Optimizing the Next-Generation Resistance Welding Cell

This article summarizes trends affecting resistance spot welding and suggests the direction that the next generation of resistance welding cells will take

BY NIGEL SCOTCHMER, JAVIER DURAN, AND KEVIN R. CHAN

> *"While it may be hard to live with generalizations, it is inconceivable to live without them"*
>
> — Dr. Peter Gay, *Schnitzler's Century*

The next generation of resistance welding cells can be seen as a microcosm of changes evident around us. There are a number of trends driving these developments: increasing globalization, advances in automatic and electronic controls, and a worldwide interest in standardization. These trends are echoed in welding cell developments.

This article suggests that the current resurgence of the North American automotive industry is an opportunity for companies to upgrade and reexamine the ways welding has been done in the past. The methods and processes that have worked for so many years have proven to be outdated and too costly in the current market, and inadequate for the future demands of cost and quality. Furthermore, as adversity is a powerful tool for change and improvement, this article recommends careful analysis of current practices in light of emerging trends and observed facts. It focuses on examples of features that need to be considered in designing and specifying a new welding cell.

Interrelated Trends

The recent malaise affecting North American automotive companies was neither unique nor unexpected. It involves the three interrelated issues of globalization, electronics, and standardization. The fact that they are interrelated makes the issues harder to categorize, understand, and analyze. A dispassionate view is required, as the issues themselves have both good and bad factors and consequences. To be truly effective and successful, one must be able to sift through the alternatives and pick the choices that best meet the particular — and often changing — needs of the situation.

Globalization

Globalization is a term easier to use than to define. Here, it is meant to include a number of characteristics that currently affect the resistance welding industry in particular.

1. Crashworthiness and fuel economy concerns have led to the pursuit of new thinner steels and aluminum as well as new hybrid materials and coatings that are stronger and lighter, with all their attendant unknowns of consistency, performance, and aging.

2. The use of these new materials has led to the analysis of the suitability of new processes such as riveting, laser welding, adhesive bonding, ultrasonic welding, and friction stir welding in addition to spot welding, with all their attendant unknowns. These alternatives pose a threat to resistance spot welding.

3. There is a "fall of Rome complex," a sense that North America's glory days following World War II are over. Many feel that management has become ossified, unions lazy, and innovation and vision clouded, with too many new products on the market that do not meet the needs of the customer. Costs are cut in the face of declining sales, experienced employees

NIGEL SCOTCHMER is with Huys Industries Ltd., Canada; JAVIER DURAN is with Tecnologías Huys S.A. de C.V., México; and KEVIN R. CHAN is with Huys Welding Strategies Ltd., Canada.

Based on a paper presented at the AWS Detroit Section's Sheet Metal Welding Conference XIV, May 12–14, 2010, Livonia, Mich.

are let go, and research and development is curtailed.

4. There is also "the East is rising obsession." Many in the West fear that countless young engineers in huge and nameless Chinese cities scheme late into the night, dreaming up improvements to the myriad products they produce — "all on a bowl of rice a day," the saying goes.

5. Protectionism is gone. In an age of instant twitting of newsworthy events around the world, long-term protectionism is not going to work. If a better mouse trap is made in Russia, it will find its way onto the market. Stopping it is not a practical alternative — no more feasible than putting the H-bomb back into the genie's bottle.

While the degree to which globalization affects the future welding cell can be debated, it is clear that, due to their sheer size, India and China will inevitably become leviathans on the world stage. Thus they will become trend setters, if not determinants, of the needs and wants in future welding cells. It is all the more important to understand where they are now, where they are headed, and why.

Fig. 1 — The Liberty Ship Benjamin Warner *was built at the Kaiser Richmond Shipyards in California. The keel was laid June 13, 1944, and it was launched July 1, 1944. Visit* www.sanpedro.com/kaiser_richmond/kaiser-richmond_12.htm.

Electronics

Where do electronics come from today? If you design an IC chip today, where will it be made? Where do software writers live? What product today doesn't have electronics as its most important and defining feature? Who has seen the greatest rise in issued patents in the last five years? We all know that the answers to these questions are not North America.

