Fig. 4.

The reflection of light from one side of the joint to the other and then reflecting back to the imager associated with the laser stripe method is not a problem with the scanning spot sensor. Since the detector is only looking on a line perpendicular to the scan, it literally does not see the

reflection. Scanning spot laser sensors also perform well in situations where there is a requirement for a small width of field but a very large depth of field, such as welding deep, narrow grooves. Since a profile of the weld joint is obtained, other advanced software solutions can be applied to calculate the volume of the joint and adaptively control the process to compensate for variances in the groove and sidewalls to achieve more even fill. Finally, because it is measuring at a single point, it is easy to implement an effective automatic gain control on a laser spot scanner so that the sensor compensates dynami-

cally and automatically for variations in surface conditions.

Meta Vision Systems has optimized such a scanner specifically for this application. The joint profile information from its DLS 300 scanning system can be combined with the weld head and torch angle position to accurately determine and display the position of the wire tip with respect to the sidewall and bottom of the joint. Figure 4 also shows a scan of the weld profile from a weld in progress. The + marker on the display indicates the position where the wire intersects the bottom of the joint. This scanner also provides important information for controlling the head cross-seam and height slides to maintain the constant sidewall position. The scanning spot laser sensor is, therefore, a powerful tool and a key component in the successful automation of the process.

## Advanced Digital Power Supplies

All the efforts to accurately characterize the joint in real time and precisely place the wires are for naught if consistent and reliable power cannot be delivered to the wire contact tips. This process can demand more than 700 A per supply for more than 24 hours. It requires both accurate DC and AC output and the ability to switch between modes. The most advanced power sources have enhanced digital control circuitry and software that compensates for variances in power input, temperature, and demand to ensure a consistent, stable output.

In addition to enhanced performance characteristics, the ability for direct digital control has also markedly expanded the automation possibilities of difficult welding processes. This direct control allows these supplies to become an integral part of the complete system and all of their capabilities to be accessed and controlled from a single controller. With the ability to enable/disable the supplies, change modes between DC and AC, vary current, voltage, and AC phasing, all based on part or torch position, automated continuous root-to-cap multipass welds are achievable.

The Lincoln Electric Co. has developed its Power Wave® digitally controlled power supplies specifically for these demanding applications — Fig. 5. The Power Wave® AC/DC 1000® SD is a high power, high-speed inverter design that delivers Waveform Control Technology® for submerged arc welding. The power supplies provide constant current or constant voltage operation and allow variable frequency and amplitude for AC output. The software-driven AC, DC-positive, or DC-negative output allows the user to control

the deposition and penetration. The result is a more consistent, smoother arc at a wider range of parameters, increased weld speeds, consistently higher-quality welds, and improved efficiencies in a single- or multi-arc environment.

The sophistication of the software-based inverter design allows a significant ability to be integrated into an adaptively controlled dynamic system required for the challenging narrow groove environment. Previous-generation SAW power sources had a limited range of functionality, which greatly limited the capability of the welding process to execute a high-quality, high-productivity weld. Newer, more advanced power sources and seamless integration into the overall narrow groove system architecture have dramatically enhanced the operating envelope and flexibility of the welding process.

It is important to note that the efficiency of these inverter-based power supplies yields significant savings in operating costs over traditional transformer/rectifier designs. In a typical industrial operating environment fabricating pressure vessels, each machine can potentially save up to \$15,000 per year in operating costs due to its unique design and use of energy-efficient, high-speed inverters.

## Integrated Control and Process Monitoring Systems

A complex automated system, with servo-controlled weld heads, turning rolls, manipulator boom, two wire feeders, two articulating weld torches, scanning spot laser systems, two advanced power supplies, flux delivery/recovery — each with its independent control devices — can overwhelm even the most experienced engineers and operators. Setting up and monitoring all of the controls for these devices is a procedural challenge and has potential for many costly errors. Process repeatability, minimized operator setup, ease of programming, and reliable process verification are all associated with the quality and design of the control system.

