CASE STUDY

Readiness Plan Put Into Action

A CASE STUDY ON TRANSFER FUNCTION-BASED DESIGN FOR RELIABILITY AND ROBUSTNESS IMPROVEMENT IN DFSS

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The demand for reliability and quality of any engineered system has never been greater than it is today. This puts additional responsibility on engineers to not only design components and systems that have optimum nominal performance, but also design them to be insensitive to variations such as manufacturing tolerances and variability in operating conditions. Due to cost and competitive pressures, it is not possible to conduct reliability estimation based on full-scale system and component physical testing. Increasingly, organizations are promoting transfer function-based reliability estimation and robust design approaches.

The process power of design for Six Sigma (DFSS), especially in the identify phase of identify, characterize, optimize and verify (ICOV), can identify and define the opportunity to get the project started on the right foot (for example, the identification and the definition of voice of customers [VOC] and the market needs). When reliability is identified as a key critical-to-satisfaction (CTS) requirement of a product, it will be captured on a list of system design requirements.

Transfer function-based simulation and optimization techniques can provide DFSS practitioners with reduced reliance on physical models, rapid time-to-market, and minimal defects and post-design rework. These advantages lead to quantifiable benefits in terms of time and cost within the product development life cycle.

The implementation of the ICOV discipline allowed a team to achieve a robust and reliable design that ultimately led to a shortened time to market, with higher quality and reduced product cost. ICOV is not always implemented as a single project (from design concept to product launch). Identify and characterize (IC) projects can be used to identify the best design concept. Identify, optimize and verify (IOV) projects can be used to optimize a given design, which is either a product or process. The swell packer reliability and robustness improvement DFSS project is the IOV type of project.

Critical-to-reliability requirements

Identify: As covered in the first installment of this two-part series of articles,[1] the purpose of the identify phase for the reliability effort is to clearly and quantitatively define the reliability requirements and goals for a product, as well as the end-user product environmental and use conditions. These can be at the system, assembly and component level, or even down to the failure mode level. Requirements can be determined in many ways or through a combination of those different ways. Requirements can be based on contracts, benchmarks, competitive analysis, customer expectations, cost, safety and best practices.

Of particular interest to design for reliability (DFR) are the requirements that are critical to reliability (CTR). Reliability is identified as a key to CTS in the swell packer product. A swell packer system is a smart (equipped with sensors) open-hole zonal isolation in completions, which is designed for opened hole and cased hole isolation in many varied applications, including the completion of wells.

The objectives of this DFSS IOV project may be summarized as:

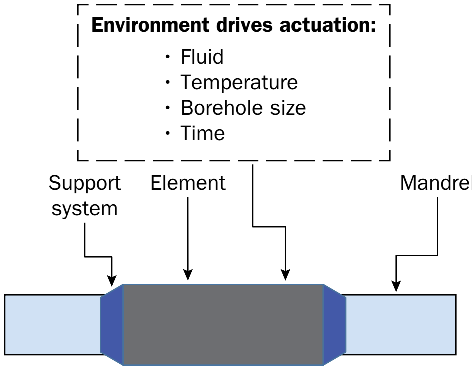
- Integrate VOC into product requirements in a way to improve reliability and robustness of the product.
- Improve swell packer reliability by optimizing the swell packer design in the presence of noise factors using transfer function.

A well thought-out approach for reliability design will result in a product that has high reliability performance. Emphasizing the need for effectiveness, it is essential to consider up-front reliability design, reliability prediction, early analysis for identified critical subsystems and components. For example, the swell packer is a critical subsystem for the reliability improvement in this case study. Transfer function enables such effort in earlier reliability design and prediction, especially when useful reliability field data are not sufficient.

Due to insufficient reliability field data and an unstructured reliability approach, a DFR assessment was provided to help the team understand what the basic and minimum requirements are for a meaningful reliability improvement effort. This effort includes reliability goal setting, understanding the quality history, identifying and defining uncontrollable user environment (noise condition), tool application (for example, design failure mode and effects and analysis [DFMEA], robust design and others), testing strategies and reliability demonstration through DFR gates review aligned with the DFSS ICOV roadmap.

