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THE FUTURE

Chapter

26

The Future

Introduction

I have asked several recognized experts in the field of dimensioning and tolerancing to assess what they think the future holds in the area of dimensioning and tolerancing. The opinions below represent the voices of corporate management, practitioners, authors, and college professors. They represent many years of study, training and practice. These voices, along with the ones you have already heard from in this book (see section 5.17, The Future of GD&T), have expanded our horizons and broadened our understanding of a field once narrowly interpreted and dismally misunderstood.

I thank the contributors for their wisdom and insight. I look forward to seeing how these predictions unfold.

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The Future of Dimensional Management

Dimensional management as a methodology will continue to gain in acceptance with the more sophisticated companies, where high volume and high complexity exist in the product lines. The concept of dimensional management will be of interest in other types of companies where low volume and low complexity exists, but the cost of implementation in terms of training and process change will be the major barrier.

The Future of Geometric Dimensioning and Tolerancing (GD&T)

GD&T will continue to gain acceptance. The standard(s) will need to continue to evolve to (1) eliminate ambiguity, (2) improve assembly level tolerance definitions, and (3) be further consolidated to simplify the concepts for more practical usage.

The Future of Standards

Standards in the area of geometric definitions, like STEP *(STandard for the Exchange of Product)*, are critical to the long-term interoperability required by companies as they migrate across computer aided design systems, and further integrate with supplier base and customers. There will continue to be emphasis on STEP like compliance by product developers and CAD/CAE *(Computer Aided Design/Computer Aided Manufacturing)* tools providers, to allow for flexibility and ease of use.

The Future of Tolerancing in Academics

More universities are already developing courses and research expertise in the area of tolerancing. Better alliances between industry and academia will need to be forged, like ADCATS *(Association for the Development for Computer-Aided Tolerancing Systems)* at BYU *(Brigham Young University)*, to guarantee the transfer of research to the industry. If the research does not turn into easy-to-adopt concepts, methods and technologies, then the interest by industry in supporting academia will wain.

The Future of Tolerancing in Business

As Six Sigma type initiatives continue to broaden and become the critical differentiator in many companies, tolerance analysis will elevate to the same level of importance as reliability and warranty analysis for all companies. As ease of use continues to improve, the adoption of tolerance optimization techniques will proliferate in all areas of system design.

The Future of Software Tools

Software tools will go through a consolidation process whereby the basic analysis is a natural part of the design capture process. Requirements flowdown, surface-based modeling and analysis, and part producibility will become natural to the engineer, as the software tools providers continue to bury the process of tolerance optimization continuously in the design through manufacture process. Basically, ease of use will dominate the tools suppliers agenda until the tolerancing process is virtually undetectable.

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Future of Tolerance Analysis

It is a pleasure to address the question: "What is the future of tolerance analysis?" It is a subject about which I have strong feelings. I first began teaching a course in Design for Manufacture after returning from two summers working for John Deere in 1980. Two gray-haired engineers there, who were brothers, one a designer and the other a manufacturing engineer, persuaded me that mechanical engineers should include manufacturing considerations in their designs. They spent a lot of time with me, "filling in the gaps in my education."

I began to see that tolerance analysis was the vehicle to bring design and manufacturing together. Using a common mathematical model that combines the performance requirements of the designer with the process requirements of the manufacturer provides a quantitative tool for estimating the effects each has upon the other. It truly promotes the concept of Concurrent Engineering.

At last, I can honestly say the tools are here, ready to earn a place alongside other standard CAD applications, such as kinematics, dynamics, vibrations, and finite element analysis (FEA). CAD-based tolerancing is quite sophisticated and advanced for a new CAD/CAM/CAE *(Computer Aided Design/ Computer Aided Manufacturing/Computer Aided Engineering)* tool. It had to be. No one today will accept an analysis tool that is not graphical and integrated with CAD.

Major Hurdles

As I see it, there are two major hurdles that must be overcome before tolerance analysis can succeed in becoming an enterprise tool for reducing cost and improving product performance:

1. Management acceptance.

It is not enough for a manager to see a new tool demonstrated at a trade show and buy it for his engineers. He must determine exactly where it fits in the enterprise. What problems will it solve for us? Who will be responsible for its implementation? How much will it cost to implement? Who will champion its adoption? How can we tell if we are using it effectively? How can we tell if it has saved us money?

Sometimes a change-agent within the ranks will discover a new tool and champion its adoption. But, CAD-based tolerance analysis will never reach its full potential as a product development tool until it has high-level management support, with sufficient resources and talent to make success possible.

2. Education and training.

As with other quality improvement programs, everyone involved must be educated about the role that tolerance analysis will play in the product development cycle and its expected benefits. Management, design, production—all must catch the vision.

The most challenging aspect is the fact that there is no established user base, no established curriculum, and there are no established procedures to guide us in implementing this new tool. It is much easier for a company to begin using an established CAD application, such as finite element analysis. There are many successful examples they can emulate. But tolerance analysis is still in its infancy.

