Applying Six Sigma to Drive Down Product Defects

Probabilistic design and sensitivity analyses help engineers quickly arrive at near-zero product failures in the face of wide manufacturing variabilities and other uncertainties.

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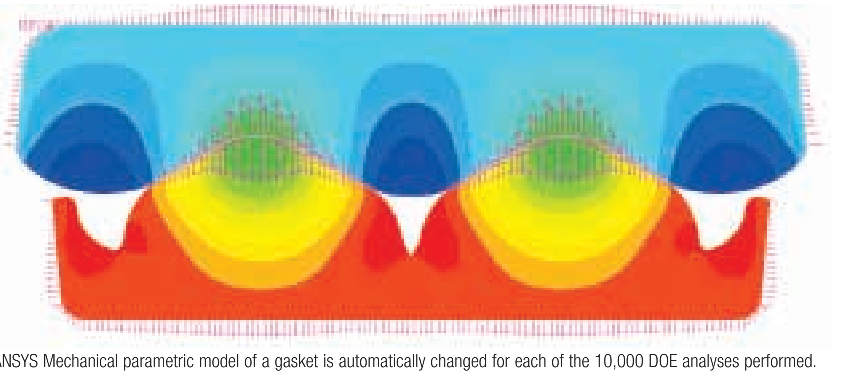
Companies often are focused primarily on time-to-market, but the advantages of fast product introductions may be quickly overshadowed by the huge cost of poor quality, resulting in product recalls, rework, warranty payments and lost business from negative brand image.

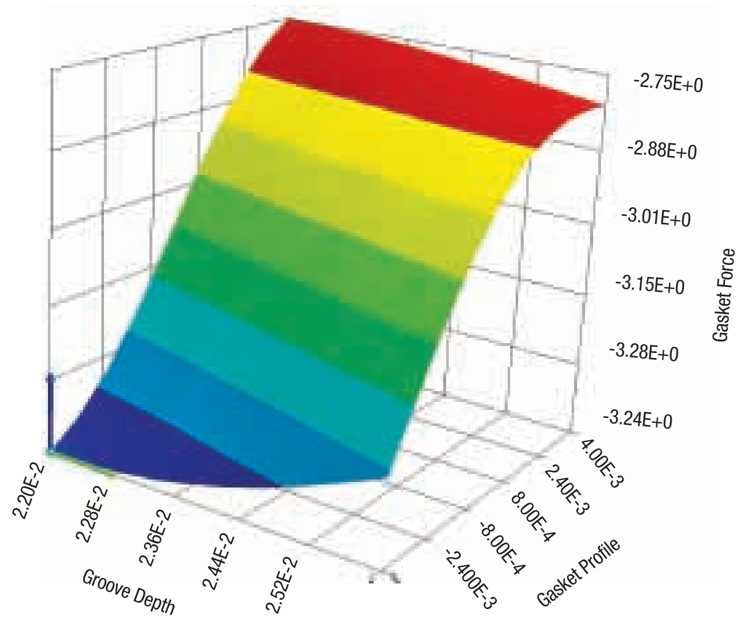
In many cases, such quality problems are the result of variations in factors such as customer usage, manufacturing, suppliers, distribution, delivery, installation or degradation over the life of the product. In general, such variations are not taken into consideration as part of the development of the product. Rather, the integrity and reliability of a design is typically based on an ideal set of assumptions that may be far removed from actual real-world circumstances. The result is a design that may be theoretically sound but riddled with defects once it is manufactured and in use.

Design for Six Sigma (DFSS) is a statistical method for radically reducing these defects by developing designs that deliver a given target performance despite these variations. The approach is a measure of quality represented as the number of standard deviations away from a statistical mean of a target performance value. Operating at three sigma translates into about 67,000 defects per million parts, performance typical of most manufacturers. A rating of six sigma equates to just 3.4 defects per million, or virtually zero defects.

Achieving this level of quality requires a focused effort upfront in development, with design optimization driven by integration of DFSS into the process and rigorous use of simulation. In such DFSS efforts, ANSYS DesignXplorer software is a particularly valuable tool. Working from within the ANSYS Workbench platform and in conjunction with ANSYS Mechanical and other



ANSYS Mechanical parametric model of a gasket is automatically changed for each of the 10,000 DOE analyses performed.



ANSYS DesignXplorer software generated a response surface showing sensitivity of each input variable to contact force.

simulation software, the program performs Design of Experiments (DOE) and develops probabilistic design analyses functions to determine the extent to which variabilities of key parameters impact product performance.