The team turned to the DFSS method to identify, translate and determine reliability requirements up front. For example, instead of observing pass or fail, the team dedicated valuable time to define and determine how to measure the degradation of swell packer's function as one of the reliability requirements. By factoring the reliability requirements into the design process using transfer function, the team overcame the challenges using limited data and increased reliability with high confidence through robust design with properly developed noise factors strategies. The results? The team developed the reliable product in less time and cost compared with the planned schedule and budget, and the team also obtained useful data for further meaningful decision making.

Figure 1. **Swellable packer architecture**



Swell packer system

Developing swell packer and swellable elastomer packers could provide the required seal function in isolation requirements even in the tight restrictions of a specific application with better seal capability and lower cost.

The basic principle of swellable elastomers is natural and simple. Add water or oil to the appropriate rubber-based compound and it will swell as it absorbs the liquid. The inherent simplicity of swellable materials does mask the real skill required to create a swellable packer solution for application.

In the application, the swellable packers were deployed in a specific environment (for example, an oil-based mud [OBM]). When the packer is immersed in the environment for which it was designed, the oil-swellable elastomer reacts with the OBM and the packer begins to set. After a few days, the packer expands to fill the available space, and an effective seal is created. If the annulus shape changes in the future for any reason, the packer will expand further and the seal will remain intact.

With a detailed understanding of exactly how any of swellable elastomer compounds developed will react in the conditions they encounter, it may be useful to predict safe run-in time (for example, reliability)—the time to first seal and the amount of unused swell available to hold pressure. However, the sensitivity of the swell packer safe run-in time in an uncontrollable user environment is not always straightforward and clear. This offers a great challenge and opportunity for design optimization to design for robust and reliable performance and better understand the limitation of a given concept design.

As discussed in the first installment in this two-part series,[2] the most cost-effective approach for reliability improvement is to make the product insensitive to the uncontrollable user environment (noise factors). Noise factors can fall into the following categories:

1. **Piece-to-piece variation,** such as rubber thickness.
2. **Change over time,** failure from material wear or changes in force or dimension with time.
3. **Customer use,** such as open-hole wellbore size.
4. **Environment condition,** such as temperature variation.
5. **System interactions,** such as element outside dimension variations and open-hole size.

The result of noise impacts may be degradation in quality (soft failure) or a malfunction failure (hard failure). A product is considered robust when it is insensitive to the effects of sources of variability, even though the sources themselves have not been eliminated. With a given concept design, it is necessary to optimize the concept design in the presence of noise factors for its better reliability and robustness performance, and the limitation of the given concept design.

Optimize in the DFSS ICOV: design for robust and reliable performance. This minimizes product or process sensitivity to uncontrollable user environment to have better manufacturability and higher reliability.

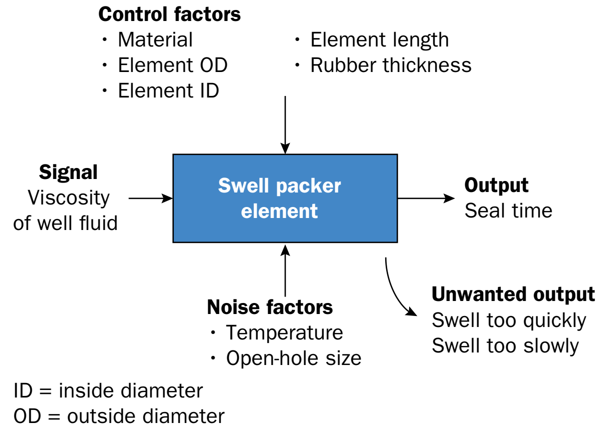
In this stage, robust parameter design helps further factor-reliability tasks into the design process by optimizing design function in the presence of noise factors to:

- Identify important variables.
- Estimate their effect on a certain product characteristic.
- Optimize the settings of these variables to improve the design robustness.

