EffectiveTraining Inc., Westland MI, 734.728.0909

Volume 01: Issue 6

Known as the "Doctor of Dimensioning," Alex Krulikowski is a noted educator, author, and expert on Geometric Dimensioning and Tolerancing (GD&T). A design manager with one of the world's largest manufacturing corporations, he has more than 30 years of industrial experience putting GD&T to practical use on the shop floor.

Web Highlights

Training to Go

While training is vital, cost is a hurdle for many companies. That's one reason for the growing trend toward what is variously called e-learning, distance learning or computer-based training.

Larry Adams looks at the savings involved in e-learning in Quality Magazine online.

To read the article, Click here

ETImail is a regular online publication devoted to Geometric Dimensioning & Tolerancing. Each edition features a host of GD&T resources and links, as well as dimensioning tips by noted GD&T author and ETI founder, Alex Krulikowski. We also invite you to visit our website, etinews.com. To view past issues of ETImail, see the archives.

ETImail is now available in PDF format. To read the PDF file, you will need Adobe Acrobat Reader.

In This Issue

Here are this issue's highlights. Click on any link to jump directly to a feature:

The Tao of Tolerancing
Part II: The System Approach to Component Design

Alex Krulikowski

This five-part article covers my experiences, thoughts, and beliefs on tolerancing. It is based on observing how many organizations around the world currently handle tolerancing and how I believe tolerancing can be handled in a far more successful way in industry. I believe that using the tolerancing methods discussed in this article can save as much as 30% of part costs.

The first part of this article covered nominal thinking. In this issue of ETImail, the article continues with Part 2, how to specify datums and dimensional relationships for all part features. It also explores "The Great Controversy" about how parts should be dimensioned.

The next part of the article covers how to establish meaningful tolerance values for each dimensional relationship on a part, and the fourth outlines a plan on how to lift your organization from Tolerancing Hell to Tolerancing Heaven. The fifth and final part of this article reviews and summarizes all of the Tao Tolerancing Principles covered in Parts One through Four.

An explanation of the title of this article: Tao (pronounced "dou" or "tou") means "the path" or "the way." Tao is an ancient Chinese religious belief and contains a philosophical aspect that can be applied to how we specify tolerances in industry. A tolerance is simply "the allowable variation for a part feature," so this article is an enlightenment of a philosophical approach to assigning tolerances to part features.

Component Tolerancing is Like a Religion

Let's begin this leg of the journey with a few comments about the article. The method of tolerancing a part (component) is like a religion; it is often a result of one's beliefs. Our beliefs guide our actions. Manufacturing, Engineering, and Inspection all have different beliefs based on what works in their departments. Each department tries to tolerance the part (component) to optimize the tolerances to their own advantage. This leads to a disagreement (the religious war) on the component tolerancing methods. Often, there is no overriding authority or philosophy in the organization to harmonize the beliefs of the individuals in the different departments. Therefore, they compromise to resolve differences. Compromises often do not result in the best solution; they keep a level of peace among the participants, but don't do anything to change the core beliefs and often sub -optimize the component design. Also, engineers involved often compromise items critical to the function of the design and the customer pays. When you compromise the customer goals, the customer never wins.

Compromising a Tolerance

When a tolerance is compromised, it is only one step better than guessing. There are three primary reasons this compromise hurts the final product:

1. Inadequate Tolerancing Skills - Design and engineering people mean well but often do not have the GD&T skills to define the component as it functions; therefore, they produce drawings with vague or incorrect tolerance specifications. Because their knowledge is weak, they cannot explain or defend the component functional relationships, so they easily compromise them.

2. Sub-optimization - In many organizations, the loudest or most stubborn people often get their way (or insist upon a significant compromise in their favor) in order to keep them from monopolizing the meeting. The sub -optimization occurs because the dogged worker usually fights for a position that helps his or her department and often hurts the organization. This results in "who's right" rather than "what's right" being a major factor in the compromise.