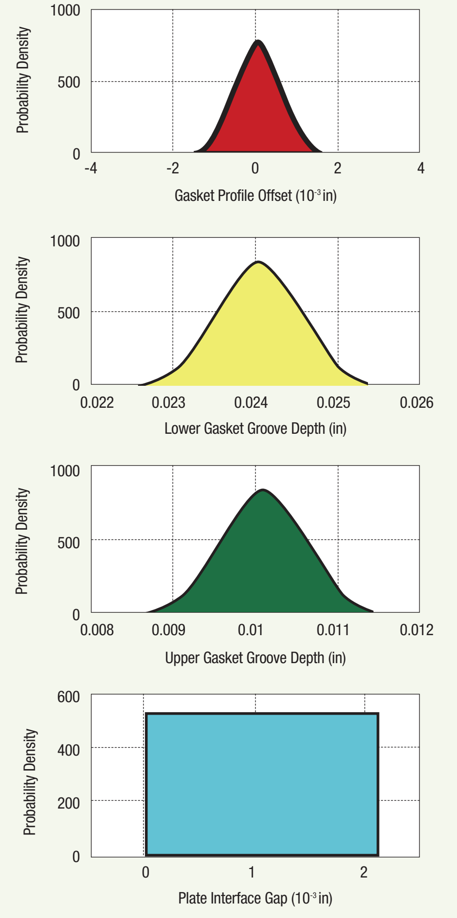
The process is accomplished in four major phases: process automation, design exploration, design optimization and robust design. Utilizing the ANSYS Workbench environment, process automation ensures that simulation tasks are well defined and flow automatically to extract and evaluate key performance variables.

ANSYS DesignXplorer software then performs the DOE, running numerous (usually thousands) analyses using various combinations of these parameters. The ability to quickly and effortlessly execute such an extensive study on this wide range of parameters allows users to perform quick and accurate what-if scenarios to test design ideas. In this way, design exploration — combined with knowledge, best practices and experience — is a powerful decision-making tool in the DFSS process.

Next, design optimization is performed with the ANSYS DesignXplorer tool in order to select the alternative designs available within the acceptable range of performance variables. Design parameters are set to analyze all possibilities — including those that might push the design past constraints and violate design requirements. Finally, robust design is performed, arriving at the best possible design that accounts for variabilities and satisfactorily meets target performance requirements.

Throughout the process, ANSYS DesignXplorer software employs powerful sampling functions and probabilistic design technology. It also provides valuable output in the form of probability design functions, scatter plots and response surfaces that are critical in DFSS. Seamless interfaces with parametric computer-aided design (CAD) programs — used to import geometry for analysis and to set up parametric models in mechanical solutions from ANSYS — is essential for ANSYS DesignXplorer software to automatically perform numerous iterations in which various design geometries are created and analyzed. In this way, ANSYS DesignXplorer software is an effective means of integrating DFSS into a company's product development process. The software provides individual engineers a unified package for quickly performing probabilistic design and sensitivity analyses on thousands of design alternatives in a few hours; otherwise, this would take weeks of effort by separate statistics, simulation, DOE and CAD groups.

One recent project designed to improve hyper-elastic gasket configurations in proton-exchange membrane (PEM) fuel cells illustrates the value of the ANSYS DesignXplorer tool in DFSS applications. In this example, several gaskets provide a sealing barrier between the cell and approximately 200 bipolar cooling plates. In designing the fuel cells for commercial use in harsh environments, the goal was to lower the failure rate of the gaskets, which tended to leak on occasion — even in a carefully controlled research lab setting.



Probability density functions of parameters that vary with each analysis iteration

