Orbital Welding

New documentation methods simplify validation of stainless steel systems

By William J. Wuertz

Swagelok

A ccording to a well-known mechanical contractor who specializes in the construction of bioprocessing systems used for the production of pharmaceutical products, the documentation required to support these installations can easily account for 30% of the total construction labor hours on a project. A significant number of these hours are spent tracking, accumulating, and compiling all of the supporting data required to verify that every welded connection made on the tubing system meets the stringent specifications for hygienic applications.

Orbital tube welding, which is the recommended method of fabrication for bioprocessing equipment and tubing systems, has not changed much since the 1960s, when it was introduced into the aerospace industry. We still use the Gas Tungsten Arc Welding (GTAW) process and orbit or rotate an electrode around a fixture welded joint with a predetermined set of weld parameters programmed into the power supply.

However, today's orbital welding equipment utilizes microprocessor technology and has the ability to monitor the weld process, capture and compile real time data and electronically transfer it to a computer where it can be formatted for statistical analysis. Weld programs can now be automatically created and adjusted by the power supply. Weld logs can be maintained electronically and imported directly to a computer where they can be easily formatted for installation qualification.

So although we may still perform an orbital tube weld much the same way we did 30 years ago, today we have much greater control over the welding process and can obtain significantly more data to verify it. Most significantly, the ability to transfer data to the computer for statistical analysis has the potential to change the way industry approaches orbital welding.

New Weld Documentation Methods

Weld documentation is required by the FDA to provide full traceability for all materials and procedures used for construction of bioprocessing systems. The documentation is required to provide the necessary verification that each weld meets the acceptance criteria as defined by the weld specification. In the event there is a problem with a system, such as contamination, the documentation provides a means to go back and review each welded connection as part of the effort to track down and find the source.

The amount of documentation a contractor must submit to support a single weld is staggering, but of particular interest for this discussion is the weld log kept by the welding operator. Throughout the construction project, orbital welding operators must keep a daily weld log. Whenever a weld is completed, the operator must manually record the event in the log. The weld is then inspected, typically with a video boroscope, and then properly identified with a unique identification number that traces it to the weld log. At the end of the day, weld logs are collected from all of the operators and submitted to a quality control administrator. The quality control administrator inputs the data from all of the operators into a spreadsheet on a computer and prints it out. The weld data report is now in the proper installation qualification format and is ready for submittal. The contractor is also required to create isometric drawings, depicting the completed welds with the corresponding identification numbers, and submit them with the installation qualification report.

Collecting and submitting all this documentation provides the verification needed to ensure the integrity of each welded connection. Or does it? The weld log that is kept manually by the operator is probably the weakest link in the weld documentation process because it is susceptible to human error. The integrity of the weld log is dependent on the operator remembering to record the appropriate information after each weld. We assume the information is recorded correctly (in the correct column) and we hope the operator’s penmanship is readable by the quality control administrator who must manually type the information into a computer.

Accumulating, compiling, and submitting weld documentation drives up the individual cost per weld. For example, a job with 10 operators completing 20 welds each per day, six days a week, would expect to complete a total of 1,200 welds per week. Using a conservative estimate of six minutes total for the combined time of logging and inputting each weld would result in 7,200 minutes per week or 120 hours. At $50 per hour, the cost for manually documenting welds would amount to $6,000 per week. This figure does not include the additional costs of generating other documentation, such as slope reports, bills of materials and weld map drawings. A typical cost per weld for a high purity system without this detailed level of documentation is approximately $80 to $100. Therefore, the same weld including manual documentation can easily cost as much as $150. If there is an error in the documentation, the weld will be suspect; in the worst case, the weld would have to be cut out and replaced at the contractor’s expense.

Today, the weld log can be kept electronically, thanks to advances in microprocessor controlled orbital welding power supply technology. The operator no longer has to record any information. Upon the completion of each weld, the data needed for the weld log is stored in memory on board the power supply. At the end of the day, the weld log data is still collected and submitted to the quality control administrator, but now it is in

W illiam J. Wuertz is manager, welding systems, at Swagelok.
the form of a PC data card. The card is read by the computer and the data is imported into a common spreadsheet or database where it is formatted for the installation qualification report. The electronic weld log is completed, requiring much less time and effort on the part of the operator and the quality control administrator, at a significant cost savings for the contractor.