Within the DFR concept, we are mostly interested in the effect of stresses on our test units. Robust design plays an important role in DFR because it assists in identifying the factors that are significant to the life of the product, especially when the physics of failure are not well understood. The robustness of the given concept design can be used to assess the limitation of given concept design from the reliability improvement perspective.

Basic packer architecture consists of a mandrel which connects to the down-hole completion, and the swellable elastomer element is mounted to the mandrel. This element is our focus on the reliability and robustness improvement effort. Based on the specific properties of the swellable elastomer, the oil-swell packer expands when it comes into contact with hydrocarbons, and eventually seals the open hole with

Figure 2. **Swell packer P-diagram**



the required ability to withstand differential pressure. There is a support system that holds and protects the element in place and improves its ability to seal to the mandrel. Figure 1 shows an illustration of well packer architecture.

Ideally, performance in terms of swell rate should be evaluated and optimized in the presence of uncontrollable user conditions. Swelling too quickly and too slowly are the error states. With limited information and test data in the up-front design stage, it is difficult to evaluate performance. Many aspects of the seal rate are difficult to predict during the early stages of product development. In addition, numerous factors can affect the eventual outcome, some of which are independent. Determining the use and environmental conditions is an important early step of a DFR effort, which provides the information about what it is to be designing for and what types of stresses the products are supposed to withstand.

The tendency for the potential failure mode occurrence is aggravated by noise factors, which are factors that engineers have little or no control over and that negatively influence designed system performance. Fundamental to designing for reliability and robustness using transfer function is including noise factors during analysis that challenge the design and uncover potential failure modes. After uncovered, these failure modes can be avoided by developing appropriate countermeasures in the design or manufacturing process. Including noise factors in up-front design analysis has encouraged engineers developing transfer function to consider appropriate noise factors and realistic levels, as well as strategies to include them in simulations.

With the given concept design, engineers must define relationships between desired response and critical dependent factors via transfer functions. One of the most important tasks in robust optimization is to select an appropriate system output response in the study. Therefore, prior to developing a meaningful transfer function, it is important to identify and select a proper system output response. The quality of this selection will affect the effectiveness of the robust design project. Any system output response is in the form of energy, material or signal. If the energy-related system output response can help to reduce the interactive effects of design parameter to a minimum for the purpose design optimization, you better find a way to convert nonenergy-related system output response to an energy-related system output response.[3]

Swell packer transfer function

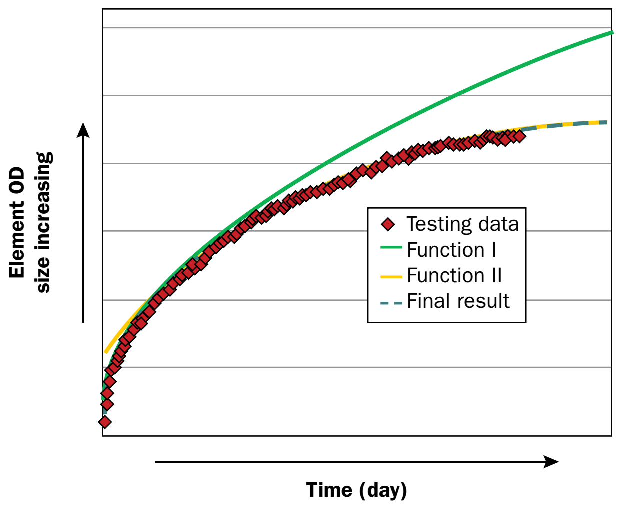
For a swell packer system, the swelling process is governed by the mass transfer of oil to the rubber. The factors that affect the process and the output response (that is, swell time) include rubber material, element size and shape, fluids and the operation conditions (pressure, temperature and borehole size). Having realized the importance of selecting proper system output response, the swell packer team spent valuable time identifying and selecting meaningful system output response to reflect design intent to avoid using error states (for example, cracking and fatigue) and nonnecessary multi-objectives optimization as output response. All factors are independent from one another. A schematically represented swell packer transfer function in a P-diagram is shown in Figure 2 (p. 11).

