Application Note 6

Design of Experiments (DoE) for Welding Trials using Weld Data Logging

This application note aims to explain some of the benefits in using a Weld Data logging system as part of the Design of Experiments (DoE) required to carry out a controlled welding trial by which a new welding process may be defined. This note is designed to help and inform Welding Engineers, Production Engineers and Quality Engineers in regard to welding equipment measurements and monitoring.

As a broad background, the technical discussion document : The Art of Weld Monitoring, explains the importance of properly defining the ideal Weld process so that the conditions achieved may be used as a permanent reference for transfer across machines and for subsequent weld monitoring. The document explains that the notion of weld data logging in a well monitored and weld defined process might be considered a relatively low priority requirement from a pure quality control standpoint.

This application note illustrates how a weld monitor with data logging capability can be used as a referencing tool in defining an initial welding condition and how weld data logs can be used to statistically help find the best process conditions.

This application note assumes a reasonable knowledge of micro resistance welding principles and if needs be, can be supplemented by additional reading of other application notes related to such principles.

Design of Experiments (DoE) : Welding Trials

When confronted with a new micro welding joint requirement, Welding trials or DoE are needed to systematically and analytically determine the ideal welding conditions that should be used in producing the joint. The purpose of such trials and experiments is to optimise the welding process for such things as joint strength, visual finish, local heating and electrode wear.

Once an optimised process has been achieved, it is very important to document how the optimisation was achieved and better still, how potential process monitoring limits have been determined.

It stands to reason therefore that appropriate measurements are made and recorded at the time of the welding trial, so that the measurement data can be used statistically for optimisation while also remaining as a record of what happened in the experiments.

What measurements should you make for Design of Experiments (DoE) : Welding Trials ?

Regardless of whether you have a sophisticated high precision servo Linear power supply or a simple Capacitive Discharge machine, it makes sense to take nothing for granted and to employ some independent equipment to verify and record the electrical activity at the weld.

This simple step ensures that you know what the equipment is actually doing and as a minimum, should amount to being able to view the current waveform and to measure the actual energy delivered to the weld.

Current measurements are relatively straightforward through employing a current sensor and an oscilloscope, whereas energy value measurements taken at the welding electrodes involve more sophistication and are often best achieved using a weld monitoring device specifically designed for the task.

In addition, you will also need to measure the welding forces applied and any pull or peel forces used to destructively test each joint. Finally of course, you will need to decide how you wish to record each set of results for subsequent analysis. E.g. Log book, spreadsheet., Database etc…

Application Note 6

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Why might you need independent measurements for DoE ?

A lot of welding power supplies incorporate their own forms of monitoring and measurement, some of which work quite well. In defining a welding process, you may want to anticipate replicating the process with a different power supply or model sometime in the future, so independent measurements provide the means by which the process can be transferred - again, for more explanation please see "The Art of Weld Monitoring".

Furthermore, internal monitoring systems may not actually provide the data you really need, hence it is important to know what exactly is being measured and why.

The following summarised table shows some real world data taken with a simple double pulse opposed weld used to join the legs of two resistors using a capacitor discharge power supply.

P1 (W/S)	P2 (W/S)	Total Power (W/S)	P2 Current Peak Amps	Force (N)	Comments
3	13	16	2152	40	Strong Weld with very slight electrode stick
3	13.6	16.6	2208	40	Strong Weld with very slight electrode stick
3	14.5	17.5	2360	50	Good weld, stable & repeatable
3	13	16	2184	50	Weak Weld
3	16	19	2480	60	Strong Weld
3	14.5	17.5	2376	60	Weak Weld

The data shows a low energy pre-conditioning pulse being used in conjunction with a secondary main welding pulse.

What should be clear from this data is how the effect of welding force is actually modifying the peak current in the second pulse and hence the final result.

The point is, the effect of the initial pre-conditioning pulse is modified by the force, which in turn modifies the residual resistance available for the main welding pulse. Exactly the same situation would occur if a controlled servo welding power supply had been used, albeit with more precise current levels.

In other words, the welding force plays a key role in determining the electrical state of the joint, hence regardless of the power supply settings or type, the independent welding force parameter plays a key role in making the joint and thus must be recorded accurately.