Maintaining the weld log electronically requires a little more time up front to input setup data into the power supply, but once this is done, usually only periodic updates are needed. User interface with the welding power supply has also improved. Modern keypads and crisp LCD screens have been integrated into the machines, making the task of data input much easier. Power supply operating systems have been designed to look and perform in a manner similar to those used with personal computers, so they are familiar to the user. Navigating the software has been made easy through programming that is intuitive, logical and easy to master.

The amount of information available from an electronic weld log is significantly greater than what is kept on a manual log. The additional information is a valuable asset to the traceability documentation. Following is a list of the some of the information that may be found on an electronic weld log:

- Date and time
- Weld count number
- Power supply model number
- Power supply serial number
- Procedure identification
- Operator identification
- Programmer identification
- Project identification
- Drawing identification
- Weld joint description
- Weld joint material type
- Material heats
- Tube diameter
- Tube wall thickness
- Shielding and purge gas identification numbers
- Flow rates for shielding and purge gas
- Weld head serial number
- Electrode identification
- Software revision level
- Date of last calibration
- Notepad

The dimensional data usually can be configured to be presented in metric or fractional units. Most power supplies will even convert logged data between fractional and metric. In addition to this input data, the output values of travel speed, time, average current, voltage and downslope will be included in the weld log. Some machines even calculate and include joules per inch, which defines the heat input.

**Benefits of Real Time Data**
Orbital welding equipment today is capable of acquiring real time data output and exporting it to a computer where it can be formatted for verification and analysis. The acquisition of real time data simply means capturing and storing the output values of the welding parameters while the weld is in progress. The welding parameters that are being tracked are those critical to the welding process; these include, but are not limited to, the travel speed (rotation speed of the electrode around the weld joint), the average current and the voltage. Utilizing the power of the microprocessor, the power supply samples these parameters at approximately 50 times per second and records the results in memory with the weld log.

Much can be determined by analyzing the weld parameters. For example, variations in the voltage may indicate a change in the arc gap (distance between the electrode and weld joint), which could be the result of ovality in the weld joint. It could also indicate that the weld joint was not properly prepared and that there is a gap or space present in the weld joint. Variations in the current may be the result of a large spike in the incoming power source to the power supply. There are numerous other possible conclusions that could be made regarding different data variations. Without the data, such an analysis would not be possible.

**Statistical Process Control (SPC)**
Statistical process control (SPC) is defined as “the application of statistical techniques for measuring and analyzing the variation in processes.” The acquisition of real time weld data provides the opportunity to apply SPC to orbital welding and improve the quality of the process. Realtime data provides the feedback loop needed to better understand how to control the process and optimize the output. By analyzing live data, or measured performance, we can determine process quality characteristics such as travel speed, average current, arc gap, weld joint position, shielding and backing gas, purge pressure and material properties. With enough data, we can establish acceptable performance standards. The control of the performance can then be measured through the feedback loop or realtime data and compared to the standard; any difference can be acted upon.

Orbital welding equipment suppliers have understood the value of SPC and now provide welding equipment outfitted with the tools necessary to implement it. The power supplies are capable of being programmed with preset acceptable standard deviations for the critical output parameters, so that, as the output data is being sampled, it is also being checked against preset acceptable limits. Should the output exceed the acceptable limits, an alarm can be enabled to sound and alert the operator. When this occurs, the printout provided by the power supply includes a statement that the performance was unacceptable. The actual output data appears on the printout, so the operator or quality control engineer is able to review it in an effort to determine what happened. The electronic data sent to memory also includes the actual data and a statement that the performance was unacceptable.
Power supplies are also capable of setup diagnostics, weld diagnostics, and machine diagnostics. The diagnostics take the form of messages that are normally displayed on the front panel display screen. In addition, the diagnostics are recorded on the printout from the power supply as well as stored in memory with the weld log data. The setup diagnostics typically include operator messages, such as invalid weld procedure, printer paper empty, PC data card not installed, etc. Weld diagnostics are messages that describe the cause of a functional problem should one occur. Examples of these messages would include: rotor jam, misfire, arc out, and tasks not complete. Finally, the machine diagnostics provide messages about the power supply, such as overheating, minimum voltage alert, etc. Equipment today can record nearly every event and make it available for review.