A swell packer transfer function is used to mathematically specify the ideal form of the signal-response relationship as embodied by the design concept for making the higher-level system work perfectly. The results of robust optimization totally depend on the correctness of the transfer function. As a start, a swell packer transfer function development, for example, may be based on the Fick's mass transfer law, without considering coupling between rubber elasticity and swelling kinetics, and assuming a constant diffusivity (D) and small material deformation (strain, ε). For a cylinder, the mass of oil and volume c, and the radial swelling displacement u can be expressed as:

$$\frac{1}{D}\frac{\partial c}{\partial t} = \frac{\partial^2 c}{\partial r^2} + \frac{1}{r}\frac{\partial c}{\partial t} \quad \text{(I)}$$

$$\frac{d^2u}{dr^2} + \frac{1}{r}\frac{du}{dr} - \frac{u}{r^2} = \frac{1+\nu}{1-\nu}\,\alpha\,\frac{dc}{dr} \quad \text{(II)}$$

Figure 3. **Comparing predicted and testing data of a specific swell packer in LVT 200 OBM at 180°F**



LVT = low viscosity technical grade
OBM = oil-based mud
OD = outside diameter

in which v, α are Poisson ratio and linear expansion coefficients of the material, respectively.

Based on the limited information of the fluid that can be obtained from the field, the transfer function for a predictor is simplified into two parts: predictor function I and II. As discussed in the first installment of this two-part series of articles,[4] the transfer function development process is similar to the inductive and deductive feedback loop. The process of developing or updating a transfer function is highly iterative, moving frequently between the inductive and deductive paths. More detailed functions can be derived from these two equations for this specific transfer function application.[5]

Figure 3 compares the swelling process from the transfer function and the testing results of a specific packer in low viscosity technical grade (LVT) 200 at 180°F. LVT 200 is the low viscosity base oil for OBM systems. The predicted values are in good agreement with the testing data, which validates the predictor.

Statistical description of noise factors

To impose noise factors in transfer function-based analytical analysis, noise factors must be described as random variables (probability distribution functions, means and standard deviations). For a manufacturing noise factor, the standard deviation for geometry factors is typically acquired from manufacturing process capability. When manufacturing information is not available, an approximation may be made based on the tolerance specifications and typical manufacturing process capability assumption. In many situations, we must make some guesstimates of the standard deviation and probability density function based on other relevant information. Three statistical distribution examples of noise factors can be:

- Manufacturing processes are often assumed to follow a normal distribution.
- Many load conditions can be represented using log-normal distributions.
- Material properties often follow Weibull or log-normal distributions.

Table 1. **Levels of the control factors and noise factors**

1	**Output response** Swell rate (time): The optimized range of the first seal time should be three days ~ two weeks (that is, 72 < t < 336 hours).
2	**Input signal** Composition of well fluid (CWF): CWF1, CWF2, CWF3, CWF4, CWF5, CWF6
3	**Noise factors** Temperature: 150°F, 170°F, 180°F, 190°F, 200°F, 220°F Open hole size (OHS): OHS1, OHS2, OHS3, OHS4, OHS5
4	**Control factors** Material (M): M1, M2 Element OD, EOD1, EOD2, EOD3, EOD4, EOD5 Element ID, EID1, EID2, EID3, EID4, EID5 Element length (EL), EL1, EL2, EL3, EL4, EL5 Rubber thickness (RT), RT1, RT2, RT3, RT4, RT5, RT6

EID = element ID
EOD = element OD
ID = inside diameter
OD = outside diameter

Noise strategy

It may be difficult to know and include all potential noise factors in the transfer function-based reliability and robustness optimization. Frequently used noise strategies include:

- Surrogate noise factors.
- Compound noise factors.
- Treat noise factors individually.

