Design of Experiment (DoE) Primer for Laser Butt Welding

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The words, “Design of Experiment” generate instant fear in the minds of most manufacturing personnel responsible for any type of welding or joining process. Complex mathematics and software put off most people from even trying. This primer seeks to take the fear out of the DoE process and provide a starting point for conducting your own DoE on your next welding project.

DoE Definition

The DoE process is simply a scientific approach to understanding how the input affects the output. Inputs include some combination of machines, materials, methods, people, and environment. Outputs include quantitative measurements like pull testing and hermeticity and subjective factors like weld splash.

Why Use the DoE Process?

The DoE process is the quickest way to identify which input variables are important, how the key input variables relate to output measurements, and where on the set of operating curves do you need to be to have a robust welding process. Six-sigma manufacturers are insisting on reducing scrap and to do that, they must have a robust welding process.

What Are the Limitation of the DoE Process?

The DoE process can not replace a thorough understanding of any process, nor can it find “missing input variables” or provide a starting point to begin DoE experiments. These “negatives” are far outweighed by the positive reasons for using a DoE and this primer will provide you with a starting point strategy.

Step 1 – Identify Key Input Variables

Identify both the controllable and un-controllable input factors. The Table A lists some of the key input variables for making a laser butt-weld with two different materials.

Step 2 – Reduce Input Variables

Reduce the number of controllable input variables to no more than four. Fix variables like Beam Diameter, Fiber Type, Working Focal Length, Material Overlap, and Cover Gas Flow. Note, the Pulse per Second value, Beam Diameter, and Parts Feed Rate control the amount of Weld Spot overlap. The selection of material for parts A and B automatically places controls on the material alloys and plating. Guard against possible inadvertent changes that can occur due to plating thickness variations in a new lot run of material.

Table A – Key Laser Butt-Weld Variables

Variables	Controllable	Un-Controllable
Peak Power	Y	
Pulse Width	Y	
Pulses Per Second	Y	
Beam Dia.	Y	
Working Focal Length	Y	
Fiber Type	Y	
Fiber Dia.	Y	
Parts Feed Rate	Y	
Weld Spot Overlap	Y	
Cover Gas Flow	Y	
Material Gap	Y*1	Y*1
Material Overlap	Y*1	Y*1
Material [A]	Y	
Plating [A] Thickness		Y*2
Material [B]	Y	
Plating [B] Thickness		Y*2

*1 Controlled by fixture and automation tolerances
*2 Vendor controlled within specified tolerance.

Step 3 – Identify Key Output Measurements

Identify key output measurements. Table B shows some typical laser butt-weld output measurements.

Table B – Output Measurements

Output Measurement	Quantifiable	Un-Quantifiable
180° Peel	Y	
Hermeticity	Y	
Weld Splash		+1 = None 0 = Slight -1 = Severe

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. The experimenter must generate these values before beginning the DoE.

To find the minimum "corner of the box", experiment with the minimum peak power, pulse width, material air gap, and weld overlap to produce a 0.25 inch long seam weld that just sticks together when pulled. Hold all other input variables constant.

To find the maximum "corner of the box", experiment with the same variables to produce a strong weld with minimum weld splash.

Step 5 – Conduct the DoE
To conduct the following DoE procedure, you will need to obtain a copy of the *Kiss*® DoE software from Digital Computations and Air Academy Associates (719-531-0777). This author uses *Kiss DoE Pro*®.

Using the *Kiss* software, set up a 3-Level, 4 factor (input variable) L9 Taguchi experiment. There are 9 different weld settings for the L9 Taguchi DoE. Use at least 4 repetitions at each weld setting to get the average pull strength. Reduce the pull strength values for spitting and blow holes in the weld joint.

Step 6 – Analyze the DoE
After completing the DoE, run the regression model. This action creates a prediction model relating the inputs to the outputs. The regression model provides access to the plotting function, which allows you to plot each input variable combination against the output measurement.

The following plots represent a laser butt-weld weld consisting of two pieces of .010 304L stainless steel.
First Plot = Peak Power versus Time
Second Plot = Peak Power versus Overlap
Third Plot = Overlap versus Gap

Step 7 – Select the Optimum Weld Settings
The strongest welding process occurs using the following combination:

Peak Power (KW)	Pulse Width (msec)	Weld Spot Overlap (%)	Air Gap (inches)
1.5	2.0	52	.0000