More Certainty by Using Uncertainties

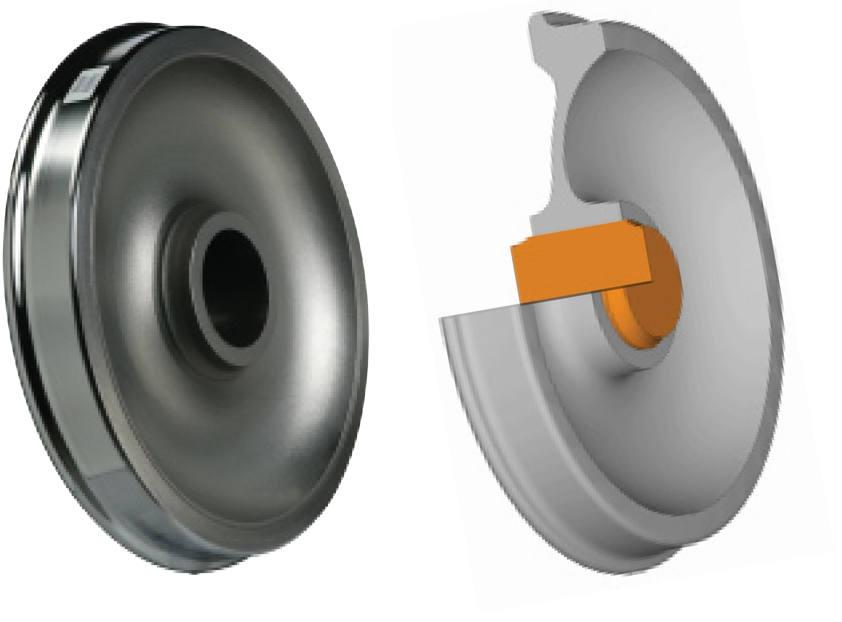
Engineers apply probabilistic methods to historically deterministic problems.

By Kexiu Wang, Griffin Wheel Company, Illinois, U.S.A.

Rail cars carry enormous loads, often triple that of the largest 18-wheeler trucks. These loads pass entirely through the wheels, which not only bear the weight but are subject to a number of other structural, thermal and fatigue loads. Griffin Wheel Company, a division of AMSTED Industries in the United States, produces 90 percent of rail wheels for the North American railroad industry. The company recently applied probabilistic tools from ANSYS, Inc. to their wheel design process.

A basic freight car wheel is relatively simple, yet the wheels are subjected to extreme forces and, therefore, must withstand tremendous amounts of abuse. The wheel not only bears the load of the car, but also its tread surface is used as a brake drum, absorbing varying loads under constantly changing thermal conditions. In addition, the flange guides the train on the track, conveying lateral loads throughout the wheel. Although deceptively simple in construction, the multi-faceted character of the freight car's load environment makes for an extremely complex analysis.

Freight car wheels are solid steel castings. Heat-treating strengthens them, improves wear resistance and induces circumferential residual compressive stresses in the upper rim to prevent fatigue crack formation. Heat-treating, however, generates axial tensile stresses in the lower part of the rim, causing vertical split rim, a rare but catastrophic failure mode. Understanding the factors that can affect these types of stresses is essential in effectively optimizing wheel design.



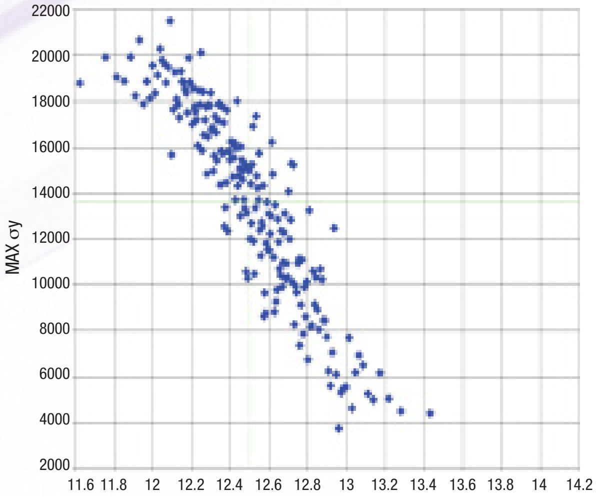
Computer-aided design (CAD) model (right) of railroad freight car wheel (left)

For an engineering analysis, many features are inherently variable and uncertain: operational loads, geometry, manufacturing processes, material properties and operational environments, as well as testing. These uncertainties lead to uncertainty in product development and manufacturing. The traditional deterministic design approach accounts for variations by using safety factors. But this approach does not account for the random nature of design parameters. Treating the various parameters as singly determined values decreases predictable reliability. Without measuring this reliability, performance levels become inconsistent. Moreover, since common practice assumes the worst-case scenario for each singly determined value, the resulting design is often less than optimal, and subsequent changes produce undetermined effects in other areas.