Noise factor candidates are identified and listed in a P-diagram as a standard robust design procedure. However, many analytical (for example, computer-aided engineering [CAE]) models may have limited capability to represent noise factors and thus may require surrogate noises. If a model does not include noise factors such as temperature or degradation, for example, the model may include surrogate noise factors such as the variability of material property for temperature noise or the dimensional changes for degradation and manufacturing variation.

To reduce the number of runs in the experiment, a compound noise is often used. For this approach, a single compound noise factor can be with two levels called N1 and N2:

- N1—The least demanding noise combination (high-performance expectation).
- N2—The most demanding noise combination (low-performance expectation).

Table 2. **Partial collected data based on transfer function**

Input signal: composition of well fluid						**CWF1**					
	Noise factors		**Temperature**			**150**					
			Open-hole size			**OHS1**	**OHS2**	**OHS3**	**OHS4**	**OHS5**	**OHS6**
	Control factors										
#	**A**	**B**	**C**	**D**	**E**						
1	1	1	1	1	1	174.852	359.06	789.2	1258.6	142.26	292.127
2	1	1	2	2	2						
3	1	1	3	3	3						
4	1	1	4	4	4						
5	1	1	5	5	5			**Data**			
6	1	2	1	2	3						
7	1	2	2	3	4						
8	1	2	3	4	5						
9	1	2	4	5	1						
10	1	2	5	1	2						
11	1	3	1	3	5						

CWF = composition of well fluid
OHS = open-hole size

Because this approach requires only two noise experiments for each control-factor combination, a compound-noise strategy tremendously reduces the number of experimental runs. Compound noise is a simplification of the outer-array noise combinations to reduce the number of experimental runs and therefore must be used with extreme caution because:

- Compound noise can be used only when the directionality of the noise-factor effects does not change with the control-factor combinations and the signal level.
- Compound noise may not provide consistently harmful effects for different combinations of control factor and signal settings.

Data collection and simulation

Table 1 (p. 13) lists the four levels of control factors, noise factors, output response and input signal for the robust optimization summary.

Table 3. **Optimized design parameters**

Design parameters	Baseline	Optimized
Element OD	EOD3	EOD3 or EOD4
Element ID	EID1	Cost/size factor Tolerance may be open up more
Element length	EL3	Cost/size factor Tolerance may be open up more
Element thickness	ET2	Cost/size factor Tolerance may be open up more
Material (M)	M1	M1

EID = element ID
EOD = element OD
EL = element length
ET = element thickness
ID = inside diameter
OD = outside diameter

Table 4. **The reliability performance of the optimized design in terms of seal time**

Seal time	
Mean	258.84
Standard deviation	29.73
Minimum	162.22
Maximum	367.92
Probability > 72 hours	1
Probability < 3,336 hours	0.99393
Probability between limits	0.99394

Based on the discussion included in the first installment of this two-part series,[6] for any design concept, there is a potentially large space of control factor settings that will nominally place the function at the desired target value. In this swell packer design, there are five identified control factors, two identified noise factors and one identified input signal factor. The developed swell packer transfer function includes these factors as minimum.

By providing a pair-wise balanced comparison, orthogonal array may replicate better dynamic nature of real-world conditions. The number of tests required was much less than full-factorial experiments. Certainly, the transfer function-based full-factorial experiments are feasible. But the full-factorial experiments' run time could take longer than you may think, which depends on a developed analytical model.

To have quicker feedback, the orthogonal array is employed to explore the design space initially and followed with full-factorial experiments as meaningful. Based on the number of control factors and levels, a L50 orthogonal array is selected.[7]

At the same time, outer arrays or compounded noises are used to explore the range of possible operating conditions. Compound noise strategy can be considered an effective way of improving reliability confidence in tests. Fundamental to designing for reliability and robustness using transfer function is including noise factors during analysis that challenge the design and uncover potential failure modes. Data collection was planned and collected in the L50 orthogonal array as a start. The data are collected based on the L50 orthogonal array in Table 2, which shows the partial L50 orthogonal array data collection form.