Electronics, and the associated controls and sensors, come more and more from the East. Whereas America once produced cameras, CNC machines, and robots, nowadays high-technology items are increasingly made elsewhere. Whereas Tonka toys were once sneered at, Americans increasingly buy Acuras, Lexuses, and the Genesis. We also need to remember that Chinese nationals now constitute the highest number of foreign graduates in the sciences in doctorate programs at American universities (Ref. 1).

At the same time, computer manufacture and design have drifted East, perhaps best symbolized by the Chinese buying the laptop business of IBM. In Shenzhen, a large industrial city just north of Hong Kong, whole sections of the city are filled with multistory buildings housing hundreds of small electronics manufacturers, who design, produce, and sell everything for your computer. Many of these small components can only be purchased there. This is a cogent sign of China's new-found ascendancy in the field of computing.

In other words, all the essential electronic hardware for the computer's performance, its sensors, automation in general, and advanced programming logic controls are effectively in others' hands. This raises the spectre of a future where we here in North America may flip the burger, but the meat, the oven, the thermometer, even the flipper is made by someone else, somewhere else.

Standardization

Standardization has always been part of American manufacturing. Not too long ago, the American Welding Society and companies such as The Budd Co. were setting the standards for welding, and resistance welding in particular (Ref. 2). Standards and procedures for resistance welding aluminum and stainless steel alloys set by Americans in the 1920s and 1930s are still recognized as the best by Germans, for instance (Refs. 3, 4).

Increasingly, though, standardization is becoming a larger and larger issue. For example, as more robots come into use around the world, the prices drop and their hardware and software become more like commodities, while at the same time, knowledge of their proper use becomes better known.

At the same time, more people today are questioning the utility of standardization. This may sound paradoxical. On the one hand, there are those (especially in standards-setting organizations) who will argue that standardization has helped lower prices and improve living standards. There are others, however, who will suggest that standards protect incumbents and stifle innovation. Once a standard is set, it is hard to improve or change it. Thus, if you are not the incumbent who wrote the standard, then you have a hard row to hoe to gain market share. For example, if you no longer make robots, you will have to take what is on offer from other countries where practices and habits may be quite different.

In addition, with standardization there will be fewer suppliers offering a smaller selection of tools. Many would suggest that the Standard Oil Co., the chaebol of Hyundai or Baosteel did not grow in a free and open market, but rather grew through monopolistic characteristics. Some might even suggest Boeing and Airbus dictate the price for large airliners, or that Microsoft sets the price for computer operating systems.

Worse, there are also those who say there is a "dumbing down" with standardization, in that there is a desire for the lowest common denominator in the specifications of the technology. Skilled workers are gone, the knowledge is base lost, and these have been, in effect, replaced by the computer, over which you may have little control or knowledge.

Clearly, standardization is increasing and is unavoidable. But no matter how good clay bricks made on the banks of the Mississippi may be, they are not going to be shipped to Mumbai. Cost savings and efficiencies are not likely to overcome logistical common sense.

Even so, increasing standardization will also permit further specialization. This specialization will be particularly germane for resistance welding, which is already an inexpensive and effective tool for joining metal. Indeed, specialist standardization programs such as the European Union's "Xpress" automation and flexible manufacturing program will, without doubt, further separate those who can operate economically from those who will drop by the wayside.

Summary of Trends

Lean–agile manufacturing is one of the current buzzwords, but a trendy word misses the real point, which is that the next-generation resistance welding cell will incorporate, through choice and/or necessity, those items from current welding trends. It will have to take into account, to a greater or lesser extent, the increasing role of nonresistance welding processes, increasing electronics, design criteria over which you may have little control, and the need to be flexible