3. Flawed facts - Often, in the religious wars (oops, meetings), a person will use flawed facts to argue a point. The fact may be true, but it is being used to argue for or against a set of conditions that do not apply to this particular case. Then important decisions are influenced away from the real truth.

One more point before I stand aside and let the journey proceed: When you finish reading, the article will leave you in one of two states: Either you will be offended or you will want more. I believe many of you will want more.

The Great Controversy

In the last three decades, I have worked with hundreds of companies from five continents, and have found one controversy that nearly all engineering and manufacturing organizations share. The Great Controversy is over whether part tolerancing should be based on product function or manufacturing practices. I have found five tolerancing approaches common in industry, all are a variation of tolerances based on functional requirements or on manufacturing practices. Each one has some merit from a departmental viewpoint, but is detrimental from an organizational perspective.

The first tolerancing method that is common in many organizations is copying tolerances from similar parts in production. I call it the "TBR" method. TBR stands for Toleranced by References. In this method, datum features and dimensional relationships are established by copying from similar parts in production.

There are two perceived benefits of the TBR method: it allows the designer to complete tolerances quickly, and past users of similar parts toleranced the same way have a perceived understanding of the tolerance specifications (ie. copying tolerances doesn't rock the boat). If someone complains, the designer can say, "What do you mean it's a problem? This is the way we did it in the past. Just look at part number XXXX."

The results of the TBR tolerancing method are shown in the chart below.

The second tolerancing method that is common in many organizations is to base the tolerancing on how the component is manufactured. I call this method the "TBM" method. TBM stands for Toleranced by Manufacturing. In this method, the manufacturing engineer dictates what component features are to be used as datum features, and the dimensional relationships are based on how the part is processed.

This method has three perceived benefits: 1) The component will be easier to manufacture because the process is represented in the tolerancing method. 2) Gaging costs are lower because one set of gages may verify both manufacturing and engineering requirements. 3) There are fewer machine changes because the component dimensioning can come from one set of datums that match the machine process. At first glance, this appears to be a viable method, but in reality, it is very dangerous.

See the chart for the results of the TBM method.

The third tolerancing method that is common in some organizations is to base the tolerancing on how the component is inspected. I call this method the "TBI" method. TBI stands for Toleranced by Inspection. In the TBI method, the inspection department influences the decisions on datum features and dimensional relationships to simplify the inspection process.

The TBI method has two benefits: The inspection time is shorter because the inspection process is represented in the tolerancing method. The inspection process may be less expensive. At first glance, the TBI method appears to be a viable method, but in reality, it is also very dangerous.

See the chart for the usual results of the TBI method.

The fourth tolerancing method that is used in some organizations is to base the tolerancing on how the component functions. I call this method the "TBF" method. TBF stands for Toleranced by Function. In the TBF method, the component function influences the decisions on datum features and dimensional relationships to ensure the component functions as it is intended.

The TBF method has four benefits: Fewer problems at initial production, improved customer satisfaction, lower manufacturing costs, and a distinct competitive advantage.

The chart shows the results of the TBF method, when correctly applied.

Although the TBF method has great potential to save a significant amount of money in an organization, many companies often do not realize any benefits. This stems from a partial, unorganized, or inconsistent use of functional tolerancing. Later, this article will introduce a systematic method for applying functional tolerances.

The fifth tolerancing method that is quite common in many organizations is to base the tolerancing on a combination of the above methods. I call this method the "TBC" method. TBC stands for Toleranced by Compromise. In this method, the various departments of the organization negotiate what component features are to be used as datum features and dimensional relationships based on the personalities of the people in the organization.

The TBC method has two benefits: It keeps peace among all the adamant defenders of departmental thinking, and the inspection is believed to be less expensive. At first glance, the TBC method appears to be a viable method, but in reality, it is very dangerous.

The usual results of the TBC method are shown in the chart.

