Sensors for Feedback Controls in Solid State Resistance Welding

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DOE Contract No. DE-AC09-96SR18500

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SENSORS FOR FEEDBACK CONTROLS
IN SOLID STATE RESISTANCE WELDING OPERATIONS

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Abstract

The presentation will include a survey of sensors for use in resistance welding processes. The results of the application of the analog laser position sensor will be presented along with data indicating how the displacement parameter defines the weld process. Opportunities to close the control loop by taking sensor data into the weld controller will be discussed.

Resistance welding processes in industry have traditionally been based on open loop controls. Variances in weld materials and control parameters can have significant impact on weld quality. In recent years, more emphasis has been placed on controlling variables in the weld process in order to produce more consistent and acceptable results. There are a number of special weld processes at the Savannah River Site involving nuclear containment vessels that depend not only on controlling those process variables but measuring the weld parameters during the weld event. Several real-time data acquisition systems have been developed and deployed to provide feedback from the welding process in order to assure weld quality. One key measured parameter, especially in a solid state resistance weld, is the physical displacement of the two pieces being joined. The key challenge in making this measurement during the weld is that most sensors commonly available for this are magnetically based. These include proximity sensors and linear variable displacement transformers (LVDTs). Magnetically based sensors are very difficult to work with in a resistance welding operation because of the extreme magnetic fields associated with the welding current. Optical sensors have been researched and deployed for use in this application. An analog laser position sensor was designed into a welder data acquisition system, producing good results.

Overview

The Savannah River Site (SRS) has a 40-plus year history of producing and processing tritium primarily for use in nuclear weapons. This gas is stored at high pressures in reservoirs that are manufactured and sealed through the use of special resistance welding processes. There is an interest in maintaining the quality and consistency of these welds to avoid leaks in the reservoirs. The reasons for this are the limited supply and high cost of producing tritium, the necessity of assuring nuclear safety and to promote weapon system reliability. Precisely machined 304-L and 316 stainless steel components are the materials used in the fabrication of the reservoir. The processes
used to join these components and seal the reservoir are AC driven, solid state resistance weld processes. By solid state, we mean that no metal melts in the fusion process. While weld current is applied, a large force is exerted between the pieces being joined in a manner to avoid a state change and the formation of a weld “nugget”. The result is that the mechanical tolerances of the fit-up between the two joined pieces are low and the bond quality is consistently very high. These processes are well proven and are continually tested through, leak tests, burst tests and destructive metallurgical examinations of test weld samples. Because destructive tests can be used only to make inferences about the weld quality of actual production components, the weld process parameters are measured for every weld. Studies have shown the acceptable bounds for each measured process parameter necessary to achieve an acceptable bond. The weld process parameters that are measured are weld current, weld volts, ram pressure, ram force, ram displacement and of course the duration of the weld current.

**Measured Resistance Weld Parameters**

There are several parameters that are critical to the quality of the weld. These are: weld current, weld volts, ram force, ram pressure, AC supply volts, electrode displacement, weld duration and weld energy. The significance of these are outlined as follows:

- **Weld Current** is the primary controlling parameter and indicator of the total energy deposited in the weld joint. This parameter is dynamic since the resistance of the weld joint changes through the weld event. As the weld interface heats, the interfacial contact area increases causing a corresponding decrease in the joint resistance.

- **Weld Voltage** is the voltage drop seen across the weld joint at the electrodes during the weld event. This quantity is dynamic and depends on the regulation of the supply voltage feeding the weld transformer, the regulation of the weld transformer and the weld current/joint resistance during the weld.

- **Ram Force** is a measure of the amount of mechanical force applied to the welder electrodes and the pieces being joined. This quantity is measured prior to the application of weld current and during the event. The force must be maintained throughout the weld event to assure proper bonding for a solid state resistance weld.

- **Ram Pressure** is a measure of the nitrogen gas pressure exerted on the welder ram cylinders. This variable is largely determines the force component, however is useful in diagnosing faults in which the force is not constant. These can be nitrogen supply restrictions, supply volume limitations and welder mechanical faults.