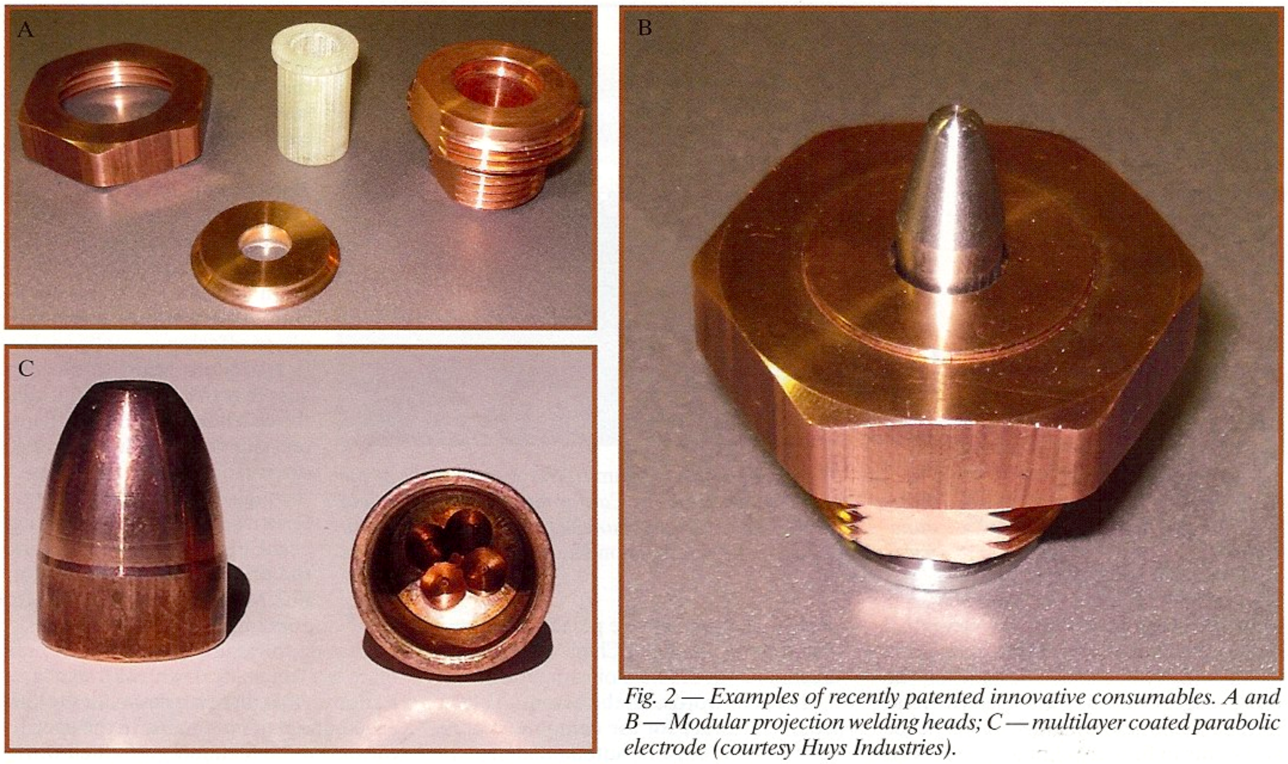

Fig. 2 — Examples of recently patented innovative consumables. A and B — Modular projection welding heads; C — multilayer coated parabolic electrode (courtesy Huys Industries).

enough to handle varying and changing manufacturing needs. Chances are the next-generation welding cell will be modular in design, highly automated, and very powerful.

An illustration of how quickly an innovation can make rapid and fundamental change to an industry is the Liberty Ship of WWII — Fig. 1. The Liberty Ship was a British design, but the innovative Americans welded the ship rather than riveting it and built it in an average of 42 days, five times quicker than the British, and employed one-third fewer people in the process. British shipbuilders, the biggest in the world, never recovered and faded from the world stage (Ref. 5).

The changes brought about by the Liberty fleet are an example of how American production methods had an immense impact upon the world. The unique characteristics of Canada and the United States — openness, freedom to operate, workforce flexibility, the fairness of our way of life, and the impartiality of laws — make our countries the envy of the world and the ideal environment to adopt, adapt, and improve upon the trends of globalization, electronics, and standardization. But that is if, and only if, we open our eyes to see what others are doing around us, and learn from them.

The Welding Cell

The standard automotive production line resistance weld cell today consists of a weld controller or timer, which feeds the electrical power to the physical weld gun typically held and manipulated by a robot, which in turn creates the weld on the worksheets held in place by a fixture or robot. The cell is typically loaded manually. In this case, the weld controller is programmed manually for each specific weld to be performed, and the weld sequences, or schedules, are "called out" by the programmable logic controller (PLC), which oversees the entire operation and ensures that the process is operated in the correct sequence (Ref. 6).

Each of these components can have a failure of some sort if not properly maintained and regulated, and it is not always easy to determine what has gone wrong in the event of failed welds or poor weld consistency.