THE GREAT TOLERANCING CONTROVERSY

Current Tolerancing Methods and Their Results

[Click on a link for a printable version of this chart: PDF; Word doc]

METHOD	RESULTS
TBR **TOLERANCED BY REFERENCE**	• A tolerancing scheme that may not be related to the functional requirements of the component • A designer or engineer who only understands the component tolerancing at a superficial level • Vague, incomplete, or illegal component tolerance specifications • Confusion and poor drawing specifications—or—an organization that exists in Tolerancing Hell Back to article
TBM	• A tolerancing scheme that may not be related to the functional requirements of the component • Vague, incomplete, or illegal component tolerance specifications • Multiple drawings for some components (if a component is processed in multiple plants, a separate drawing is often made for each plant);

ETI Services

ETI Offers On-Site Training

Effective Training brings the most up to date, easiest to understand GD&T instruction in the industry right into your location. Either Alex or one of his personally trained instructors will come to your site to conduct a series of three workshops that add up to a total GD&T education. Workshops can be customized to include your drawings and parts.

To find out more about what ETI has to offer your organization. Click here

ETI's Employment Opportunities Board

ETI provides a free forum that enables job seekers and employers to meet. If you're looking for employment in a GD&T-related industry or you're a company who needs someone with GD&T knowledge, post your needs here. Click here

ETI'S Discussion Board

TOLERANCED BY METHOD	when more drawings exist, there is a greater chance that an engineering change may not be updated on all the drawings. • Tolerances that are often tighter than they need to be • Lack of focus on customer requirements • Confusion and poor drawing specifications—or—an organization that exists in Tolerancing Hell Back to article
TBI **TOLERANCED BY INSPECTION**	• A tolerancing scheme that may not be related to the functional requirements of the component • Many dimensions measured from a single datum reference frame • RFS modifiers used where MMC is more appropriate • Less tolerance for manufacturing • Higher risk to the customer • Confusion and poor drawing specifications—or—an organization that exists in Tolerancing Hell Back to article
TBF **TOLERANCED BY FUNCTION**	• Larger tolerances for manufacturing • A tolerancing scheme that is related to the functional requirements of the component • A better understanding of how functional requirements are related to tolerance specifications • Clearer tolerance specifications • Low risk to the customer • Focus on customer requirements Back to article
TBC **TOLERANCED BY COMPROMISE**	• A tolerancing scheme that is not related to the functional requirements of the component • A combination of several methods being used, so no method is really being used • No accompanying guidelines on where each method should be used • Higher risk to the customer • Confusion and poor drawing specifications—or—an organization that exists in Tolerancing Hell Back to article

That covers some of the more common tolerancing methods used in industry. However, the truth is that none of the methods is being used effectively, which leaves most of industry in Tolerancing Hell. The problem is so severe and widespread, that most executives do not want (or know how) to address it. There is a better way, and it can make a significant impact on the bottom line. But it is only for those who have the courage and patience to pursue it.

The component requirements are communicated by the tolerancing. If the tolerancing reflects the manufacturing or inspection perspective, where are the functional requirements communicated?

I believe three documents are needed to produce a component: The component tolerancing (on the product drawing) is where the functional relationships of a component should be communicated. The process plan is the best place to communicate the manufacturing requirements of a component. The measurement plan is the best place to communicate the inspection requirements of a component.

A Better Way: An Introduction to the System Approach to Component Design

As you can see, there is a lot of confusion on how to tolerance components. Even the experts don't agree. I believe it is critical for an organization to adopt a method and work to commonize the product development process around that single method. The method I propose is the System Approach to Component Design. In SACD, the component tolerancing is based upon the needs of the final

ETI's website has an interactive forum that's easy to access and may give you a broader knowledge of GD&T-related topics. Drop by the Interact section of our website and take a look at the Discussion Board. Click on any subject title and you can browse through GD&T topics, where you may find ideas to spark your own questions.

ETI's Discussion Board can provide a place for you to find answers to questions, an exchange of ideas, and a continued discussion of the ever-changing world of GD&T.

To visit the board, click here.

Back to top

Tech Calendar

Stay up to date on the latest industry news with the ETI Tech Calendar. Click here

Back to top

Quality Quote

Quality is the degree to which a specific product conforms to a design or specification.