In terms of the effects of the control factors for the product performance (that is, seal time), the data analyses were conducted based on:

- The initial L50 orthogonal array of experiments (with input signals and outer array noise strategies for the two levels of material).
- The five levels of five other control factors.
- The two noise factors (one at five levels and the other at six levels).

To provide more intuitive information to see how the control factors may change the experiment output response, Figures 4-6 are selected as partial graphics to show the 3-D graphical results (that is, response) of swell packer seal time with the change in outside diameter (OD), open-hole size and downhole temperature design parameters.

Because this case study is based on transfer function computer experiments, it is possible to explore potential difference, if any, between the L50 orthogonal array experiments and the full-factorial experiments. The full-factorial experiments (for example, 562,500 runs) also were conducted to compare the results. The effects (trends and patterns) of the control factors' behaviors in the full-factorial experiments are similar to the effects obtained from the L50 orthogonal array experiments.

Analysis and optimization

In robust design, signal-to-noise (S/N) ratio and sensitivity are used to analyze the problem quantitatively. An optimized design has a maximum S/N ratio and the least sensitivity to the noise factors.

Figure 7 (p. 16) shows the control factor S/N ratios and sensitivities to noise factors for the swell packer system. You can see that the element inside diameter (ID), element length and the rubber thickness have no big impact on the S/N ratio. This indicates that these control factors have no significant impact on the performance variation. We may use these factors to consider potential opportunities for cost reduction and larger tolerance without compromising required quality and reliability.

The element OD and the material are the most sensitive control factors, which show a small change in the element OD or the different material will result in a significant change in S/N ratio. This is the opportunity for engineers to find solutions to reduce design sensitivity as meaningful as possible and to understand the limitations of the given concept design. This is important for the design-in-quality and reliability efforts.

Table 5. **Six Sigma analysis of the optimized design**

Parameter	Sigma level	Probability of success	Probability of failure	Defects/ million
Seal time	4.13	0.9959	0.006	4,363

Based on this analysis, in addition to combining the S/N ratio and sensitivity-to-noise factors, optimized design parameters were selected and are listed in Table 3 (p. 14). Because of the insensitivity of the element ID, length and thickness, their tolerances in manufacturing may not be critical, which provides a cost reduction opportunity.

The reliability performance of swell packer in an open-hole size (with optimized design parameters in terms of seal time) may be estimated as in Table 4 (p. 14), in which the standard deviation of element OD is estimated. The Six Sigma analysis of the performance is shown in Table 5.

A Six Sigma process refers to the process short-term performance or how it is currently performing. Due to the provided process variation, the estimated sigma level here is a short-term performance. A long-term

