Quality Includes Tolerance Analysis
Along with 3D CAD, PMI and GD&T

White Paper
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Manufacturing companies depend on the quality of a product. Quality does not happen by accident. Companies with the best quality have created processes and invested the time to ensure that their quality expectations are met. This often means that the instructions that they give to their shop floor are accurate, easily understood and supported by analysis. In doing so, they manage to avoid many problems during manufacturing and assembly.

While higher quality is a widely held goal, companies may not have a complete understanding of the technology available to make it happen. This white paper focuses on the contribution to quality through 3D CAD, GD&T, PMI and tolerance management and analysis.

Conventional Tolerancing and Shop Practice

Manufacturing has a long history of trying to solve tolerance issues. Most companies start out with traditional plus-and-minus tolerances, also known as stack-up analysis. This is a worst-case analysis and does not consider likelihood, or what is probable.

Their drawing title block often drives these tolerances with exceptions called out in the drawings for features that were problem areas or required special attention during fabrication. This often addresses only the known or anticipated problems for that design.

Reliance on plus-minus tolerancing can lead to overly tight tolerances as engineers see this as a way to ensure fit in assemblies. This can drive up the cost of the part as extra care must be taken during manufacturing to hold these tolerances. Setting tolerances too loose can result in machine shops pushing parts through at a maximum speed, sometimes going to the edge of acceptable tolerances.

A part is held to tolerance by the competency of the personnel on the shop floor and the type of machinery in use. NC machines have an expected tolerance that a company should be well aware of and maintain.

Small shops rarely work on complex assemblies. Machinists employ tricks such as oversizing holes or turning holes into slots, obtaining necessary clearance with a grinder and even using hammers to get parts to fit. This results in inconsistency and inefficiency. There is much to gain in removing shop time spent on workarounds that get parts to fit — and in adjusting design practices that may be necessitating them.

For companies to grow and prosper with increasing time constraints, tougher competition and shrinking profit margins, companies need to become more and have more consistent and reliable manufacturing to ensure profitability.

The Need for GD&T
Learning how to tolerance and communicate the design and quality intent throughout a company’s organization is the very basis of GD&T (geometric dimensioning and tolerancing).

GD&T requires an investment. It has a cost over time and requires patience, determination and a willingness to learn from painful lessons. GD&T can be thought of as teaching a foreign language, and fluency is not achieved overnight.

Says GD&T consultant John Stolter, “When you learn the language of GD&T, you learn what distinctions the language allows you to make, which opens up possibilities and expands your thought process, thus allowing you to engage in a deeper and more specific conversation.”

**Scenario A: Company Adopts GD&T**

Company A doesn’t have a quality department. The shop is small, of the kind that can be found in nearly every town in America. They rely on continued business from local customers and have created a faithful following in a specialty.

This company will get GD&T training for an engineer, convincing management with a presentation and an ROI done on spreadsheets. It helps if the management is of an engineering/quality mindset, capable of understanding the basic tenets of GD&T.

After the training, GD&T starts appearing on drawings. The company makes the necessary adjustments on the shop floor. The shop personnel start to understand and speak in the terms of GD&T. Due to a common language and an understanding of engineering and manufacturing that GD&T brings, Company A can now take contracts from larger companies or improve their own designs.

Company A has used GD&T as a solution — but not as a practice. They may well meet the ROI prediction but will soon find an end to the improvements and reach a plateau quickly. Worst of all, they may find that there are still lingering quality problems.

Company A may go back and change more GD&T tolerances, but a real analysis of the actual tolerances is not done, which leaves what may be the root cause of the problems. They have only corrected the problems downstream of design, not realizing that the bulk of the cost is determined during design and the costs of fixing design issues in the shop or afterward can be sizeable — even crippling to a small company.

However, many companies are content with this scenario and may never realize they need something different. While they have realized some benefit from their GD&T investment, the problem isn’t completely solved.

**Company B: GD&T and Tolerance Analysis**

Company B is also a small or a medium-sized company and also undertakes GD&T training similar to Company A. They also have been studying how variation of size in the parts has led to problems with the parts not fitting in the assembly area. However, they have been doing tolerance stack analysis in the design phase, using a combination of hand calculation, educated guesses, tribal knowledge — or, with the more advanced, Excel spreadsheets. They have specified GD&T in their product development process. They have developed a quality department or process to ensure expectations are met per the drawings. Tooling and fixtures are part of their manufacturing process with the understanding of GD&T as the basis for their requirements.
Company B now has a bigger investment in GD&T than Company A. Company B gets the benefit of a quicker ROI.

**Company C: GD&T and Tolerance Analysis with Software**

Company C, another small or medium-sized company, also decided early that tolerance stack analysis would be part of their GD&T implementation. They embraced GD&T, budgeted for the infrastructure and downtime as their staff learned and adapted to GD&T, and subscribed to its best practices. Similar to Company B, they realized the importance of tolerances when fitting parts together but also realized that the analysis of tolerances was taking a lot of time. They wanted to make the tolerance analysis as quick and accurate as possible.