—Harold Gilmore, *quoted in Quality Quotes, by Helio Gomes* (Milwaukee: ASQ Quality Press, 1996)

Back to top

product (or system). The SACD is a more organized approach in comparison to the informal TBF method used in industry today. The SACD method treats the product as a system, where the functions of the product become the system requirements and the component tolerances are based on fulfilling the system requirements. If SACD is applied correctly, it can provide numerous benefits to an organization. The SACD method is simple and powerful.

The concept of the system approach to component design is only introduced in this article. There is not enough information here to teach you to apply the method. Since many of you will want more than the introduction, I am developing a book and a course that covers the system approach to component design in greater detail. You will have to be patient, prepare yourself for the coming of the method, and use the information you have to guide you closer to Tolerancing Heaven.

Examples of the benefits of SACD are:

1. Larger tolerances for most dimensions
2. A good understanding of what tolerances are important to the proper functioning of the product
3. Increased focus on quality goals
4. The use of GD&T and functional relationships results in the flexibility for parts to be multiple - sourced
5. The use of GD&T lowers inspection costs
6. Increases CTK
7. Imports Six Sigma design processes
8. Reduces design changes due to process changes

Earlier in this article, I discussed the problems with compromising the component tolerancing. When something is compromised, a middle way between two extremes is chosen. This is not necessarily a better way, just a way for both sides to get some of what they want. Using the SACD method doesn't compromise tolerancing; it optimizes tolerancing.

An Overview of the SACD Steps

In the SACD method, the main focus is on ensuring that each product function is protected through tolerance specifications. Applying the SACD method requires the user to be proficient in geometric tolerancing, because the language of GD&T allows the ability to express functional relationships. The SACD method defines what is best for the system in order to determine what is required for each component.

The SACD method has two parts: system analysis and component tolerancing. The system analysis must be done before the component analysis, because before you can tolerance a component, you must understand its role in the system. The system analysis has four basic steps. The component tolerancing has seven simple steps.

The steps for system analysis are:
1. Identify all product/system functions.
Create a list of all the functions of the product (or subassembly). This can be done through a design team meeting. The typical members at a design team meeting include: design, product, and systems engineers; marketing; service department representative, and others as necessary. Also, a Design Failure Mode Effects Analysis (DFMEA) may be used if one is available. The list of functions needs to be documented for the following steps:
2. Prioritize all product/system functions. Classify the functions as essential, critical path, or secondary. Functions may include issues like safety, government regulations, or serious product failures (like a walk home failure in the auto industry) are examples of essential functions.
3. List the criteria (or limits) for each function.
The criteria will be different depending upon the product you are working on. Some examples of criteria are a max limit, a min clearance between two parts, an eccentricity, a noise level, an output torque, etc. The list of criteria needs to be documented for use in determining geometric symbol types and tolerance values.
4. Create a matrix of function vs. component(s).
The function vs. component matrix shows which components are used to perform each function. This ensures that all functions related to a component will be considered when the component is being toleranced. The matrix needs to be documented for use in the component tolerancing process.

The component tolerancing steps are:
1. Identify the component mounting features as datum features. (Unless the part is not oriented or located by its mounting features.)
This includes specifying a relationship between the datum features. A form tolerance on the primary datum feature, an orientation tolerance, and location tolerance if appropriate, on the secondary and tertiary datum features as necessary.

ETI Staff

President
Alex Krulikowski

Product Development
Jamy Krulikowski

Programming
Cindi Rowe
Jim Todd
Nathaniel Kraft

Sales
Kathy Darfler
Nancy Davis

Website/Internet Svcs.
Brandon Billings

Artist/Network Admin.
Matthew Pride

Writer/Editor
Katherine Palmer

Order Processing
Tina White
Gary Walls

Receptionist
Lindsay Carlington

www.etinews.com

2. For each product/system essential/critical path function that is related to the component: a. Identify the component features or features of size involved in performing the function.
b. Specify the dimensional relationships (controls for location, orientation, form) necessary to protect the function.
Specify the location and orientation controls for the feature or feature of size with respect to its related functions. This may involve establishing additional datum (performing) features. Repeat this step until all essential/critical path functions are addressed.