- **AC Line Voltage** are measured to assure the input voltage is within limits before and after the weld. Regardless of the transformer turns ratio, voltage is one determining factor on weld current in a resistance weld. The AC supply voltage is easily controlled.

- **Electrode Displacement** is measured on some of the larger solid state resistance welds and is a primary indicator that a bond has been made. The pieces being joined are mated with an interference fit prior to welding. The extent to which that interference has been penetrated after the weld is an indicator of the contact area of the fusion of the two pieces. This parameter is dependent on all the other weld variables.

- **Weld Duration** or the time of the application of weld current is a critical parameter that determines the amount of energy that is deposited in the weld joint. This parameter is primarily a function of the weld controller.

- **Weld Energy** is a calculated parameter that is an indicator of the total energy deposited
in the weld joint. This calculation is based on the following: Joules = Watts Seconds = Volts Amps Seconds. RMS volts and amps are used in the calculation because of their dynamic nature and our interest in determining the "area under the curve".

Obviously some of these parameters are more critical in characterizing the weld and some are dependent on others. However, this is a fairly complete set of parameters that can be measured to assure weld quality.

Sensors

The sensors used to measure each of these described parameters are all commercially available. Let's detail each individually:

**Weld Current** is measured with a shunt or a stand-alone current monitoring instrument. Most frequently at SRS, we use a 30,000 Amp Holt shunt. The shunt has a basic accuracy of 1% and has excellent long term stability. The shunt must be monitored by instrumentation with high impedance inputs in order to isolate the instrument from the weld current.

**Weld Voltage** is simply measured by looking at the voltage across the welder electrodes. This is accomplished by inserting common banana plugs into holes in the electrodes. The voltage measurement points should be located as close to the weld joint as possible in order to see the voltage across the weld joint instead of the voltage drop across the electrodes. High impedance inputs should be used for the instrumentation to isolate from the weld current. The voltage sensing leads should be twisted near the weld head to cancel magnetically induced voltages.

**Ram Force** is measured with Strainsert universal flat load cells. The 25,000 pound unit has a full load deflection of less than 0.00179 inches. The 10,000 pound unit has a full load deflection of less than 0.00104 inches. The stiffness or spring rate is 9,600,000 pounds/inch. These units consist of a strain gage in a bridge connected configuration. Non-repeatability is specified at 0.05% of full scale. Non-linearity for the precision grade units is 0.10% of full scale.

**Ram Pressure** is measured with a variety of transducers manufactured by Precise Sensors, Sensotec, Rosemount, Barksdale or Teledyne Taber. 0 to 300 PSIS (sealed) units are used with accuracies of 0.25% of full scale. These units consist of a strain gage in a bridge connected configuration or have a 4-20 mA output.

**AC Line Voltage** is measured with an Ohio Semitronics RMS voltage transducer. This device functions as a peak detector to convert 0 to 600 VAC linearly to 0 to 10 VDC. Accuracy is 0.25% of full scale with ripple less than 1% of full scale.

**Electrode Displacement** has been measured with proximity detectors and linear variable differential transformers (LVDTs). These devices both function on magnetic principles and are easily overwhelmed by the 60 Hz magnetic field from the weld current unless a low pass filter is used. The LVDT must be mechanically coupled to the welder assembly to detect the ram movement. More recently, an analog laser position sensor manufactured by Nais and marketed by Aromat has been used successfully. It makes a non-contact, linear measurement that is not subject to the magnetic field and is easily calibrated. The resolution is from 0.0002 inches to 0.0020 inches depending on the response time chosen. Linearity is +/- 0.0008 inches +/- 0.2% of distance from center point. The measurement range is +/- 0.394 inches and the nominal center point distance...
Weld Duration is measured by waveform analysis of the weld current signal by the data acquisition system (DAS) or by a stand-alone weld current monitor. The DAS uses crystal oscillator based computer system timers and signal analysis to measure the weld duration. Since data sampling is periodic, the time measurement of the acquired signals is straightforward. This measurement merely confirms the proper function of the weld controller and the programmed weld schedule.