**Limitations of 1D and Manual Data Entry**

Most hand calculations and Excel-based analyses of tolerances are limited to one dimension, called 1D analysis. Templates are available at relatively little cost.

1D has substantial limitation, being able to analyze tolerance only along one axis. Engineers input numbers from 2D drawings into Excel, which often contains formulas. This is a very time consuming task and therefore limited in its implementation since companies end up electing to use it sparingly or only for what they suppose are critical fits. This can result in tolerance stack analysis fading from use.

But even if it is forced into ongoing use, 1D analysis has its limitations. Not only is it confined to one dimension, it is also not linked to the 3D CAD model. Any change to the 3D geometry and the 1D analysis will have to be redone.

**Role of PMI**

Inputting the dimensioning and GD&T information in the design phase will attach the tolerance information to the 3D CAD model. This is known as product manufacturing information, or PMI. Having PMI allows 3D tolerancing and GD&T on every model. A model does not have to be fully defined with PMI, but the more the better. PMI can make tolerance analysis a largely automated process.

PMI sets the stage for an increased awareness and understanding of GD&T principles. It also furthers drawing-less and paperless environments since the CAD program and tolerance analysis software are now linked.

**Tolerance Analysis Software**

Use of tolerance analysis software is similar to how designers and engineers would us FEA. Both types have standalone, CAD-agnostic versions, as well as integrations or add-ons that work with a CAD program. They all have varying capabilities and can be specialized for a particular industry. Analysis is accomplished using different statistical models (RSS, Monte Carlo, etc.).

**Commercial Examples of GD&T and PMI Software**

SOLIDWORKS, one of the most widely used CAD programs for mechanical design, includes full GD&T PMI integration. It’s not an add-on or an afterthought. The PMI can be created during design by GD&T knowledgeable engineers with little effort and even in the concept phase of a design. Many other CAD packages offer this level of PMI integration. This, of course, makes communication of GD&T as easy as possible.
SOLIDWORKS also offers TolAnalyst in their high-end packages. The level of integration with this analysis tool is as tight as can be imagined. In traditional SOLIDWORKS fashion, the feedback is very visual and the product is streamlined to be as efficient as possible.

TolAnalyst does min/max tolerance as well as RSS tolerance analysis. It does not do Monte Carlo analysis. Also, it is not available as a standalone so it can’t help you if you use another CAD product instead of SOLIDWORKS.

**Standalone or Integrated Tolerance Analysis**

There are many other vendors specializing in tolerance analysis that offer software that works with various CAD programs as well as in a standalone capacity. Many are add-ons to specific CAD packages. Others are CAD agnostic, offering levels of integration to CAD programs.

*Sigmetrix Tolerance Analysis software works with three CAD Packages: SOLIDWORKS, CATIA and Creo (formerly Pro/ENGINEER), with which it is most tightly integrated.*

Reading PMI data is key for tolerance analysis programs, saving users from re-inputting data. Working interactively with a CAD program also lets tolerance analysis software suggest feature controls, show errors if something violates current GD&T standards, and advise on solutions. Working directly with the 3D nature of modern CAD programs, a full 3D tolerance analysis can analyze variation in all directions. It is scalable and can apply to large assemblies. It also gives many options for a variety of reporting and analysis approaches depending on how a company wants to consume and communicate their reports.
Sigmetrix CETOL shows a problem, highlighting unacceptable samples after a statistical tolerance analysis.

Having tolerance analysis software will let engineers quickly question how tight a tolerance needs to be, preventing excessively tight tolerances that lead to higher manufacturing costs. Also, they may be able to determine that changing the type of tolerance offers an advantage to changing the design. Tolerance analysis can provide reports and analytics in a quickly accessible graph form for sharing and understanding prior to finalizing decisions.

**Conclusion**

If a company is looking to implement GD&T, it is suggested they first have and implement a 3D CAD program with PMI. A good knowledge base of GD&T is an invaluable investment for all stakeholders. A robust tolerance analysis software that has direct access to the design geometry and PMI data will go a long way toward making tolerance analysis part of the design and manufacturing process to ensure better fitting assemblies and reduce waste and rework.

For more information, please visit the [Sigmetrix website](http://www.sigmetrix.com).

**About the Author**

Ryan Reid is a CAD administrator, PLM enthusiast, designer, GD&T specialist, lead, lean philosophy supporter, Microsoft Office expert, 3D printing hobbyist and manufacturing-focused professional with 17 years of combined experience in those areas. Reid has accomplishments in all aspects of manufacturing engineering, from cradle to grave plastics/mold to structural, systems, process and change management design.