3. For each product/system secondary function that is related to the component:
a. Identify the component features or features of size involved in performing the function.
b. Specify the dimensional relationships (controls for location, orientation, form) necessary to protect the function.
Specify the location and orientation controls for the feature or feature of size with respect to its related functions. Modifiers should also be assigned based on the type of relationship involved. This may involve establishing additional datum features. Repeat this step until all secondary functions are addressed.

4. For each feature of size, determine the maximum amount of size variation allowed without jeopardizing the system functions.
Specify the size variation allowed for the feature of size with respect to its related system functions. This may involve calculations, design guidelines, or tolerance analysis. Repeat this step until all features of size are addressed.

5. For all remaining component features that are untoleranced, define their dimensional relationship back to the mounting datum features.
These are what many people consider the non-functional (or appearance) features. (They could also include gussets and ribs for strength, material savers [pockets] in plastic, weight reduction holes, etc.) These can be defined with geometric controls or covered with general tolerances. Modifiers should also be assigned based on the type of relationship involved. Usually, they are related to the mounting datums. In some instances, the non-functional features may be justification to define some of these features relative to a functional datum reference frame.

6. Determine the maximum tolerance value for each dimensional relationship.
The techniques to determine tolerance values are covered in part three of this article. For now there are a few thoughts I will share with you. The tolerance value is an important aspect of the dimensional relationship. The tolerance value affects the ability to function as well as the cost to produce the part. In order to generate savings, specify large tolerances and use modifiers (as long as the system function is not jeopardized) so that manufacturing will enjoy more flexibility.

7. Check the dimensioning scheme to ensure robustness.
Dimensioning a part is a very complex task. One cannot only rely on using a process without using common sense and evaluating the results for potential problems. The last step is a check to help catch problems.

· Each datum reference frame has an interrelationship between the datum features specified
· Each datum reference frame has a relationship to the mounting datum reference frame
· Each part feature is defined for size, location, orientation, and form, as appropriate
· Each part feature is not dimensioned more than once

The SACD method goes a long way in systemizing the dimensioning process, but there are some cautions one must practice:

· The method requires the users to have a good understanding of GD&T
· The user must faithfully follow the process to obtain legitimate results
· Be careful that each control only affects the function involved and does not add any unnecessary restrictions to the components
· Be sure to complete the system analysis before doing the component tolerancing
· There are a few areas where additional steps are needed. Some examples are:

Conflicts will arise when a part feature is involved in multiple functions
- A part feature may end up with more than one tolerance that overlaps or contradicts

These conditions are addressed in the full explanation of SACD.

There are forms to guide the user through the SACD process. The system analysis portion of the process is documented on forms and the component tolerancing portion of the process is documented on the engineering drawing. This article introduces the process; a full explanation with examples and additional topics is going to be included in my new book on the system approach to component design. (Note: I warned you that you would be left wanting more.)

Need for a Common Tolerancing Method

As you have read, there are many ways to establish dimensioning relationships on drawings -The Great Dimensioning Controversy. Most of them favor a departmental viewpoint and often hurt the organization and ultimately the customer. What is used in industry today is not very efficient and causes great waste in many organizations. That's why I believe they are in Tolerancing Hell. The SACD method is a better way. We must be willing to work to master it.

I will close by summarizing the Tao Tolerancing Principles (TTPs) covered in this part of the article. (TTPs 1-4 are covered in Part I of the article.)

TTP # 5 - Tolerances should be optimized, not compromised.

TTP # 6 - When you compromise the customer goals, the customer never wins.

TTP # 7 - You must understand the role of a component in the system before you can tolerance its features.

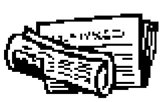
TTP # 8 - When a tolerance is compromised, it is only one step better than taking the path of least resistance.