Figure 4. **3-D graph on OD, open-hole size and seal time**

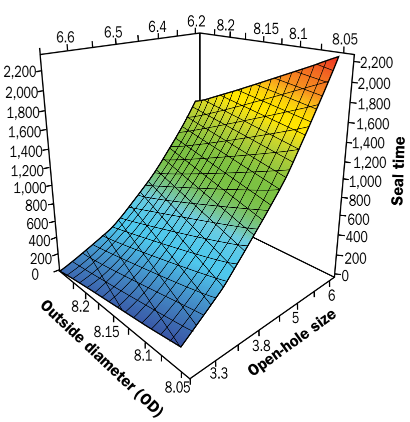


Figure 5. **3-D graph on open-hole size, temperature and seal time**

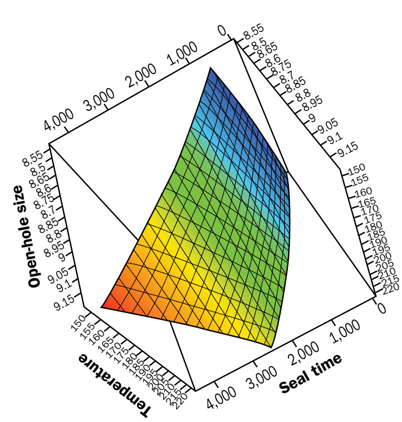


Figure 6. **3-D graph on OD, material and seal time**

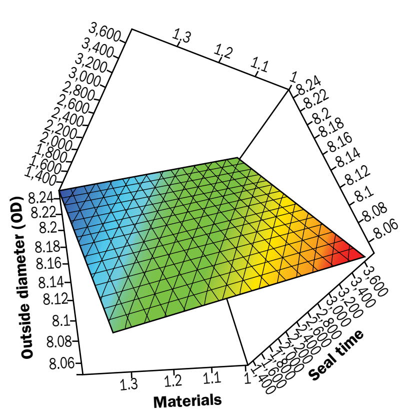
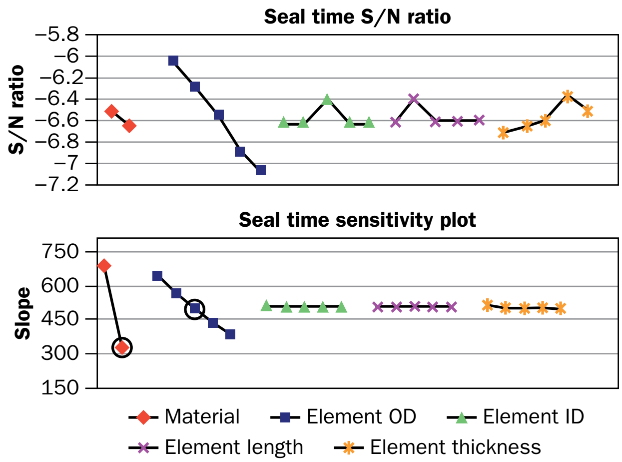
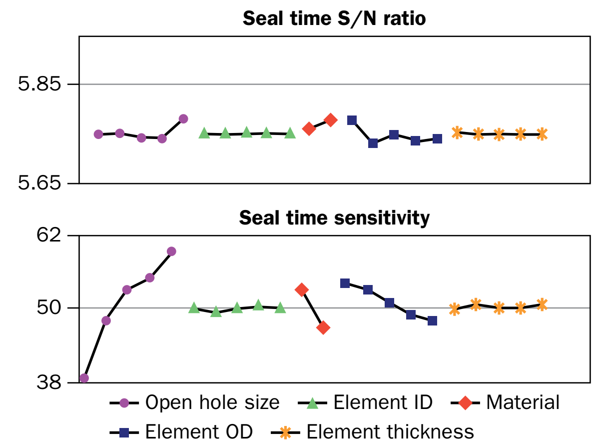


Figure 7. **S/N ratios and sensitivity plots of control factors of the swell packer system**



Note: The circles indicate the optimized parameters.
ID = inside diameter
OD = outside diameter
S/N = signal to noise

Figure 8. **S/N ratios and sensitivity plots when open hole was considered as a control factor**



ID = inside diameter
OD = outside diameter
S/N = signal to noise

Six Sigma process that is rated at 4.5 sigma is considered to have a short-term sigma score of 6 sigma.

Considering open-hole size as a control factor and temperature was kept as the only noise factor, another similar study was conducted. Effects of design parameters to the seal time were estimated. Figure 8 shows the S/N ratios and the sensitivity plots for this design.

Not surprisingly, the open-hole size has significant impact on the seal time. However, the open-hole size was the only significant factor that has a big impact on the seal time. The remaining control factors showed some or little impact on the seal time. It seems as though we had no way to improve design except by "beefing up" the design, which covers up the intrinsic characteristics of the system.

This is the typical situation in which overdesign may happen and yet the quality of performance will never be appreciated, leading to dissatisfied customer and increased cost. Because we know that the open-hole size is beyond the control of operator in the field, the question is, "What can we do about it, from an engineering perspective?" The answer is a key message from earlier: "Make the product insensitive to user environment and therefore better suited for reliability improvement at the lowest possible cost."

