microJoining Solutions – microTips™

5563 Hallowell Avenue • Arcadia, CA 91007
Phone: 626-444-9606 • Fax: 626-279-7450 • Email: mjs@microjoining.com • Web: www.microjoining.com

Design of Experiment (DoE) Procedure for Capacitive Discharge Resistance Welding
By David Steinmeier

Background
The capacitive discharge (CD) resistance welding power supply is a low cost approach to joining small and miniature scale metal parts. User adjustable CD power supply parameters include: a) watt-second energy, b) pulse shape selection, c) optional upslope, and d) single or dual pulse capability. The graph below shows the user adjustable welding parameters for a single pulse. The second pulse of a dual pulse weld profile has the same user adjustable parameters. However, the time between the first and second pulses is not adjustable.
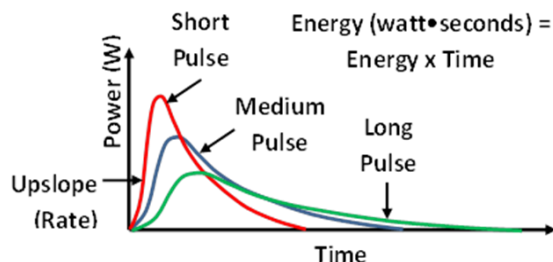
CD Technology Basics
Capacitor discharge technology is "open loop". There is NO active feedback loop at the electrodes to maintain constant weld current, voltage, or power. CD technology does regulate the capacitor bank to a set voltage. However, once the capacitor bank is discharged, there is NO active feedback loop to ensure that the stored energy actually reaches the weld. Electrical resistance losses in the weld cables, electrical connections, weld head components, electrodes, and part geometries all affect the weld energy reaching the weld.

In addition, variations in actual capacitor bank values between "identical" CD welding power supplies will affect the actual energy stored in the capacitor bank. Energy = $CV^2/2$, where C=capacitor bank capacitance in farads and V^2=capacitor bank voltage squared.

The Problem of Energy Equivalency
It is very important to note that each weld pulse heats the weld parts very differently. For example, a 10-watt•second short pulse produces very different heating compared to a 10-watt•seconds medium or long pulse. The 10-watt•seconds medium and long pulse welds are cooler compared to the 10-watt•seconds short pulse. This lack of watt•seconds heating equivalency occurs for the following reasons:

1. Upslope or rise time controls how fast the weld heat builds up in the parts. A short pulse pumps heat into the parts much faster compared to the medium or long pulse.
2. The pulse length competes with how fast the weld heat dissipates in the parts. A medium or long pulse allows more heat to dissipate during welding, compared to a short pulse.
3. The peak weld current is higher for the short pulse compared to the medium and long pulse. A high peak weld current can cause the weld to blowout before a weld is completed. Using a medium or long pulse reduces the peak weld current, thus reducing blow-outs.

The Problem of Using Energy (watt•seconds) as an Input Factor
Energy, in watt•seconds, represents the power (watts) integrated over time. There is no way to separately program power (watts) and time (pulse shape). Conducting a Design of Experiment (DoE) using energy presents a problem because a 10-watt•seconds short pulse is <u>NOT</u> equivalent in heating or peak weld current to a 10-watt•seconds medium or long pulse.

The Way Forward
Fortunately, there is a way around the problem of using energy as an input factor. Use peak weld current as the input factor controlling the peak weld heat. Adjust the watt•seconds to produce the desired peak weld current required by your DoE procedure. Some CD power supplies have built-in peak weld current measurement capability, which makes conducting a DoE quite easy. If your power supply does not have this capability, then use a weld monitor to measure and set the peak weld current.

Step 1 – Identify Key Input Factors
Identify both the controllable and un-controllable input factors. Table-A lists the key input factors used in conducting the DoE example in this microTip.

Step 2 – Fix Input Factors
Fix input factors like electrode tip area, tip material, Overlap, and Upslope. Use single pulse for all brass and copper materials. Use dual pulse only if single pulse does not produce the desired results.