The probabilistic method makes use of statistical tools as a more reliable means to account for these multi-faceted uncertainties. During an analysis, parametric uncertainties are characterized statistically in terms of probability density functions (PDFs). These PDFs quantify the inherent risks in a system and allow evaluation of input parameter variations in relation to changes in output performances. Probabilistic analysis yields a more comprehensive understanding of the entire system, allowing engineers to develop a better understanding of product behavior in, and responses to, real-life conditions.

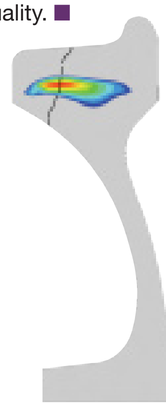
When used in simulation, once the random variations of boundary conditions, geometry and material properties are specified for a specific analysis case, the input variables are studied simultaneously by using statistical sampling methods. The parametric finite element analysis (FEA) model then is invoked repeatedly, performing deterministic analyses over the resulting input parameters.

Deterministic approaches have shown that the residual stress (from heat-treating) varies in relation to many parameters. To investigate the effects of different parameters in the heat-treatment process and to identify parameters that have the greatest impact on residual stress, Griffin engineers analyzed a CJ36 freight car wheel using the probabilistic tools from ANSYS. After performing a deterministic de-coupled thermo-mechanical analysis on a baseline model, engineers performed a Latin Hypercube sampling probabilistic analysis. This determined the variations in the residual stresses when given the uncertainty of the manufacturing process parameters, boundary conditions and material properties. The scatter plot showed that the residual stress was especially sensitive to creep.



The scatter plot compares maximum axial stress to the stress exponent. Correlation coefficients show strong sensitivity of the stresses to creep.

The probabilistic analysis is being used to identify future steps needed for further optimization and eventually will lead to optimizing the Griffin wheel's residual stress field, thereby improving wheel reliability. The process illustrates how simulation technology from ANSYS can be used to understand production process uncertainties and related parameter variations in a manufacturing process, leading to increased product reliability and quality. ■



Vertical split rim and contours showing the residual tensile stress

Probabilistic Analysis with ANSYS Workbench

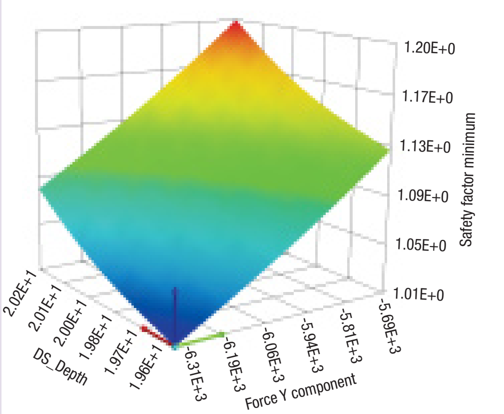
By Pierre Thieffry, ANSYS, Inc.

As a complement to the ANSYS Workbench environment, ANSYS DesignXplorer software provides a number of probabilistic analysis tools. Engineers use these tools to describe a parametric model in terms of statistical distribution functions for variations in the input parameters.

The technology uses two methods to estimate analysis variations. The Direct Sampling method, based on Monte Carlo sampling, requires a large number of simulations and can benefit from the parallelization techniques offered by products from ANSYS, Inc. The other method, called Design of Experiments (DOE), is based on response surfaces. DOE requires fewer simulations than Direct Sampling and builds an approximation of the system response from which probabilistic results are drawn.

Both methods analyze results variability and allow standard statistical analysis techniques (mean, standard deviation, kurtosis, etc.) as well as statistical sensitivity measures, with the latter actually identifying critical parameters driving the design.

ANSYS DesignXplorer software also provides information about the probability to reach a given performance. This data helps assess the risk of failure for a given design at a given target value, such as maximum stress, maximum displacement and minimum eigenfrequency. An equivalent Sigma level also is given, based on the Six Sigma quality criteria.



Variation of the simulation results with respect to design parameters