When we now introduce the actual energy measurement at the weld, it is much clearer what is going on :

P1 (W/S)	P2 (W/S)	Total Power (W/S)	P2 Current Peak Amps	Force (N)	Total Energy Value	Comments
3	13	16	2152	40	5.62	Strong Weld with very slight electrode stick
3	13.6	16.6	2208	40	5.96	Strong Weld with very slight electrode stick
3	14.5	17.5	2360	50	5.56	Good weld, stable & repeatable
3	13	16	2184	50	5.3	Weak Weld
3	16	19	2480	60	5.94	Strong Weld
3	14.5	17.5	2376	60	5.02	Weak Weld

An actual weld energy value provides an intuitive way to appreciate the actual heat energy developed at the weld. You can see that by reducing the force, the resistance will increase slightly, thereby making the joint a little hotter (more energy). By measuring and optimising the weld energy level, the welding engineer is aiming to minimise power transfer via the electrodes while maximising heat energy at the joint.

Application Note 6

Design of Experiments (DoE) for Welding Trials using a Weld Data Logger

Benefits of weld data logging for DoE

The preceding basic example aims to shows that with capacitor discharge applications, the actual settings W/S on the machine mean very little in terms of actual energy at the weld and hence the need for independent measurement is clear. With a controlled servo machine operating in constant current control, very similar results would be seen in that increasing the welding force would of course decrease the weld resistance and hence decrease the heat energy at the weld. Hence a current value alone is not enough to define the process.

Thus, unless the welding power supply is able to accurately monitor the weld energy (i.e. measure both the welding current and the voltage at the electrodes and derive an accurate energy value), the ability to capture the welding process details will be very much compromised, especially if the process if ever required to work with other equipment.

This example shows just a basic data summary whereas a detailed welding trial would be taken over many welded samples in order to gather the underlying statistical average and standard deviation data for each set of conditions.

Such data gathering and collation is often simplified by using data logging features often found on weld monitoring units. Simply put, the user defines a set of welding conditions and the weld monitoring unit will record the results to an electronic file for subsequent analysis. A simple example is shown below.

datalog

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581;820;580;0;0;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 40N; Jan 19 2021 18:31:42
708;820;580;0;1;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 40N; Jan 19 2021 18:32:13
723;820;580;0;2;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 40N; Jan 19 2021 18:32:43
705;820;580;0;3;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 40N; Jan 19 2021 18:33:04
712;820;580;0;4;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 40N; Jan 19 2021 18:34:39
656;820;580;0;5;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 50N; Jan 19 2021 18:35:33
641;820;580;0;6;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 50N; Jan 19 2021 18:35:57
641;820;580;0;7;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 50N; Jan 19 2021 18:36:10
640;820;580;0;8;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=13J   Force = 50N; Jan 19 2021 18:36:40
721;820;580;0;9;0;G;5;5;5; Resistor Cross Wire P1=3.0J P2=14.5J Force = 50N; Jan 19 2021 18:37:25
724;820;580;0;10;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 50N; Jan 19 2021 18:37:48
714;820;580;0;11;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 50N; Jan 19 2021 18:38:04
718;820;580;0;12;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 50N; Jan 19 2021 18:38:23
650;820;580;0;13;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 60N; Jan 19 2021 18:39:07
665;820;580;0;14;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 60N; Jan 19 2021 18:39:19
658;820;580;0;15;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 60N; Jan 19 2021 18:39:30
651;820;580;0;16;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=14.5J Force = 60N; Jan 19 2021 18:39:43
643;820;580;0;17;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=16J   Force = 60N; Jan 19 2021 18:40:29
720;820;580;0;18;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=16J   Force = 60N; Jan 19 2021 18:40:53
712;820;580;0;19;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=16J   Force = 60N; Jan 19 2021 18:41:10
745;820;580;0;20;0;G;5;5;5;Resistor Cross Wire P1=3.0J P2=16J   Force = 60N; Jan 19 2021 18:41:31
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As the welding trial progresses, the welding engineer will start to hone in on conditions that give best welding results in conjunction with minimal energy dissipation across the electrodes.

By statistically analysing the weld energy value over multiple samples, a sense of the stability of the welding process will soon start to become apparent and as shown in the above example, the best and strongest welding conditions do not necessarily mean the highest levels of current.

Once the welding trials are complete, the weld data log files can be stored for reference and used again should reference to the original trials ever be required. Furthermore, with statistical values and variances, such logs can then form the basis for setting up process limits and using a weld monitoring unit for subsequent product production.

If process monitoring conditions are set correctly, then production data logging has limited value since the monitoring process should take care of any conditions outside of the process window already established.