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Adaptive Control Techniques Advance Automatic Welding

Smarter welding control technology simulates human decision-making skills

BY PAUL SAGUES

Manual welding continues to play a significant role in welding applications for several reasons. Humans tend to be more adaptable to variations in the welding process. Skilled human welders can learn what parameters to adjust and by how much in order to keep the welding process under control.

A skilled and experienced welder can examine a part to be welded noticing the variations in the part and in a split second come up with the adjustments necessary to make a good weld. An example is a welder noticing a wider groove because of mild bowing where he or she will immediately increase the oscillation, decrease heat, and adjust the electrode extension to keep the voltage at an appropriate level. Welding, in essence, is a multivariable control problem that makes it difficult to automate.

Conventional Automation Solutions

Fully automatic welding today is employed in only a limited number of mostly high-volume applications because these systems cannot adapt to variations as humans can. Commercially available automated welding systems use simple control techniques that focus on linear system models with a small subset of the larger set of process parameters, thereby limiting the number of applications that can be automated. There is a compelling need for automation in high-volume applications and those involving welding underwater, in tight spaces, hazardous, or remote locations.

In the real world, this requirement by the welding control system to evaluate a number of parameters and build a strategy based upon multiple deviations from the desired values leads to an explosion in complexity of the problem. Because the control system cannot evaluate what can easily be millions of possible responses, there is a tendency to take a simplistic approach. In turn, this control system simplification leads to processes that are not robust. A machine that is welding parts correctly may suddenly begin making bad parts. No manner of fiddling with control system parameters will get the machine making good parts again. The machine is deemed to be temperamental.

The Holy Grail of Welding

Adaptive welding systems have been called the Holy Grail of the industry. The approaches to adaptive welding employed today have primarily focused on dynamic joint tracking.

Significant advances have been made in adaptive welding by integration of a larger set of the process variables (such as weld power, wire feed, torch position, and torch motion) into the machine control system, combined with the measurements of the actual joint to produce a high-quality weld, while allowing for a greater degree of variability in joint configuration and other process parameters.

One way to illustrate these advances is to use the three basic steps shown in Fig. 1.

Step 1: Observation and Recording of the Parts to Be Welded

An automated welding system starts with a careful observation of the entire part to be welded before the arc is struck. The system will notice deviations (just as the human welder would have) such as the bowing of the part asymmetry in the groove walls or one side of the groove higher than the other.

The system performs a comprehensive inventory of the joint to be welded. Observations include measurements such as the uniformity of the groove and comparing the mean value to specified process value. The system also keeps an inventory of previous welding passes and draws from the previous experience using it as a knowledge base. For example, the welding system can identify previous tie-in points as well as decide the next steps in the process. Additional parameters such as

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temperature of the metal are also observed and recorded to aid the decision-making recipe discussed below.

Step 2: Recipe for Decision Making

The automated welding system then prioritizes the effects of the various process variables. The prioritization is itself a multistep process involving decision-making. The decision recipe is created by the welding process engineer for a given type of weld. One example is the case of a plate butt joint weld with beveled edges where the first step is to scan the entire weld path and measure the maximum, minimum, and standard deviation of the differences in height between the two plates on either side of the weld. A score is given to the measured statistics. The recipe then looks at the variation in weld joint gap, in the case of the same plate weld. What is the variation from nominal along the length of the weld? A score is given to this set of statistics.

Other parameters that might have been derived from the scan information are gone through step by step in the decision recipe, each receiving a score that represents its importance. One of the problems facing early attempts at automated welding was the explosion of possible strategies to deal with variations in welding parameters. This scoring of the scanned values manages this explosive problem. The scoring system enables some automated welding systems to emulate the expert human welder by providing a mechanism to focus on the most important parameter and then subsequently go down the list of priorities.

Step 3: Integrating the Rest of the System

The power supply, torch motion, and wire feeder need to be coupled to the welding control system. Some currently available automated welding systems can precisely control the heat by independently controlling these three parameters, especially when the piece to be welded has asymmetrical or nonuniform heat capacity. With such a joint configuration, it is often preferred to make the oscillation motion itself nonuniform, dwelling on the high-heat capacity side of the groove, while perhaps increasing power supply power. Power is often lowered during the transit across the groove to the other side where power is then increased to a lower level than on the high-heat capacity side. Synchronizing wire feed rate with torch motion can produce a better weld. Sometimes decreasing wire feed rate during the longer dwell on the high-heat capacity side of the groove results in a better weld than not changing wire feed rate.

Coordinating Critical Elements

The trend to put more intelligence in all the disparate parts of a welding machine does not necessarily ensure that they will work well together, unless they can be coordinated and synchronized. For example, if the welding power supply controls the wire feeder and the power level to the torch, can the weld control system quickly command a change in power and wire feed speed? The answer is generally negative if the weld power supply is intent upon doing overall weld control. At the same time, however, the welding power supply is ill-suited to run the part of the machine that moves the torch. If that is a robot controller, then we ask if the robot controller is capable of more general control of the welding process.