SPC can also be applied to the weld procedures used in the orbital welding process to produce a more uniform weld quality. Weld procedures often include detailed setup specifications, which play a key role in the control process for SPC. For example, the arc gap (which is the distance between the tip of the electrode and the work piece) is a parameter that plays a significant role in the orbital welding process. Even a difference of 0.005 inch can result in a variation of a completed weld. Because the arc gap is a critical parameter, the operator must, upon initial setup, install the electrode in the weld head and position it to the best of his ability, to obtain the desired arc gap. Throughout the course of the job, the electrode will deteriorate and will need to be changed. How does the operator know when to change the electrode? How can the operator be sure that the new electrode will be installed in the same position the original electrode was for initial setup and coupon testing?

SPC may provide the answer to these questions. Analyzing weld data for repeated welds using the same electrode might reveal a change in the process that can be attributed to electrode deterioration. If this can be established, an optimum number of welds per electrode might be determined and become part of the weld procedure.

There is a simple solution that will improve the likelihood that the arc gap is set in the right position during setup and that it is set in the same position every time it is changed. Equipment suppliers provide simple gages or procedures that are used to set the position of the electrode. The gages are set to a specific position and then locked in place. Whenever the electrode is changed, the gage is used to reposition the electrode to exactly the same place it was on the initial setup.

Similarly, the weld joint must be positioned in the fixture so that it is aligned with the electrode. A shift of just a few thousandths of an inch in the joint position can result in a weld with incomplete penetration. Simple gage blocks supplied with the fixtures provide a means to position the weld joint in the center of the fixture every time. Including the use of such gages with the weld procedures can improve setup protocol and result in a more consistent weld process.

Industry’s knowledge of material chemistry and understanding of its effects on weldability has significantly improved over the last ten, or even five years. Today, material suppliers are producing with controlled chemistries, specifically designed for improved weldability and corrosion resistance. As a result, material is becoming less of a variable for welding. The more we understand about the relationship between welding and material chemistry, the closer we become to being able to predict the exact weld parameters needed to perform a weld.

Currently, corrosion testing of stainless steel welded joints seems to be an ongoing effort in different industries for different reasons. The testing normally includes material of known chemistries, input data defining the weld program and calculations that describe the heat input. The corrosion tests provide documented results and physical samples. But what is often missing from the documentation is the realtime weld data. The ability to capture and analyze realtime data can help us gain a better understanding of material chemistry and welding.

Although our understanding of material weldability has evolved considerably in recent years, there is still a great deal we do not know. Using real time data to analyze weldability issues, such as sulfur content, will be a valuable tool in improving methods or finding solutions. The analysis of weld data may indeed someday provide us with the ability to predict the exact weld parameters needed to perform a weld based on a chemical analysis of the material.

Predicting weld parameters is being done right now with very impressive results. Some orbital welding power supplies now have programs built into the software that will automatically create a program based on the material chemistry. Realtime data analysis, combined with existing weld program development practices, has enabled these programs to be developed. Creating a new program is now a matter of going into the programming mode on the power supply and responding to prompts from pull-down lists for weld configurations and materials. Then, with the simple push of a button, the power supply will execute a series of calculations and instantly generate and load a weld program. If, after trying the weld program, it is determined that an adjustment is necessary, the user is again prompted by the power supply to select the segment or location on the tube where a change in heat input and subsequent weld penetration is desired. After making the selection, the machine can instantly create a new program with a small adjustment made to the heat input in the selected location. Manually determining weld program parameters requires hand calculations, reference tables and manual data input, which can be a difficult and time-consuming job, and often requires a highly skilled programmer or operator.

The ability to generate weld programs quickly can bring an immediate benefit to verifying the weldability of incoming material. Often, as tubing and other components are received, they are checked in, the paperwork is verified and the material...
receiving report is filed. If the material has a weldability issue, it may not be discovered until it is pulled from inventory and taken to the work site. At this point, the material may have to be returned and replacement material must be ordered and expedited in. If weldability test samples are made as material is received, this situation may be avoided. The programs that are created to perform the weldability tests on material as it is received can be saved until they are needed later when the material is being used.

