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Resistance Welding – "Weld Monitoring Prediction Technique Reduces Destructive Testing" By David Steinmeier

The Problem

Visual inspection metrics such as the weld mark size and shape, surface discoloration, and the degree of "sparking" during the welding process do not predict weld quality.

Destructive weld quality metrics such as tensile or peel testing provide measurable indicators of the weld quality. Unfortunately, these tests can only be conducted on a sampling basis, and they consume valuable welded products. Cross-sections provide information about bond type, but not weld strength.

Present Weld Monitor Technology

Most resistance weld monitors are digital volt-ohm meters (VOM's). These instruments typically measure peak, average, or Root-Mean-Square (RMS) for weld current, resistance, or voltage values during the entire weld period. Some instruments include weld force and displacement. Most weld monitors can also capture the waveforms for each measurement. Figure-1 shows the maximum, minimum, and average values occurring within a typical weld force signal. The weld current begins at the start of the WELD period and ends at the end of the WELD period. Most weld monitors do NOT predict weld quality.

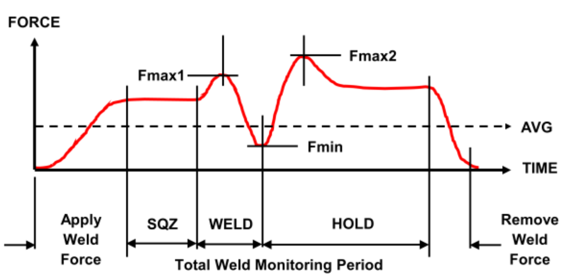

Figure-1, Weld Force Signal

Placing upper, lower, or window limits around a weld signal provides an alarm should any deviation occur in the weld signal. These alarms are useful in recognizing that the welding process has deviated from the normal process. However, there may be NO correlation between the deviation and weld quality metrics.

Weld Quality Predictor Measurement Issues

Each potential weld quality predictor has noise components. The quality of the signal can best be described by its signal-to-noise (S/N) Ratio. Improving the S/N Ratio of the signal creates a more robust prediction model since the average noise is inversely proportional to the square root of the number of samples. There are several ways to improve the S/N Ratio for each potential predictor.

Weld Current – Measure the voltage signal across a precision resistor to calculate the weld current. Use a precision resistor made from Constantan to minimize the change in resistance caused by the temperature. The precision resistor captures the dynamic signal much better compared to a "current coil".

Weld Voltage – Attach the voltage measurement leads as close to the electrode tips as possible. Unwanted voltage "noise" can quickly overwhelm the true weld voltage signal. Noise sources include electrically resistive electrode tips, electrode shanks, and electrode holders. Weld voltage is a poor predictor due to its very low S/N Ratio.

Weld Force – Place the weld force sensor directly in line with the electrodes. This position ensures that measured weld force represents the actual weld force.

Displacement – The displacement signal includes the actual collapse of the parts and any deflection in the weld head. Subtract the weld head deflection from the total deflection by making a displacement measurement without weld current flow.

AI, Machine Learning, Data Regression, and Predictive Analytics – The Future!

Can weld quality be predicted without having to employ constant destructive testing? Is there prediction information contained in the non-destructive weld monitor signals? Referring to Figure-1, are F_{max1}, F_{min}, or F_{max2} potential weld quality predictors? Linear regression searches weld quality predictor waveforms for data samples that predict weld quality. The linear regression method uses a two-step process. The first process uses a set of "training welds" to generate a prediction equation. The second process uses a set of "test welds" to validate the prediction equation.

IMPORTANT - Linear regression works best for variable data response processes such as welding. Predictive analytic techniques work best for binary attribute response data such as "Fail" or "Pass".

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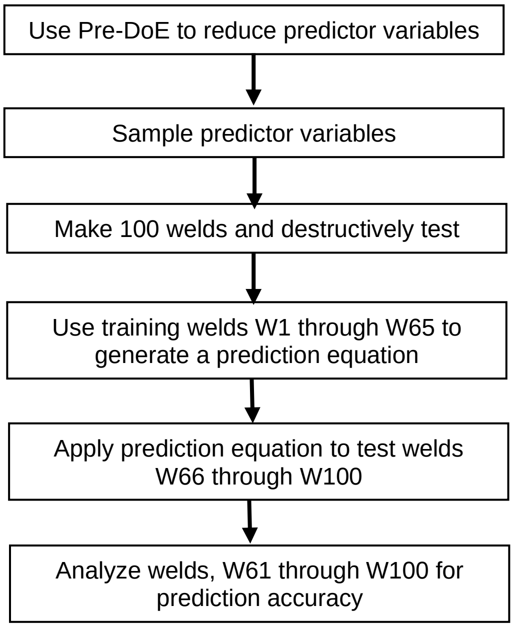
Simplified Process for Generating a Linear Regression Prediction Equation:



Analyze the "training welds" using Stepwise linear regression to create a prediction equation. Do NOT try to maximize the R-sq (Pred) prediction model. Adding more terms in the prediction equation and using interactions higher than 2nd order interactions causes over-fitting the prediction model, resulting in higher prediction errors.

Use statistical analysis to find the maximum, minimum, average, and standard deviation of the test welds database. The most useful statistical metrics for prediction purposes are the total error range (%) and 6 times the standard deviation (6σ).

Resistance Welding Example - Prediction Model:

- Weld quality predictor = Weld Force signal
- Weld quality metric = Tensile strength
- Digital sampling rate = 800 samples/second
- Samples per measurement period = 27, where:
  - S1 is the first data sample starting at the beginning of the WELD period.
  - S27 is the last data sample.
- Welding database = 100 welds
- Training welds = 65 welds (W1–W65)
- Test welds = 35 welds (W66–W100)

Resistance Welding Example Results:

Minitab® Stepwise Regression Equation for predicting test welds tensile strength:

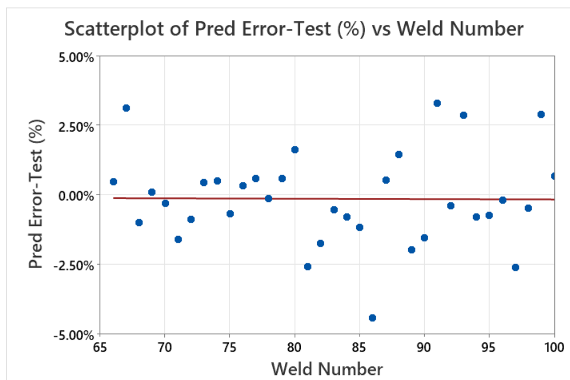
Tensile = 907 - 7.89S2 + 4.84S8 - 5.17S10 - 4.52S24 - 14.42S27

Minitab Regression Model Summary:

S	R-sq	R-sq (adj)	R-sq (pred)
4.53099	41%	37%	27%

Prediction Error (%) and Total Error Range (%)

- Prediction Error (%) for a single test weld = (Actual Tensile-Predicted Tensile)/Actual Tensile, normalized to 100%.
- Single prediction errors range from +3.3% to -4.4%.
- Therefore, the total error range is 7.7%.



Conclusions:

- While the R-sq (Pred) value of 27% seems low, the prediction equation produces a total test welds error range of 7.7%, which is still very useful in a production monitoring environment.
- If the total welds test error range % is unacceptable, then repeat the stepwise linear regression process by adding:
  - Additional weld quality predictors
  - More training and test welds.
- Once the prediction equation is validated, weld quality monitoring can be implemented with significantly reduced destructive testing.

Contact microJoining Solutions to help you and your engineering team discover the best weld quality predictors for your application.