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Selecting Laser and Resistance Welding Optimization Models

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Introduction

The Design of Experiment (DoE) process offers the manufacturing engineer a scientific approach to optimizing his laser or resistance welding process.

This microTip provides guidance for selecting the best DoE model for a given welding application. This microTip assumes that the reader has some familiarity with the DoE process.

DoE Model Selection Goals

There are many DoE models to choose from. However, most manufacturers will want to select a DoE model that will help them to:

- Find key input factors quickly
- Understand input/output relationships
- Find the optimum confirmation run starting point

DoE Model Structure

All DoE models have the same basic elements. The number of input factors determines the number of "runs" or test conditions. The number of repetitions for each run affects the prediction value of the DoE model. More repetitions are better. Output responses are collected for each repetition within each run. The final analysis establishes the relationship between the input factors and output responses.

Full factorial, half factorial, and Taguchi DoE models comprise the simplest and most easily understood DoE models. In comparison with a three-level simple model, complex DoE models such as the Central Composite or Box Behnken usually don't offer any additional prediction capability compared to the simpler DoE models for developing and optimizing laser and resistance welding processes. In addition, the Central Composite and Box Behnken DoE Models require quantitative output response values, a situation not always possible for developing and optimizing laser and resistance welds.

Therefore, based on the stated DoE model selection goals and the very important fact that laser and resistance welding are high variance processes, the remainder of this microTip focuses on how to choose between the full factorial, half factorial, or Taguchi DoE models.

Key DoE Model Selection Criteria

Narrowing the choice of DoE models requires evaluating the following criteria:

- Cost of parts
- Time to conduct the DoE
- Number of input factors
- Input factor levels, 2 or 3
- "Background Noise" inherent in the welding process

Cost of Parts

The number of parts required to conduct a DoE depends on the product of a) number of "runs" or different test conditions per DoE model, b) number of repetitions per run, and c) the number of responses per part.

If the individual part cost is inconsequential in relation to the manpower costs required to conduct the DoE process, then use the full factorial DoE model. The full factorial DoE model identifies all important input factors, key interactions between the input factors, and provides the best predication capability of all of the DoE models.

If the manpower costs to conduct and analyze the DoE are substantially lower than the total part costs, then use the half factorial or Taguchi DoE models.

Time to Conduct the DoE

If achieving the quickest understanding of what input factors are most important to the welding process, then use the Taguchi DoE models. But keep in mind that the Taguchi DoE models cannot identify all interactions between the input factors.

Number of Input Factors

Even though it is possible to conduct a DoE with more than four input factors, finding the minimum and maximum input factor values and achieving understandable results becomes more difficult beyond four input factors. If you have more than four input factors, select the four that you think are most significant. Conduct your first DoE and then remove all insignificant input factors. Conduct a second DoE using the significant factors from the first DoE and add your next group of input factors. Always keep the total number of input factors at four.

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Level of Input Factors
Input factors can be classified as 2- or 3-level. 3-level experiments produce surface response results that show curvature, allowing for visual optimization of the results. However, 3-level input factors require more parts to conduct the DoE.

A 2-level input factor DoE has a minimum and maximum value for each input factor. The table[1] below provides a summary of 2-Level Input Factor DoE Models. Note the switch to half factorial and Taguchi models for input factors of five or more in order to conserve parts.

DoE Model	Input Factors	Min No. Reps	Total Welds
Full Factorial	2 3 4	9 5 3	36 40 48
Half Factorial	5	3	48
Taguchi L12	6	4	48

A 3-level input factor DoE has a minimum, mid-point, and maximum value for each factor. The table[1] below provides a summary of 3-Level Input Factor DoE Models. Note that the Taguchi L18 DoE model allows the use of four 3-level input factors and one 2-level factor. This model is very useful for investigating the effect of weld current polarity on weld strength when conducting a resistance welding DoE. Polarity is always a 2-level input factor.

DoE Model	Input Factors	Min No. Reps	Total Welds
Full Factorial	2 3 4	9 5 3	45 45 51
Taguchi L9	4	3	36
Taguchi L18	4 (3-level) 1 (2-level)	4	72

"Background Noise"
"Background noise" represents factors that are deliberately not controlled in the experiment. For example, variations in part plating thickness, electrode wear, and laser cover glass contamination all represent "noise". Increasing noise reduces the prediction capability of any DoE Model. If the noise level is high, then use the Taguchi DoE models. They provide a slight advantage over the half factorial DoE models.

Full Factorial DoE Model Comparison

Advantages	Disadvantages
• Identifies important input factors • Finds multiple interactions between input factors • Best prediction capability compared to Half Factorial and Taguchi models	• Cannot include one 2-level with multiple 3-level input factors • Requires many parts

Half Factorial DoE Model Comparison

Advantages	Disadvantages
• Identifies important input factors • Identifies two-way interactions between input factors • Uses less parts	• Cannot include one 2-level with multiple 3-level input factors • More susceptible to background noise compared to Taguchi models

Taguchi DoE Model Comparison

Advantages	Disadvantages
• Identifies important input factors • Uses less parts • Less susceptible to background noise • Can have one 2-level and multiple 3-level input factors	• Can't identify interactions between input factors • Poor optimization prediction compared to Full and Half Factorial models

Summary
1. If the cost of the parts is inconsequential, always use a full factorial DoE.
2. If time is critical and there is a high level of "background noise", always use Taguchi models.
3. Use a maximum of 4 input factors to conduct the DoE and understand the results.

References:
[1]*Understanding Industrial Designed Experiments*, Stephen R. Schmidt, Robert G. Launsby, 1998.
microTip: Weld Quality Assurance for Laser and Resistance Welding