Tolerance Analysis: Preparing Your Model for the Real World

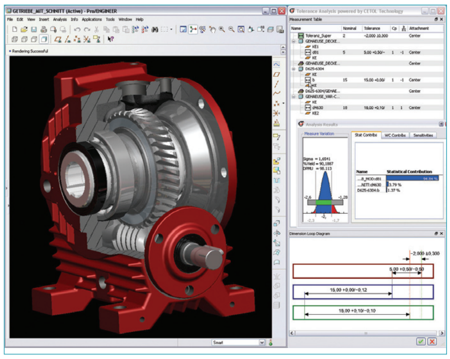
PTC®

DID YOU KNOW

In the real world, plastics will shrink, cutters will lose their edge, and parts may not fit perfectly. Tolerance analysis is the solution – but only if it's applied correctly.

Take a long, extruded aluminum block from a container. Cut it into 10 pieces. Then place the pieces end to end. Now determine whether they will fit back into the original holder. Thanks to any number of conditions – a slightly dulled cutter blade, a small vibration in the milling machine, an increase in temperature or humidity – chances are very good that they won't fit.

As an engineering company that sells parts, assemblies, or even CAD models to customers for final production, you understand the risks of manufacturing process variation all too well. Your CAD model represents the ideal version of the product your manufacturing partner or customer will build. But unless your model's specifications make allowances for some level of manufacturing variation, your customer may end up with an unacceptable quantity of production scrap – and you may end up with a lost customer.



With the Pro/ENGINEER® Tolerance Analysis Extension powered by CETOL Technology®, PTC makes it simple for design engineers to perform 1D tolerance analysis without leaving their Pro/ENGINEER application.

The need for balance

Understanding the realities of manufacturing process variation – also known as "variational behavior" – is critical today due to the ever-increasing globalization of product development and continually tightening time-to-market pressures. With less time and opportunity to build and analyze physical prototypes, today's web-based, globally dispersed design teams are instead using virtual prototypes to drive innovation and make informed product development decisions. Critical to this process is the design engineer's ability to first predict how the CAD model will be affected by manufacturing variations, and then to set tolerances accordingly.

Setting tolerances manually, however, is easier said than done. The easiest method is for the design engineer to apply standard tolerances wherever they exist. Standard tolerances are typically associated with common parts and assemblies. But this practice can lead to trouble later on, either in later design steps or when the model is turned over to manufacturing.

First, the standard tolerances simply may not fit into the final dimensions of the product-to-be. This might force the designer to make compromises as the model or assembly grows, and these might either compromise the quality – or delay the time-to-market of the product. Secondly, using standard tolerances can prove costly for manufacturing if, for instance, the standard tolerances are tighter than necessary for this particular product. Too-tight tolerances may force Manufacturing to use specialized machinery; if the designer can relax the tolerances – but still keep them within the product's specifications – then Manufacturing can machine the part using less expensive machinery.

Instead of going with standard, generic tolerances, the designer should therefore set tolerances only as precisely as required: too tight, and you may incur higher manufacturing costs or higher scrap percentages than necessary; too loose and the product, while manufacturable, may not satisfy its end-user requirements.

How tolerance analysis software works

Tolerance analysis software, historically very complex and affordable by only large manufacturers, is now migrating to small- and medium-size engineering companies, through its integration with 3D CAD software.

In essence, tolerance analysis software works by taking in as much information about the model and the model's expected behavior as possible. It then applies expert algorithms to show the CAD designer – graphically and in near real-time – how a change in tolerance will affect the manufactured product.

As part of the modeling process, for instance, tolerance analysis software identifies the model's critical dimensions, and then introduces variations that test the dimensions' sensitivities to different manufacturing and performance scenarios.

When used within 3D CAD software, tolerance analysis software can be valuable throughout the model-building process. Some examples:

- **Concept modeling –** Even with a skeleton model, tolerance analysis software can help determine where the critical dimensions will be, and, with input from manufacturing, what tolerances will be possible from existing tools and/or capital assets. This information can help you decide whether the product-to-be-designed will work within the designated budget.
- **Functional assembly modeling –** Here is where bearing interfaces, joints, bolts, materials and other factors come into play, and where it's particularly helpful to be able to model a wide range of variations, something that even a physical prototype cannot do. Here, too, is where a simple design change may compensate for a condition that would otherwise require an expensive machining change. As an example, to bring the seat-clearance of an auto engine's valve train into acceptable tolerance, the CAD designer might change the position of the valve-guide's center hole – a far less expensive change than adding a new machining process.
- **Detailed part modeling –** As the model nears completion, tolerance analysis can help the designer and the manufacturing engineer agree on any compromises that may be necessary in the "as-manufactured" model – to accommodate a certain machine setup, for example, or to run on two different machines simultaneously.