**Statistical Quality Control (SQC)**

Statistical quality control is defined as “The application of statistical techniques for measuring and improving the quality of processes.” Statistical analysis of real time data can be applied to quality control practices currently being used with orbital welding. The power of the computer can be used to scan data and look for irregularities. Spotting an unusual number among hundreds of other numbers may be a challenge for the human eye, but it will appear as a flashing yellow light to a computer.

A bit of data outside an acceptable window of deviation may be a clue to a bigger problem. The opportunity now exists to re-inspect the suspect weld and the supporting data to verify its acceptability. As an example, consider that a construction job with 1000 welds may have had 5 welds rejected. Is there something that the 5 rejects have in common that may also be common with other welds in the system? Were they all welded by the same operator? Did they all involve the same material? Were they all welded within the same hour? Computer analysis of the data provides a practical and timely way to sort through the weld data and look for such commonalities between the rejected welds. If a particular link is found, a search through all the other weld data can be easily conducted to look for other possible suspects.

We know that variations in material properties can affect weldability. How material is selected and where it comes from can make a significant difference in welding productivity. Data analysis can provide information that may be useful when specifying tubing, fittings and other components. For example, fittings with poor control over the dimensional characteristics can yield irregular weld beads due to ovality or wall thickness variations. Tubing or other components that frequently present weldability problems may be supplied from a source that should be evaluated. Data analysis may also provide the necessary information to allow users to match tubing and components of similar material chemistries in an effort to improve the likelihood of compatibility for welding.

**Realtime Data Reports Improve Management**

Compiling detailed weld data into a database makes it possible to generate different reports for different purposes. A database is an invaluable tool for managing activities such as productivity analysis, costing, expense management and quality control. For example, a project manager preparing a proposal for a construction job may be looking for costing information on welding. A query of the database could quickly provide a wealth of information regarding the average costs associated with welding different sizes, configurations and materials. This kind of actual costing information would also be very useful to justify bids based on time and material.

Welding productivity is certainly an important issue that must be managed properly to be competitive and profitable. Productivity statistics, such as weld per hour and welds per day for each operator, provide the visibility managers need to establish a benchmark for their productivity. Further data analysis could result in determining key initiatives to improve productivity. One common productivity improvement is training; the effectiveness of a training program effort can easily be measured through routine reports that measure productivity. The reports may also indicate that equipment is the bottleneck and, thereby, provide justification for the selection of new equipment.

The quality control engineer can also use data analysis to improve the quality of the welding process. Investigation into the primary causes for weld rejects allows the quality control engineer to develop and implement actions to prevent or minimize them from reoccurring. The database could provide a report that lists the most frequently encountered quality problems sorted by the number of occurrences. For example, if an issue such as misalignment or discoloration should appear on the list, the weld fixture, purge practices, or setup protocol should be reviewed.

The 1960s brought orbital welding to industry. In the 1980s, we began to learn how important material chemistry is to weldability and orbital welding. The 1990s may be remembered as the decade of data.

Advanced welding power supply technology has improved weld data collection and analysis. Real-time data collection and electronic weld logs make weld information readily available. Weld data analysis can provide information for:

- Documenting welds to provide full traceability.
- Controlling the welding process and optimizing output.
- Producing a more uniform weld quality.
- Predicting weld parameters.
- Creating weld programs.
- Managing welding productivity.
- Justifying bids.

In the past, it was not possible to easily acquire the necessary data and subject it to statistical review. Today, with easy access to complete weld data comes the ability to analyze and implement quality tools such as SPC and SQC. In addition, electronic weld logs will bring relief to contractors who will diligently compile what seems like mountains of documentation for weld verification.

Advancements in microprocessor-controlled orbital welding power supply technology offer an opportunity to improve welding processes and procedures. Our challenge now is to not be too busy doing things the old way to learn how to do them a better way—a way that can change industry’s approach to orbital welding technology.

**References**

3. Ibid.