The future welding cell will likely not have exclusively resistance welding equipment. It might include, for example, other processes such as adhesive bonding (for noise suppression and leak prevention), or riveting (for dissimilar materials).

The future weld cell will consist of modules able to communicate with each other and adapt to changes in the system, sensing workpieces, and adjusting accordingly. Although this goal has not yet been reached, aspects of the technology have already been developed and are in use today.

As always, the goal in production is to make welds that meet a minimum standard for size and strength consistently on every part. If the weld schedules are not programmed correctly, or are called out improperly, the weld could fail causing downtime and costly repairs.

Welding Consumables and Fixturing

Resistance welding, while employing no shielding gases or filler metals, still consumes electrodes and replaceable fixturing parts. We believe there will continue to be subtle but important improvements to consumables in the years ahead. The use of solid ceramics such as ZrO_2 and SiC, already the standard in Europe and Japan, will continue to grow in North America. The speed of acceptance will increase as older robots with poor repeatability are slowly phased out and replaced with robots with easier programming and improved accuracy.

Environmental issues over leakage of oil and air, combined with the cost and inaccuracy, will ensure the servo will continue to replace hydraulic and pneumatic cylinders. New coppers and improved coatings will appear on electrodes (Ref. 7). The simple modular head design for projection welding is already proving to reduce costs significantly (Fig. 2) (Ref. 8). Sensors will improve and increase in number as more processes and steps are automated, programmed and tracked.

Weld Controllers or Timers

The resistance welding controller is the heart of the resistance spot welding process. It provides the necessary weld current for the specified amount of time as required in the weld schedule. Weld timers are available in both AC and DC secondary current, and both have their advantages and disadvantages. DC weld timers run at much higher frequencies than AC, and so lend themselves to more precise control over the current profile and any changes that occur. In most cases, the primary power to the unit is monitored, and fed through a transformer with a known turns ratio, which provides the output of the desired secondary current. In some cases, the secondary current is directly measured to ensure that the correct current is being delivered to the weld. In most cases, the weld controller will only deliver what the weld schedule calls for, and so slight adaptations and allowance for material consistency and electrode tip wear are manually compensated for by using either a weld current stepper, or other external means.

For the next-generation weld controller, several options are already available and are being used. The adaptive weld controller is one that can sense the changes or differences in the weld during the actual welding cycle, and adjust the current accordingly to ensure a sound weld is made. The ability to judge whether or not a weld is sound differs from one manufacturer to the other, but the concept of being able to sense and adapt to varying welding conditions remains the same.

Adaptive weld timers have mainly been developed in Europe and the United States. Generally the practice has shown that sensing voltage and current from the secondary circuit of the weld gun is commonly used. It is important to note that, currently, adaptive weld timers work on spot welding and not on projection welding or seam welding.

As we continue to describe the technology of adaptive timers, it is helpful to review why adaptive weld timers are useful in production plants. The weld process involves current, resistance, and power over time. The equation is

$$E(R, I, t) = I^2R*t$$

This equation shows that energy is dependent upon the current I, resistance R, and time. It is a very simple description of the process. Energy is required to melt the material. This energy can be brought to the weld spot by varying the current and/or the time. The resistance is a natural consequence of the materials used and cannot directly be influenced by the power source.

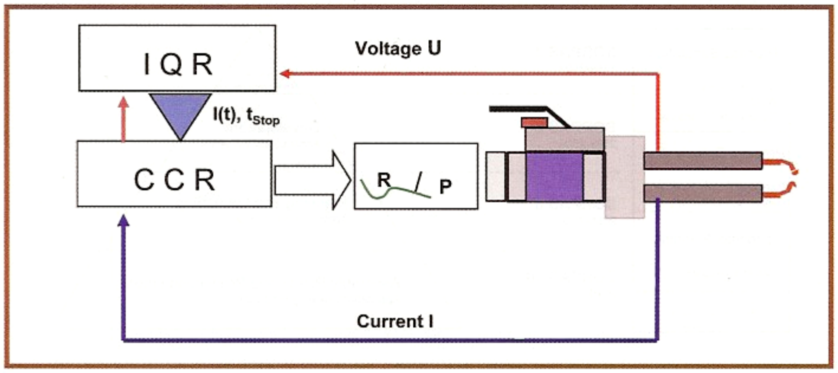

Fig. 3 — Adaptive weld control diagram (courtesy Harms & Wende).

