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Case Studies: DOE Eliminates Defects

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Tier 1 automotive supplier Johnson Controls Inc. produced 6 defects out of 10,000 units fabricated each week, resulting in a Sigma level of 5.1. The company wanted to achieve higher quality levels and contacted Middle Tennessee State University (MTSU), requesting a design of experiments (DOE) study to determine root causes of torque failures and areas of improvement.

Johnson Controls Inc. used a design of experiments (DOE) study to determine root causes of torque failures and areas of improvement for the welding of automotive seat frames. *Source: Stat-Ease Inc.*

Tier 1 automotive supplier Johnson Controls Inc. (Murfreesboro, TN) was achieving a good level of quality in its manufacturing process for welding nuts to a metal seat frame.

The operation produced 6 defects out of 10,000 units fabricated each week, resulting in a Sigma level of 5.1. The company, however, wanted to achieve higher quality levels. They contacted Middle Tennessee State University (MTSU) and requested a design of experiments (DOE) study to determine root causes of torque failures and areas of improvement.

The MTSU project team used Design-Ease software from Stat-Ease Inc. (Minneapolis) to perform a full-factorial model requiring a total of 36 runs. The experiment provided optimal values for each factor and showed, surprisingly, that quality improves as the tip pressure is reduced-the opposite of what was originally thought. After the company implemented the optimal values determined by the experiment, the torque failures quickly disappeared.

Finding the Solution

The welding operation in question involves attaching four nuts to the lower seat support in the front bucket seat of an automobile. Bolts are then used to fasten the nuts to guide rails that allow the occupant to adjust the seat. In the welding station operation, the lower seat-support-pan fixture rotates counterclockwise to align the seat frame with four projection nut welders. Each welder feeds a 6-millimeter nut to the pan using the same basic welding equipment configuration. A weld nut is automatically fed to each lower alignment pin with a pneumatic feed system. An upper cylinder has an attached electrode that mates with the seat pan, weld nut and lower electrode. When this cylinder is extended, an electrical circuit is made that allows high current to flow from a transformer through a copper shunt to the electrode. This current passes through the nut and seat pan, generating heat to weld the nut to the seat pan. The four profusions on each nut are melted and fused with the sheet metal. The projection geometry permits the use of flat electrodes, thus producing welds at the projections.

The factors in the welding operation include:

- Tip force-the pressure level with which the electrodes contact the metal, controlled by an air pressure regulator
- Weld current-current amperage levels, controlled by a transformer and weld timer controller
- Squeeze time-the amount of time the electrodes make contact before the current is passed through
- Hold time-the amount of time the upper electrode makes contact with the nut while the current is passing through
- Cool time-the amount of time the electrode makes contact while the weld is in the cool-down period

The response for the experiment is the torque at which each nut weld fails as measured with a peak-reading torque wrench. The low specification limit that assures a proper weld is 354 inch-pounds. Because there are four weld nuts per seat and 10,000 units fabricated per week, the original defect rate per million opportunities was 150.

“The challenge in optimizing this process is that every operations person had their own recipe that had proven successful for them in the past,” says David W. Gore, associate professor at MTSU and project leader for this study. “All of these recipes worked but they did not provide optimal results. DOE offers the opportunity to move manufacturing operations to a higher level by scientifically mapping the application space. While human intuition is usually only capable of grasping first order effects, DOE also considers second order and multiple factor interaction effects. Design-Ease greatly simplifies the use of DOE by automating the process of designing experiments and analyzing the results.”

Gore used Design-Ease to design a two-level, full factorial experiment with four midpoints for linearity checks. The tests were run with MTSU students handling the identification, welding and torque measurement of the parts, and company personnel operating the welder. Each part was tested until failure and the breakaway torque recorded.

Two-level, three-factor model with power transformation

Test	Current	Time	Tip Force	Output torque
1	10,000	4	35	425
3	10,000	30	35	500
5	10,000	4	70	315
7	10,000	30	70	426
9	12,500	17	52.5	480
10	12,500	17	52.5	500
11	12,500	17	52.5	511
12	12,500	17	52.5	500
2	15,000	4	35	625
4	15,000	30	35	800
6	15,000	4	70	407
8	15,000	30	70	675

The analysis of variance (ANOVA) for the five-factor model indicated the model was significant with an F-value of 13.11. The weld current, weld time, tip force and interaction between squeeze time and weld time were identified as significant factors.

Hold time was not a significant factor. The model “predicted versus actual” showed some correlation but not strong enough for reliable predictions. The company welding engineer suggested combining squeeze time and weld time into a new factor called time and dropping hold time. The same results were re-analyzed as a three-factor interaction model. The ANOVA for the new model provided a much-improved F-value of 136.8. Weld current, time, tip force and interactions between weld current and time and between time and tip force were all now significant. To improve the normal plot of residuals, the data was transformed with a power transform, which further improved the results.

This model was robust enough to reliably predict output torques for a range of factor settings. Based on this model, Gore concluded that the current setting of 70 psi for tip force is a primary contributor to low torque failures. Most participants in the study felt that a higher tip pressure would improve breakaway torque by holding the parts more tightly together. But a company engineer pointed out that reducing the tip pressure increases the resistance of the joint, which in turn increases the electrical resistance and results in more heat being generated by the welding operation. Gore recommended that tip force be reduced to a value based on the desired throughput time and welding amperage.

For lowest four-cycle weld time, Gore recommended that the tip force be set to 35 psi and the weld current to 12,100 amps. The breakaway torque will then have a mean of 500 inch-pounds and be above 400 inch-pounds within a 99% confidence level. For lower weld current and a more typical weld time setting, Gore recommended setting the weld current to 11,350 amps and the weld time to 10 cycles total at the 35 psi tip force. The predicted torque measurements will then be the same as the preceding settings. If it is necessary to increase the tip force to 52.5 psi, the weld current will need to be increased to 12,500 amps for a weld time of approximately 11 cycles to duplicate the torque levels of the previous two examples.

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Benefits

- The design of experiments (DOE) study helped Johnson Controls Inc. reduce welding defects from 24 to 0 per month.
- After the company implemented the optimal values determined by the experiment, the torque failures quickly disappeared.
- Improved quality can mean cost avoidance by eliminating costs attached to weld failures.