Welding Automation Solutions

Today, manufacturers are implementing adaptive automation solutions for welding spent nuclear fuel canisters as well as some pipe applications. All of these applications require high-quality welds,

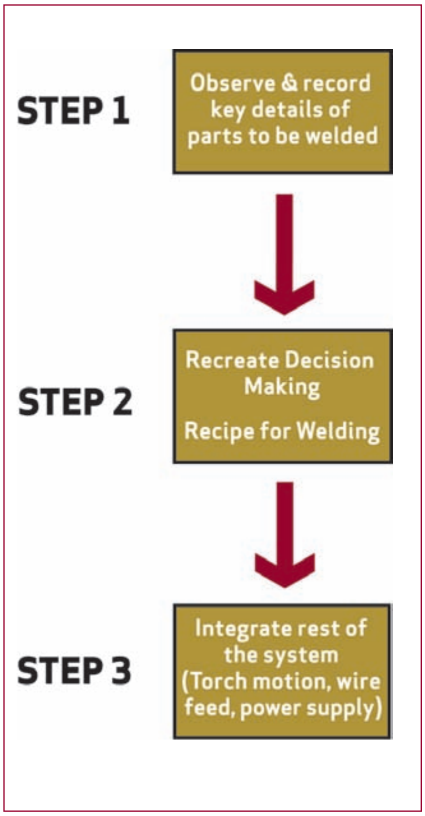

Fig. 1 — The three steps followed in designing an adaptive welding system.

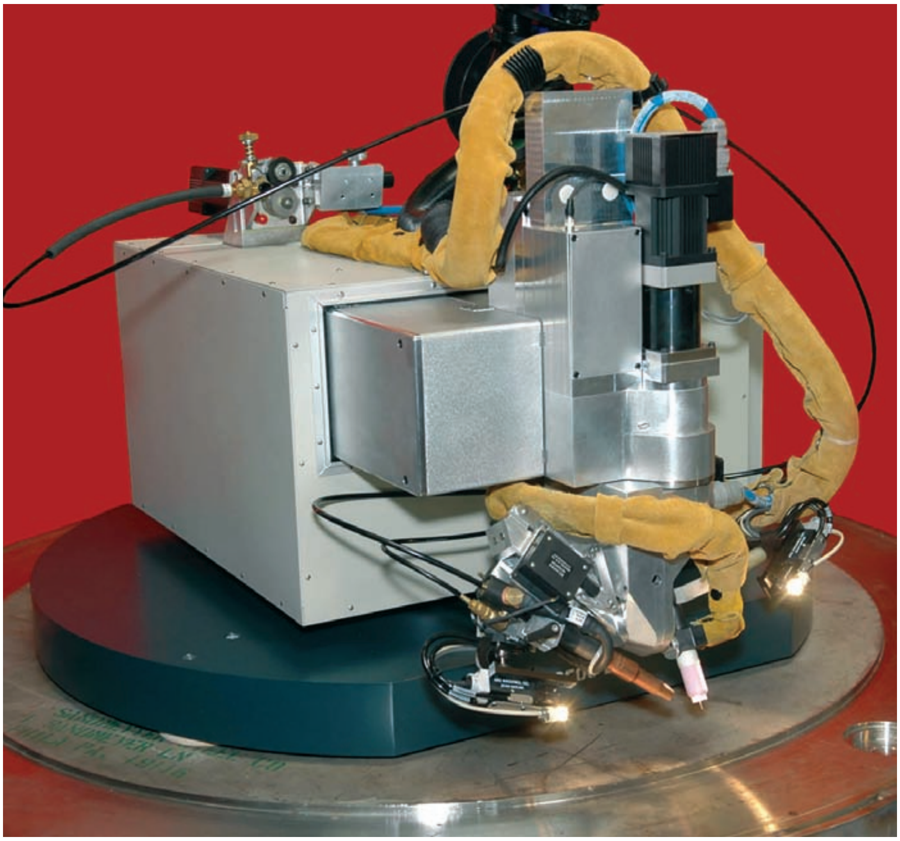

Fig. 2 — A Moog-developed automated welding system is shown atop a mock-up of a nuclear fuel canister.

plus reliable and high-productivity solutions. And manufacturers are constantly innovating to produce next-generation systems, too.

For example, Moog, Inc., has developed and successfully implemented automation solutions for several applications, including pipeline welding and welding nuclear spent fuel canisters.

These nuclear canister welding solutions are operational at a dozen power plants that have implemented remote welding as one way to minimize workers' exposure to radiation. The machines represent a key step toward fully automated adaptive welding systems.

The spent fuel from commercial nuclear power plants is placed into dry storage inside steel canisters. Generally, two lids (i.e., an inner and an outer cover) are welded to close the canister.

A gas tungsten arc welding (GTAW) process is employed, with more recent systems using an AC-heated wire to improve deposition rate. Along with a five-axis manipulator (Fig. 2) that holds the torch, the welding system controls a servo-driven wire feeder and a wire manipulator that steer the wire into the pool.

Unlike a conventional industrial robot, the five-axis manipulator canister welding machine is designed to provide both torch travel and oscillation along a path that can be mathematically specified from measured part features. This part-geometry-aware system is significantly different from industrial robots that employ a teach-playback strategy with no sensing of the part's geometry.

The automated welding system includes all motion control as well as weld power supply control, enabling the adjustment of the heat applied and the wire feed to the precise location in the weld groove. For example, the inner wall of the canister weld groove generally has a higher heat capacity than the outer, thinner wall. To obtain the same penetration with minimal part distortion, the welding system delivers less heat to the outside of the groove. In addition, the canister welding system can adjust, in real time, the width of oscillation to track variations in the weld groove due to compromised fit-up. To date, the Moog canister welding system has welded hundreds of spent fuel containers.

Conclusions

There is a shortage of skilled human welders and a need to accommodate hazardous environmental conditions as well as ergonomic concerns for workers. Economic advantages for using automation are powerful when implemented correctly, as this delivers high-quality parts via a repeatable, safe, error-free process. Yes, machines can weld faster and for longer periods of time than humans. If, however, the machine introduces defects to the weld or is not robust in the long run, then the gains are illusionary. But as manufacturers increasingly build a track record with fully automated welding systems, it demonstrates the ability to weld faster and do so with fewer defects on production parts offering results that previously could only be emulated by humans. And that, in turn, brings the industry's existing solutions closer to adaptive welding.♦