TTP # 9 - What is best for the system, is best for the components.

Next Issue: Part 3 - Where Tolerances Come From. In this part, the topics covered will include: common ways tolerance values are established, how tolerances affect costs, and how to optimize tolerance values.

We welcome your feedback. Send comments about this article to ETImailbag. Your opinions will be posted in the next issue.

Back to top



Standards in the News

ETImail's Standards in the News *takes a look at real-life issues involving standards. This month: scientists and engineers work together to save lives.*

USGS science for a changing world

Excerpts from USGS website.

SAVING LIVES THROUGH BETTER DESIGN STANDARDS

Over the past 25 years, scientists have put together a more complete picture of how the ground shakes during earthquakes. They have learned that shaking near the source of earthquakes is far more severe than once thought and that soft ground shakes more strongly than hard rock. This knowledge has enabled engineers to improve design standards so that structures are better able to survive strong earthquakes.

Full story

Excerpt from, "Reducing Earthquake Losses Throughout the United States" by Mehmet Celebi, Paul A. Spudich, Robert A. Page, and Peter H. Stauffer on the U.S. Geological Survey, Earthquake Hazards Program website.

Back to top

The ETI Mailbag

The newsletter is very helpful; however, when I print it on a laser printer, everything on the right is truncated. Changing printer properties has no effect. As it is, I have to save it as a Word document in order to get all the text. Any suggestions?

Richard R. Squires

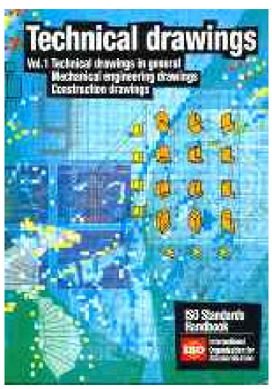
Glad you find ETImail helpful. We have had several requests for a printable version. We have now made ETInews available as a pdf file. This month, we have also included a printable chart. We are working to make the archives printable, and past issues should be ready within the month.

ETI appreciates your questions and comments.
Send your GD&T questions to: ETImailbag.

Back to top

Alex's Tech Tip

From teaching ideas to new products that will assist you in training or on the job, the ETImail Tech Tip will keep you informed about new technology and ideas. This month's Tech Tip: An affordable ISO technical drawings book that makes a great resource.



DRAWING BOOK A 'MUST HAVE" FOR STANDARDS PUNDITS
This month I'm passing along a recommendation for a fantastic, and very overlooked book. *Technical Drawings, Vol 1* is a valuable resource that contains hundreds of drawings based on ISO standards. The technical drawings section contains over 25 drawings, with another 25+ drawings in the mechanical drawings section.

Affordable and Useful
The cost of the book is only $185. When compared to the $30-$40 dollars you would pay for a copy of *one standard*, the bargain this book provides is readily apparent. Even companies who use the ASME Standard should have this excellent reference on hand for the many times you may be confronted with ISO drawings.

Technical Drawings, Volume I includes:

- Full text and illustrations for each of the ISO Standards
- Subject index of the drawings
- Table of contents with standard numbers and descriptions of each
- 784 pages

Click on the graphic for a look at the table of contents.

GLOBAL ENGINEERING DOCUMENTS™

The book is in an obscure location on the Global Engineering Documents website, so I have provided an exact link to it here: *Technical Drawings, Volume I: Technical Drawings in General - Mechanical Engineering Drawings - Construction Drawings*

At only $185 dollars, this isn't a bargain you can afford to miss.

If you know about a new tech tool or an innovative idea that would aid our readers, please write us: ETImailbag.

Back to top

ETImail Feedback

Have comments about anything you've read in ETImail? ETI will post your comments here and provide a forum for more discussion about GD&T topics.

Comments from South America:
Thank you very much and congratulations on a very, very interesting newsletter!
Curt C. Benoit
Capacitacion y Asesoria en Sistemas, S.A.

ETI would like to hear from you. If you have an opinion about any ETImail article or feature, please write to our ETImailbag.

Back to top