This is the power of robust design. Within the DFR concept, we are mostly interested in the effect of stresses on our design and test units. Therefore, it is important to identify noise factors to determine meaningful stresses and distinguish the noise factors from control factors so that noise factor management strategy (for example, change concept, robust design or beefing up design) can be identified as applicable at the earlier design phase for the effective and efficient reliability efforts.

Robust design plays an important role in DFR because it assists in identifying the factors that are significant to the life of the product, especially when the physics of failure are not well understood. Robust DFR is essential for built-in reliability.

Verify. In this phase, the reliability was reevaluated in light of additional process variables and the identified critical design parameters, including element OD. The team validated the transfer function further with additional test data and developed an action plan to include:

- Reviewing and updating the list of key product characteristics (KPC) to include OD as appropriate.
- Improving process capabilities on the identified KPCs.
- Implementing a developed control plan to monitor and control OD and others in manufacturing processes.

The results from this reliability and robustness

TRANSFER FUNCTION-BASED SIMULATION AND OPTIMIZATION TECHNIQUES CAN PROVIDE DFSS PRACTITIONERS WITH REDUCED RELIANCE ON PHYSICAL MODELS, RAPID TIME-TO-MARKET, AND MINIMAL DEFECTS AND POST-DESIGN REWORK.

improvement DFSS case study were:

- Improved understanding of the performance variation.
- Identified design sensitivity and tuning factors.
- Estimated and predicted reliability.
- Identified potential cost-reduction opportunities.
- Facilitated robustness thinking in the engineering design.
- Prepared meaningful reliability test strategies in the presence of user conditions.
- Developed effective reliability demonstration plan at high engineering confidence.

Robust design optimization, the heart of DFSS, works to desensitize the effects of noise on design-intended function. Instead of finding countless ways a system might go wrong, analyzing those failures and applying a countermeasure for each potential failure, robust parameter design focuses on the ways you can make things go right. It is a much more rewarding and effective way to think.

Cost effective and less time

Transfer functions enable engineers to introduce variation into the analytical models to understand how the distribution of variation can alter the desired performance. Reliability and robustness can be analyzed and optimized through transfer functions. Potential failure modes may be uncovered and discovered through a properly developed transfer function. Noise factors can be identified and included in transfer functions to uncover potential failure modes for reliability improvements in the up-front design phase.

It is more cost effective and less time consuming to make design insensitive to uncontrollable user environments, discover failure modes soon after they are created, and develop and implement countermeasures at the early product development phases, especially before production.

The transfer function-based reliability and robustness improvement technique is well adapted and applied in industries, including automotive. Hopefully, this approach will be used widely so cost effective and less time-consuming design decisions can be made in earlier design phases. DFR implementation can be best approached through the DFSS discipline. σ

REFERENCES AND NOTES

1. Matthew Hu, “Readiness Plan,” *Six Sigma Forum Magazine*, August 2013, pp. 9-16.
2. Ibid.
3. Instead of blindly searching an energy-related system output response based on empirical approach and experience, refer to Matthew Hu, Kai Yang and Shin Taguchi, “Enhancing Robust Design With the Aid of TRIZ and Axiomatic Design—Part I,” *TRIZ Journal,* Oct. 2000, and Genichi Taguchi, Subir Chowdhury and Yuin Wu, *Taguchi Quality Engineering Handbook,* Wiley, 2004. Both sources provide excellent discussions on how to select a proper system output response to minimize or avoid potential interactions of control factors.
4. Hu, “Readiness Plan,” see reference 1.
5. Due to the scope of this paper, focus was placed on describing how to use a developed transfer function to improve reliability and robustness.
6. Hu, “Readiness Plan,” see reference 1.
7. More information on the L50 orthogonal array is available in Madhav S. Phadke, *Quality Engineering Using Robust Design,* Prentice-Hall, 1989, or other robust engineering books.

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EDITOR’S NOTE

The first installment of this two-part series of articles, “Readiness Plan,” can be found in the August 2013 edition of *Six Sigma Forum Magazine.* Visit http://asq.org/six-sigma/2013/08/six-sigma/readiness-plan.pdf to download a PDF of the article.