Research has shown that resistance is a key factor in describing the weld process. Resistance in the materials changes as it is heated and is said to be dynamic. If we were to measure this changing parameter, it would allow for variations in the weld current. Thus, the power source would react in real-time to change the welding parameters and achieve a good weld nugget. Clearly, the formula above can either change the current, the time or both. It is obvious that it is easier to vary the current, since it has a clear bigger influence as it is mathematically squared.

Unfortunately, a car can have 5000 welds and all the parameters for a perfect weld are not likely to be present for each weld. Some of the reasons for a poor weld include

1. shunting effects from alternate current paths,
2. variations in the material being welded,
3. variations of the coatings on the surface of the material being welded,
4. voltage fluctuations,
5. material stack-up and general fit of the parts,
6. electrode wear,
7. wear of the welding gun or machine components, and
8. heat in the welding gun, electrode, or material.

There are many other variations or combinations of those factors that are possible. They occur daily. These concerns have driven manufacturers to adaptive weld timers. Reducing costs, competitive pressures, improving quality, and documenting the process will lead others to adaptive controls.

For example, weld timers from Harms & Wende use a toolbox built into the MFDC inverter that is embedded in an adaptive welding package (Ref. 9). This solution provides an intelligent algorithm to control process variations. All adaptive systems on the market today are medium frequency with a minimum clock rate of 1000 Hz or higher (when a system is operating at a clock rate of 10,000 Hz, it is called high frequency). Integration of the adaptive control technology is simple. Since the current signal is provided from the coil on the secondary side of the transformer, two additional shielded cables are required for the voltage measurement — Fig. 3.

Adaptive controls provide rapid correction of irregularities in the welding process, automatically. In addition, complex materials and different combinations can be dialed in, providing speed as well as accuracy. Additionally, new high- and ultrahigh-strength materials are difficult to weld, and the ability to change the welding parameters for production inconsistencies such as poor fitup is an incalculable advantage.

Adaptive control can also assist other production setups, such as the recent Asian interest in single-sided spot welding machines. Japanese and Korean companies have shaved valuable seconds off each weld in those applications that can employ single-sided spot welding (Ref. 10). Five seconds on each of 5000 welds on 200,000 cars per year is a large saving.

It is not hard to see how the next step is a database in the adaptive control, and the user simply chooses the material combination, electrode style and shape, and the system itself selects the appropriate weld schedules. That day is arriving (Ref. 11).

Automation and Robotics

Advances in technology are expanding what can be done without the aid of humans. Robots have been used in production environments from simple parts handling to very complex cutting and welding operations. As we look forward to the next generation of automation solutions, robots will be able to sense conditions and adapt to slight changes without the need for further programming. Modular designs will allow a single robot to perform a variety of tasks, even change tools and

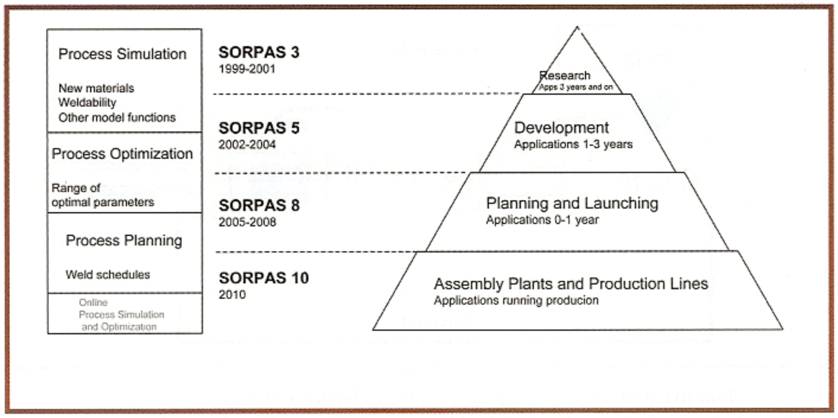

Fig. 4 — Possible timelines for implementing optimized welding schedules with online tracking (courtesy Swantec Engineering).

process, while identifying, and adjusting accordingly. With the increase in use of vision sensors, modern robots are able to verify the positioning of the parts and the tooling, as well as check the conditions of the welds after they are performed. With servo weld guns, the amount of data that can be reported and recorded for each weld and each operation is growing, allowing a tight control of process conditions in real-time. The ability to adjust the welding process as the electrode wears can greatly increase the tip life while maintaining quality and decreasing maintenance. Integration of robots and weld timers has been made quite easy with the addition of software setup screens that aide plant personnel in setup and debugging of most welding issues.

