Variation Behavioral Modeling and Analysis Optimized for Virtual Product Design Through Manufacturing Process Development

By Timothy V. Bogard, President & CEO, Sigmetrix, LLC

Variation behavioral modeling is fast becoming a key component for virtual prototyping and design robustness validation as a part of the overall product lifecycle management (PLM) vision. Other initiatives like 6 Sigma, Design for Manufacturing, Collaborative Design, all require the ability to understand the real world effects of variation sources on the performance and cost of a product. Virtual teams are working on virtual designs with virtual manufacturing process definitions in order to minimize the risk of errors by reducing the need for physical prototypes, while transitioning from design to manufacturing. There are many issues - some of them not readily seen - that must be considered to make this virtual vision a reality.

The magnitude of the cost of tolerancing problems due to variation is not usually fully understood, even in financial terms. A study conducted on over 1000 mechanical drawings demonstrated that over half of all the changes requested to be made after the design was approved for production were the direct result of dimensioning and tolerancing errors. In each case, these errors could have been avoided if variation issues had been better assessed earlier in the design process. Most companies realize that these changes can be expensive, but few seem to have quantified this cost. Here is an example. A typical part is changed at least four times as a direct result of dimension-based manufacturing and design errors. A typical assembly has more than parts. The administrative costs alone of a typical design change to a released part are between $1,500 (all dollar figures are in U.S.) and $10,000. And this does not take into account the costs of scrap or re-working, etc., let alone the potential market costs involved in production delays. In other words, the STARTING COST of the changes made for tolerancing problems on an assembly is between $15,000 and $100,000.

Manufacturing-based variations are not normally considered as a part of the design in the CAD systems, but are a critical part of the overall PLM process. Companies are now realizing that a great design has to comprehend both functional design features and the associated manufacturing process capabilities in order to produce a robust product. Current CAE and CAD geometry systems base all analysis on idealized manufactured and assembled conditions. For example, interference checking is conducted on a CAD model that is assumed to be "perfect." Structural analysis assumes a perfectly accurate form and correct location of parts in an assembly. Variations in products are introduced as functions of manufacturing processes used to produce parts that deviate from nominal on the surfaces of parts. Manufacturing variation then propagates or moves through assemblies as a function of the contacting surfaces in the assembly. This can result in significant cost and quality effects due to product failures or higher than necessary product costs.

CAD assembly and part constraint systems have not been optimized for variation behavior modeling, yet are still assumed to represent the true physical behavior of the assembled parts in real world. CAD systems are optimized to create intelligent nominal designs that can be analyzed in many ways, but not with respect to the effects of mechanical variation. The challenge is to allow the use of CAD data and constraints that are valid for real world variation behavior modeling, while allowing for alternative associative methods for rapidly including real world assembly process and fabrication process effects on the design.

One way to understand this issue is to address the three key fundamentals that define variation behavior modeling (VBM) for analysis:

- VBM is a CAE process that allows the user to analyze the effects of variation in the design and manufacturing process parameters on certain important product performance measurements.
- Variation analysis is based on the concept of generating a population of realized designs and determining the population of measurement results.

- The analysis is obviously limited by the ability of the input parameters to represent the full range of variation that can be realized in a population of manufactured designs.

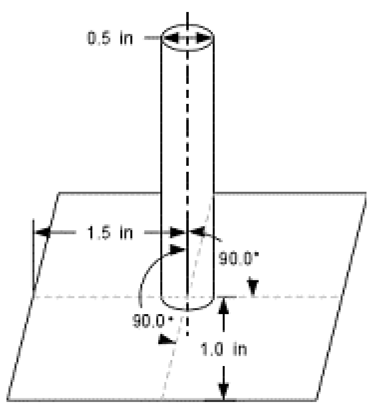
With the continuing pressure to develop designs more quickly, the opportunities for introducing variations in those design increases. The remedy lies in implementing more intelligent integration of the CAD and CAE tools to support quicker transition to stable production. Understanding the design and geometry capture practices within the CAD model and the information required for manufacturing process modeling with regards to a critical design requirement is fundamental to a great variation modeling and analysis application.