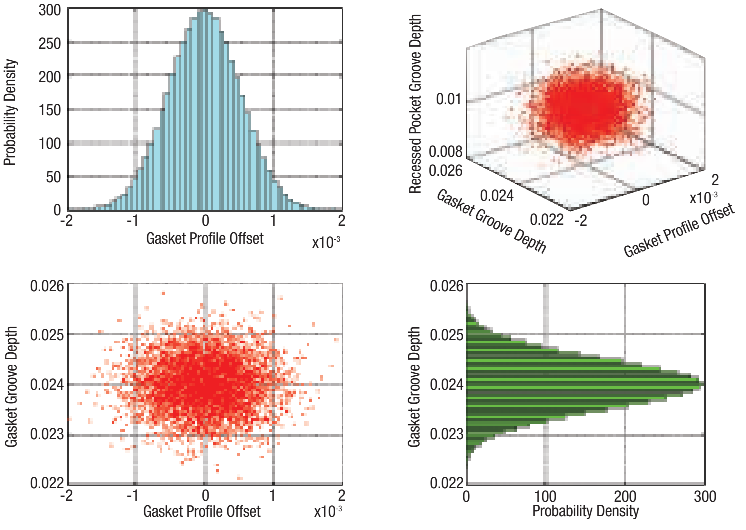
First, design variables were established — gasket profile, gasket groove depth and the opposing plate's recessed pocket groove depth — that determined the overall compressive force of the gasket under a given bolt load. These were considered to be randomly varying parameters with given mean and standard deviations as determined through probability density functions generated by the ANSYS DesignXplorer tool. The software then was set up to automatically perform a series of DOE analyses in order to determine the gasket contact force for 10,000 different combinations of these variables. Variables were randomly selected by the software for each round of analysis using the Latin hypercube sampling technique.

Using ANSYS Mechanical analysis, solutions were arrived at in which (1) nonlinear capabilities characterize the hyper-elastic gasket material properties; (2) contact elements represent contact between the gasket and plates; and (3) parametric features automatically change the geometry of the gasket configuration for each of the 10,000 analyses.

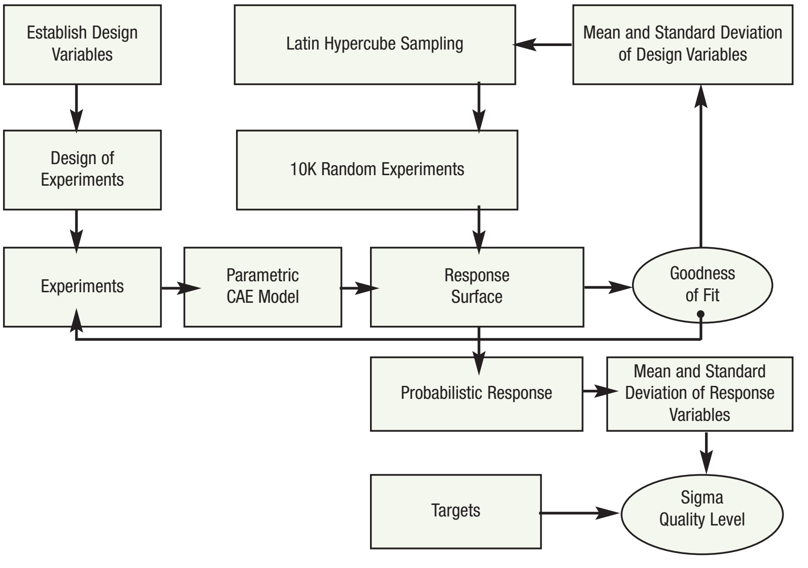
Based on these analysis results, ANSYS DesignXplorer software generated a response surface of the contact force per unit length of the gasket in terms of probabilistic input variables. With the sensitivity established for each input variable on the contact force, scatter plots of the analysis results were generated along with bell-shaped probability density functions, which were compared to the upper and lower load limits of the fuel cell and cooler interfaces. Axial forces could not be so high as to break the plates, yet not so low as to cause leaking. From this data, the ANSYS DesignXplorer tool determined the sigma quality level based on the contact force target level.

The process succeeded in arriving at an optimal gasket shape that exceeded the sigma quality level, dropping the failure rate to an impressive three parts per million — a tremendous improvement over the 20 percent failure rate that the gaskets were experiencing previously.

The entire process — including creation of the mesh models and completion of the 10,000 DOE analysis cycles — was completed in a matter of days by a single individual, as compared to months of effort that otherwise would have been required by separate design, statistics and analysis groups. Moreover, with the workflow captured in the ANSYS Workbench platform, the process now is highly repeatable and can be efficiently applied in optimizing the design of other gaskets merely by changing the CAD model and the upper/lower contact force limits.



Scatter plots of analysis results were generated, along with bell-shaped probability density functions, in arriving at a robust gasket design.



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More detailed information on the DFSS gasket project can be found in the ASME paper Fuel Cell 2006-97106 "Shape Optimization of Fuel Cell Molded-On Gaskets for Robust Sealing" by Vlahinos, Kelly, Mease and Stathopoulos from the International Conference on Fuel Cell Science, Engineering and Technology, Irvine, CA, June 19–21, 2006.