Weld Energy is calculated by the DAS based on the weld current, weld voltage and weld duration. The weld energy is expressed in Joules.

Weld Process Measurement System

Several stand-alone weld current monitors are available on the market that do a nice job of analyzing weld current and duration. They give readings of peak current, RMS current, % heat and other parameters. Weld event summary data and cycle-by-cycle analysis are possible, however they do not address the other parameters of interest in a solid state resistance weld. At SRS, each of the process welders are monitored by a custom DAS. There are four different types of data acquisition systems in use today, however the principles are the same in each. The DAS takes analog input signals from the transducers we have described for the weld characterization and digitally samples the signals with a digital to analog (A/D) converter. The signals are conditioned and buffered before being brought into the measurement system. Presently, several welder DASs are being fabricated and installed that handle as many as 16 weld stations and over 50 analog signals.

The DAS consists of a computer system with a National Instruments IEEE-488 interface connected to two Neff Instruments 470 data acquisition chassis. Analog Devices 5B series signal conditioning modules are used on inputs that require isolation from the process or filtering. A wide range of amplifier modules are available with different gain and bandwidth characteristics. Neff offers a variety if data acquisition and I/O control cards for the 470. The weld controller is a slave to the DAS. Therefore, the DAS can qualify the pre-weld conditions before permitting the weld to take place.

The DAS is controlled by custom LabView software. LabView is a software development environment that produces a graphic user interface in a virtual instrument motif. The software takes the operator through the weld operation by establishing and verifying that the pre-weld conditions are met, firing the welder, verifying that the measured weld parameters were acceptable and displaying the graphic results and calculations. Target numeric values are shown along side the pre-weld conditions and the post-weld measurements and calculations. The weld current, weld voltage and force are displayed in an oscilloscope style graphic representation. The system prints the record data sheets that are necessary for record keeping for nuclear safety welds. True RMS current is determined by taking the square root of the sum of the squares of all the sampled data points over the duration of the weld event.

Process Controls - Feedback Loop

Commercial weld controllers are used to gate the weld current to the welder electrodes
through a Kirkhof weld transformer. In the processes at SRS, a Superior Electric Powerstat variable transformer is used to control the input AC voltage to regulate the heat of the weld. The weld force is derived from a double hydraulic air cylinder fed by bottled nitrogen controlled through a manually set pressure regulator. The weld duration is controlled by the selection of the weld schedule in the weld controller. The DAS and weld operator are in effect, a "loose" feedback loop. The operator controls the process variables using inputs from the DAS to achieve acceptable measured weld parameters.

**Opportunities to Close the Feedback Loop**

All weld controllers feature weld heat control by varying the phase angle of the SCR firing, thus gating the weld current for different duty cycles. Commercial weld controllers are available that automatically regulate weld current by use of a feedback loop driven from primary-side current monitoring. The primary and secondary weld current are related by the turns ratio of the weld transformer However, the regulation of the transformer and complex impedances may cause errors in the control. Also, weld current is a naturally varying, dynamic parameter as the weld joint heats, the contact area changes throughout the weld event. Commercial weld controllers are available that compensate for AC line voltage fluctuations. This feature can compensate for variations in the supply voltage and is especially useful in a large industrial complex with unstable power. There are opportunities to dynamically control the weld duration by measuring the weld joint temperature or electrode displacement. There is no known commercial equipment that uses temperature or displacement for feedback controls. Measurement of the electrode displacement has already been demonstrated but not used in direct welder feedback controls. Optical measurement devices such as the analog laser position sensor have the necessary bandwidth and response time to be suitable for this application.

**Conclusion**

There are several special solid state resistance weld processes in use at SRS that have been well characterized. This characterization has taken place through the use of sophisticated data acquisition systems. Some of the sensors and controls that are used to tie the weld process to the measurement system have been detailed here. Opportunities exist to apply feedback controls to these weld processes as well as other industrial weld processes. The welder DAS can easily be applied to other industrial weld processes to aid in determining the process setpoints and minimize the effect of process variables on weld bond strength and product quality.