Traditional control approaches for automated systems are to link the controllers together so that the start or change of any given component is activated, or linked, together with the start or change of another component. For example, the process may start with the operator pushing the start button on the turning rolls, which would immediately activate the flux-delivery control, and then activate the controls for the power supplies, beginning the weld. A change in the part diameter or material would most likely require all settings and/or dials of several or all controllers to be changed. Also, since the



Fig. 3 — Articulating nozzle tips (top) of the AMET narrow groove head showing independent (bottom left) and coordinated (bottom right) wire tip position control.

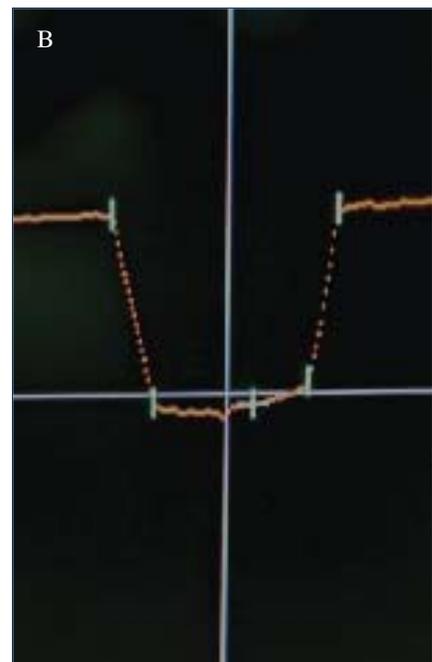
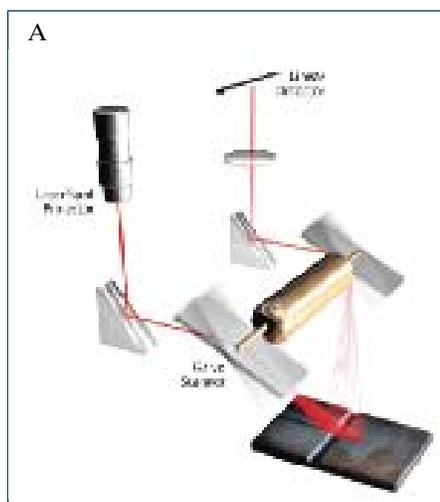


Fig. 4 — A — Schematic of the scanning spot laser method; B — a profile scan showing the intersection of the wire with the base of the joint represented by a “+.”





Fig. 7 — Integrated weld controller and process monitor displays.

according to the position of the torch or part.

- Constantly monitor each process and provide process data as well as alerts for out-of-tolerance conditions to the operator at the main controller.
- Provide ethernet connectivity so that the system performance can be monitored from a central station as well as transferring programs and data.
- Provide pre- and postweld automa-

tion programming to allow for programmed timing of flux delivery start, repositioning of the weld head to aid in setup, and other desired functions or moves before or after the weld.

- Easily integrate with other sensors such as temperature measurement because another module for the sensor can be added to the network and the information shared.

The overall effectiveness of these con-



Fig. 8 — Integrated narrow groove welding system.

trol capabilities also depends on how effectively information is obtained from and provided to system operators and engineers. Systems that can be programmed by selecting desired parameters and entering desired values without any specific programming language or code are more intuitive and valuable. Controllers for integrated systems can be specifically designed to include not only displays, but appropriately placed and integrated joysticks, knobs, and buttons with tactile feedback allowing the operator to focus on the process instead of several controllers. Figure 7 shows the operator display and controller for a narrow groove system.

## Summary

Although the welding community has historically struggled with new technologies, the advances in electronics, processing capability, laser systems, high current control, and network communications have recently provided reliable solutions for several of industry's most difficult processes. Tandem submerged arc narrow groove welding is now one of them (Fig. 8) as significant improvements in process efficiency and quality can now be achieved with the appropriate automation. ♦

### Acknowledgments

The authors would like to acknowledge the support of David Mate and the Lincoln Electric Automation Center of Excellence.