Weld Planning and Engineering

Traditionally the task of the welding engineer, the planning of the sequence of the welds and, more importantly, the specific weld schedules to be used, requires experience and expertise. With the goal of producing the best welds for the longest duration without the need for maintenance, there exists a delicate balance between undersized and oversized welds. Many differing opinions exist on the best weld schedules for use with a particular type of steel and material combination, and this leads to an almost infinite range of possible weld schedules. However, both Europe and North America are seeing many experienced engineers leaving the business and many inexperienced ones enter it in India and China.

One of the ways of addressing concerns such as these is being addressed by programs such as the European Union's Xpress initiative. This program aims to cut ramp-up times and production costs by producing a flexible and multivariant quality process that will allow the integration of various methods and interfaces into a standardized method of control for aerospace, automotive, and electronic manufacturing. Its aim is to realize flexible manufacturing by bringing all the electronic subsystems together (Ref. 12). This program, in a sense, is preparing for the next-generation welding cell.

Many companies already use FEM and simulation software to reduce time and money expended from drawings to preproduction and from preproduction to optimized weld schedules (Ref. 13). Figure 4 shows how Sorpas software, a FEM software package, has in the last ten years moved from single, simple simulations of two sheets toward the goal of online process control at actual assembly plants and productions lines for certain large automotive companies, involving thousands of welds on different materials and stackups. Such a planning tool is an integral part of the drive behind the European Xpress program.

The next-generation welding cell will employ detailed optimized schedules that work in conjunction with a program such as Xpress. This will significantly reduce setup, maintenance, quality problems, and costs overall. Those that already have or are planning to employ adaptive weld controllers and modern robots have a head start in using flexible manufacturing (Ref. 15).

Costing

Specific companies in Asia and in Europe already possess sophisticated accounting systems that allow them to track and use production data far more effectively than many North American companies. Certain Japanese companies know the accurate cost per weld on the factory floor, and work out detailed margin contribution of that extra car squeezed out of the line before the end of the shift. Generalizing, we tend to be sloppier with such analysis in North America (Ref. 16). We lack the precision and the perceived need for such accounting control that is both a boon and the bane of the German and the Japanese.

Be that as it may, the next-generation welding cell will provide a vast amount of information that will be used to provide accurate and detailed accounting information. Such information will be of profound importance in a global environment where margins are likely to continue to be under attack The recent adoption of single-sided spot welding in Asia has been an example of where, in specific situations where 'shunting' is not a major risk, significant production time has been saved. I assure you, North Americans have not yet realized what penny pinching can mean.

Summary

Today, the implementation of a robotic resistance welding cell requires detailed knowledge from the staff who design and commission the cell. Advanced knowledge of resistance welding is required to maximize performance and to minimize quality issues. The adoption of new materials and complex weld joints only increases the cost on startup.

In the future, CAD/CAM systems will gain access to databases to assist in rapid design and manufacture. Thus, the time from dream and sketch of an idea to production of the finished part will drop dramatically.

Intelligent MFDC systems with adaptive regulation modes that are already in use worldwide will improve further in terms of their ease of use and accuracy, and provide near-perfect welding by compensating automatically for fluctuations in the welding process.

Production knowledge, linked to all locations, online and in real-time, will electronically update databases and provide instantaneous reporting of quality, production, and costing information to management. New programs and production changes will be implemented even more quickly as knowledge from databases is used. More detailed costing information will be generated and summarized for management.

The next-generation resistance welding cell will be international in origin. Its success in operation will depend upon the careful choice of what you need, why you need it, and how you implement.

We believe that the natural innovative and entrepreneurial spirit of America, combined with its openness and flexibility, are ideally placed to adopt, adapt, and improve the next generation of resistance welding cells. We are actually the best guys to do this as our society is the most open — period.♦

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