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Table-A Key Resistance Welding Factors

Input Factors	Vary	Fix
Peak Weld Current	Y	N
Pulse Shape	Y	N
Upslope	N	Y
Single/Dual Pulse	N	Single
Weld Force	Y	N

Step 3 – Identify Key Output Responses

Identify key output measurements. The following DoE example uses Tensile Strength as the output response for an opposed weld comprised of two miniature stainless steel parts.

Step 4 – Find the "Corners of the Box"

The software that generates the DoE procedure does NOT provide the minimum and maximum input factor values. To find the minimum weld heat "corner of the box", experiment with *maximum* force, *minimum* peak weld current, and *short* pulse to produce a weld that just sticks together when pulled.

To find the maximum weld heat "corner of the box", you may experiment with *minimum* force, *maximum* peak weld current, and *long* pulse to make a weld. Does it blow up? If so, reduce the peak weld current until a weld is achieved. The table below shows the final min and max values used to conduct this DoE example.

| Parameter	Min Heat	Max Heat
Force (lbs)	2.5	3.5
Peak Current (KA)	0.5	0.6
Pulse Shape	-1 = Short	+1 = Medium

Step 5 – Conduct the DoE

To conduct the DoE procedure, you will need a statistical software package with DoE design and analysis capability such as *DoE Pro XL® or Minitab®*. Set up a 2-Level, 3-input factor experiment using a full factorial design. Use at least 4 repetitions for each DoE test condition. There are 8 different test conditions and 4-replications for this DoE, resulting in a total of 32-welds.

Step 6 – Analyze the DoE

After completing welding, pull test each weld and then enter the tensile data into the DoE software. Run the DoE Analysis function. This creates a prediction model relating the inputs to the outputs. The resulting graphs show what input factors are important in producing Tensile Strength and how each input factor affects the Tensile Strength.

The Pareto Chart below shows the contribution of each input factor on Tensile Strength. Note the strong interaction of Force and Peak Current in the Pareto Chart.
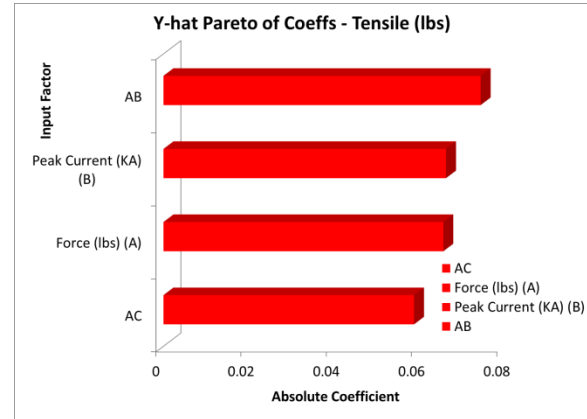
The Marginal Means Plot below also shows the effect of each input factor on the Tensile Strength.
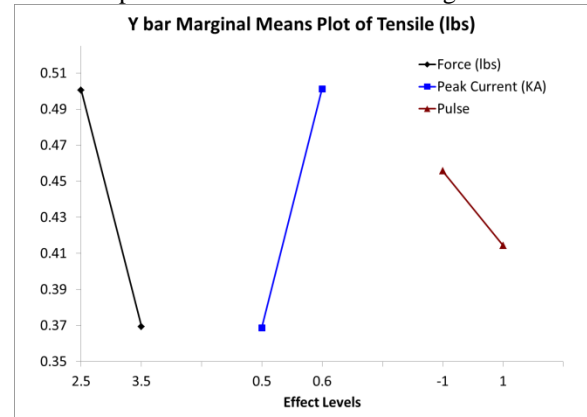
Step 7 – Select the Optimum Weld Settings

To produce the highest Tensile Strength, use the following input factor settings:

Peak Current (KA)	Pulse Shape	Force (lbs)
0.6	Short	2.5

Step 8 – Confirm the Optimum Weld Settings

A successful challenge test comprised of 30-samples was conducted using a weld force ranging from 2.5 to 3.0-lbs (non-optimal). The peak current and pulse shape were set at the optimal settings. The results are listed below:

Mean	0.55-lbs
Std Dev.	0.047-lbs
Lower Limit	0.3-lbs
Cpk	1.78