To help understand these concepts, we need to define three more key terms:

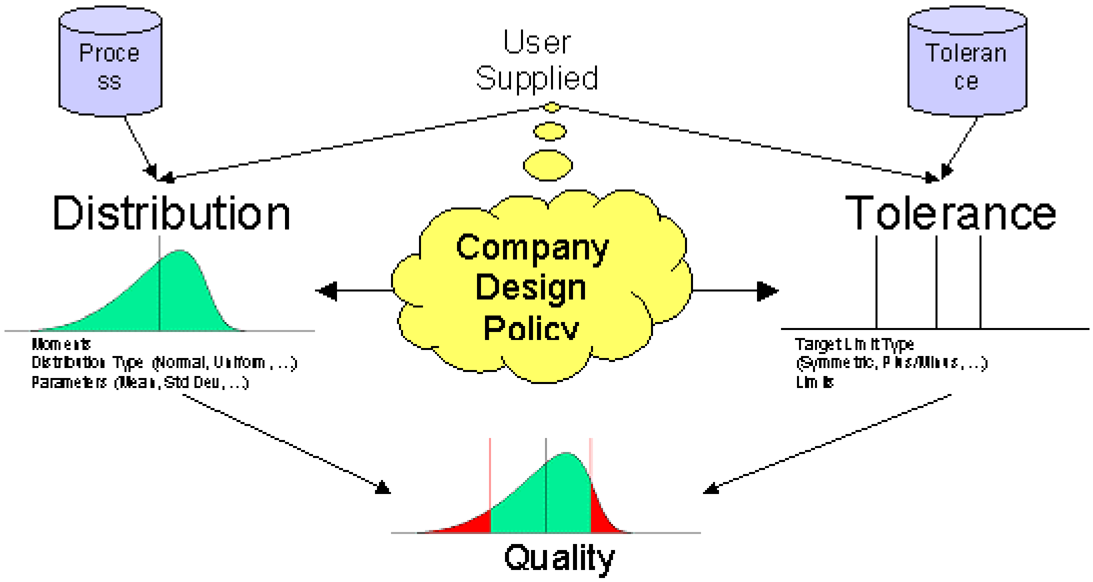
Variable -- Variables are the size, location and orientation dimensions of the part features.

Variation -- Variation describes how much the feature variables (dimensions) deviate from their nominal (design) condition. Errors in the manufacturing and assembly processes cause variation in the variables.

Tolerance -- Tolerances convey design requirements and design intent. They do not contain true variation information. Rather, they control one or more variables by defining how much variation is acceptable.



Variation information is collected from a number of sources and is used to relate the variability of the manufacturing processes to the limits of the design tolerances. Tolerance analysis assumes that tolerances can be achieved by manufacturing. Variation behavior based analysis uses actual manufacturing process data as the source of variation values.



In addition, assembly variation models provide an optimized assembly constraint definition based on real-world physical contact without dependency on design intent. When performing a variation analysis of a design, the user's ultimate objective should be to analyze the behavior the assembly will exhibit after production, rather than to analyze the behavior of the constraints used to manage geometry. Some additional concerns include environmental loads, such as a shaft in a bearing resting on one side of the bearing. Fasteners allow features to "float" between them, ensuring that they will not always be located in the same place. Fixtures tend to "adjust" the assembly during manufacturing and can introduce their own error in the assembled conditions.

Variation analysis technologies have been evolving to address these fundamental variation behavior modeling issues. CETOL 6 Sigma is a CATIA CAA V5 Based application optimized to address the ability to understand the effects of variation on design intent. Essentially, it unites the "ideal" world of the model with the "real" world of product design:

- Fundamental to the approach is the use of existing CAD surface information to re-create the physically correct assembly conditions that can automatically understand variation in the model and be used to conduct a variety of critical analysis.
- The first by-product of a robust variation model is the ability to conduct sensitivity analysis with respect to a more precise assembly constraint system.
- Being able to "bias" assemblies from their nominally precise conditions provides unique insight into the critical functional surfaces that must be more closely studied.
- Contribution analysis considers the effect of sensitivities in the design and accounting for the size of the variation as a way to separate the critical few features from the rest.
- Finally, the ability to directly introduce manufacturing process quality data as the source of the variation allows for a very precise understanding of the design through manufacturing process and driving robust design decisions.

In summary, tolerance analysis is a critical part of the PLM process because it reflects the fact that variation behavior modeling and analysis techniques are critical to truly matching design requirements while addressing manufacturing realities.