Simplifying the process: 3D, 2D and 1D

Tolerance analysis software comes with varying capabilities. High-end, stand-alone packages are able to compute tolerances for complex components and assemblies by using 3D and 2D algorithms to combine tolerance limits on multiple axes. Such packages are valuable for specialized testing applications, but they are frequently not necessary for the design engineer, whose primary need for tolerancing support involves one-dimensional (1D) or linear stack-up analysis.

By far, 1D is the most frequently used tolerance domain because the great majority of products are assembled in linear fashion. Even a product having four horizontal vertices (left, right, front, back) can be considered a linear assembly: right and left parameters first; front and back parameters next.

Because 1D analysis is popular – and, compared to 2D and 3D, extremely fast to execute – it's an effective tool for the design engineer wherever a horizontal or vertical stack-up exists. A gearbox for an automobile (or tractor or truck) drive train is an example of a horizontal stack up, where the designer must first assemble gears along a spindle, then pass the spindle through the gearbox casing, then through two gaskets and into the engine housing. An example of a vertical stack-up is an electronic assembly with printed circuit boards stacked on top of each other.

Design engineers can also use 1D analysis in certain 2D or 3D situations if they determine that the root of the tolerance problem is one-dimensional. As an example, the gearbox might require that gaskets be thicker on one side than on the other. This difference might result in one side having extra material. But the designer doesn't have to worry about finding space in the width of the gearbox to accommodate the extra material, because there's room to spare. So the gearbox gasket-casing stack-up remains the root problem for analysis.

Making informed decisions

One-dimensional analysis can help design engineers make more informed design decisions in several ways.

Designers can check to ensure that the actual tolerances are close to the tolerance goals established in the original requirements specifications. If actuals were firmly within the goal limits, that could signal an opportunity to reduce manufacturing cost by relaxing some tolerances. As well, designers can try multiple tolerancing schemes "on-the-fly" to find the best of several alternative solutions for a given problem. Used in these ways, tolerance analysis software can provide a significant advantage to the design engineer who wants to produce the highest quality models and products possible, at the lowest possible cost.

PTC: Vendor Perspective

With the Pro/ENGINEER® Tolerance Analysis Extension powered by CETOL Technology®, PTC makes it simple for design engineers to perform 1D tolerance analysis without leaving their Pro/ENGINEER application. The Tolerance Analysis extension maintains associativity with the Pro/ENGINEER model, which delivers a host of valuable benefits: any change in the model is automatically reflected in the analysis parameters; the software automatically validates dimensions and dimension loops; it uses easily understandable graphs to help design engineers compare design variations; and it supports Six Sigma design methodologies, so design engineers can build models optimized for manufacturing.

For 2D and 3D analysis, Pro/ENGINEER designers or test engineers can move easily to CETOL 6s assembly modeling software, available from PTC partner Sigmetrix, LLC. Because CETOL 6s software for Pro/ENGINEER uses the same interface conventions as the Pro/ENGINEER Tolerance Analysis Extension powered by CETOL Technology, engineers can move comfortably from one application to the other.

Tolerance Analysis: Good for You – And Your Customer

It's clear that tolerance analysis can help the CAD designer in many ways, and at many stages of design. It's also clear that, due to today's combination of globally dispersed design teams and shorter time-to-market windows, tolerance analysis is no longer a luxury for small and medium-size product development companies; it's a necessity.

Tolerance analysis helps you bring designs to maturity – and to market – quickly, not only reducing the need for physical prototypes, but also improving innovation through "what-if" scenarios carried out virtually. Perhaps most importantly, tolerance analysis software can greatly improve your collaboration with manufacturing partners or customers, because it lets you provide validated tolerance information early in the design process – the most crucial time for determining product quality and controlling costs. This early insight into product performance helps your customer plan for manufacture, which can be a significant benefit for your customer, and for you.

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