The procedures for performing a finite element analysis are well established. There are many published examples. Structural analysis departments are found in most big companies. You can hire an experienced person to help set up a program in your company. But, this is not yet true for tolerance analysis.

You can’t even hire the capability you need fresh out of school, because tolerance analysis is not found in the curriculum of our engineering and technology schools. Will it be there eventually? It is hard to say. The curriculum of our schools is under constant pressure. Most schools have reduced the number of hours required for graduation, while increasing the nontechnical requirements. You can’t push tolerance analysis in, without pushing something else out.

For the time being, industry must expect to shoulder the burden of building the expertise they need within their own ranks. Training seminars and consultants will be needed to assist in this effort.

Unresolved Issues

Among the principal issues that must be resolved before CAD-based tolerance analysis is widely adopted:

1. The relationship to GD&T must be resolved.

There are many misconceptions about the application of GD&T standards to assembly tolerance analysis. How do MMC or RFS apply to a tolerance stackup? How about bonus tolerances? Are geometric variations applied differently in a statistical analysis versus worst case? If a form tolerance is applied to a feature of size, should two variation sources be included in the tolerance stackup? Do the size variations include the surface variations, or do they represent two independent sources of variation?

Most of the misconceptions arise from a lack of understanding of the fundamental principles upon which the GD&T standards and assembly tolerance analysis are based. We also need to get a clear concept of the difference between a specified tolerance and a measured or predicted variation.

2. New standards for assembly variation are needed.

There are no standards for computing tolerance stackup and variation propagation in assemblies. ASME Y14.5 has only recently acknowledged the existence of statistical stackup analysis. How it is to be done is still open-ended. This writer strongly feels that there should be a new set of symbols to differentiate an assembly tolerance limit involving multiple parts and a component tolerance limit applied to a single part.

3. Better data on process variations are needed.

The assembly variations predicted by tolerance analysis are only as accurate as the process variation data entered into the analysis model. However, there is very little published data describing process variations and the cost associated with specified tolerance limits. If you wait until the parts are made, so measured variations can be used in the model, you will lose one of the major benefits of tolerance analysis. In the design stage of a new product, tolerance analysis serves as a *virtual prototype* for predicting the effects of manufacturing variations before the parts are made. To fully realize this benefit, we simply must have an extensive database, which characterizes process variations over a wide range of conditions and materials.

4. Realistic expectations.

Over the years I have worked to involve industries and CAD vendors in the development of CAD-based tolerancing tools. A number of companies have given enthusiastic support. I have, however, been turned away by several companies who have said in effect: “Come back when you have a finished product.” Others seem to be waiting for “push-button tolerance analysis” that will require no understanding of variation and no decision-making skills.

A state-of-the-art CAD tool cannot be developed without substantial resources and talent. It needs broad support from the CAD vendors and the end-users in industry. CAD systems will require basic changes in data structure to accommodate variation definitions. CAD vendors must adopt standard user interface tools and allow third-party access to possibly proprietary internal representations.

Industry will need to take a more active role in guiding the CAD application development and thoroughly testing the resulting software products. Industry must also develop an infrastructure for absorbing and implementing CAD-based tools into their product life cycle. Until industries learn how to apply tolerance analysis to their own enterprises, they will not be able to effectively influence its development.

Research Opportunities

Numerous opportunities exist in tolerancing research that will increase the usefulness of tolerance applications and expand their influence. They include:

1. Post-processing

Existing CAD applications, such as FEA and dynamics, have well-developed post-processing capabilities for presenting the results of analyses. Enormous quantities of numerical data are condensed into color-coded 3-dimensional contour plots, amplified deflections or dynamic animations. Similar capabilities are needed to complete the new tolerance analysis CAD tools.

2. Process capability database

This is as important to tolerance analysis as a material properties database is to FEA.

3. Early design

How early can tolerance analysis be brought into the design process? If we could evaluate the manufacturability of design alternatives at the conceptual or systems design level, significant development cost savings could be realized.

4. Flexible assemblies

Current tolerance analysis methods only treat assemblies of rigid parts. Many assemblies include flexible parts of sheet metal or plastic, which are subject to warping or distortion in addition to dimensional variation. Assembly forces are required, which can cause residual stress and distortion. By combining finite element analysis with statistical tolerance analysis, the range of stress and distortion can be estimated statistically and compared to design limits.

The Future of Tolerance Analysis Applications

As I contemplate the future of tolerance analysis, I have a vision. My vision is very optimistic. I see CAD-based tolerancing tools becoming the next "must have" CAD application. The tools will soon become available on all leading CAD platforms. There might even be some minor players who exploit a niche market by offering tolerancing tools before the major players can overcome their internal inertia. I just hope that this new tool will be technology-driven before it is market-driven

In my vision, I see a rapid expansion of training programs and short courses to fill the needs of a growing user base. An increasing number of success stories will appear in publications and corporate news reports. Established procedures will emerge. Companies will compete for the experienced practitioners. Experts will set up shop as consultants.

Skilled users will be found among designers and manufacturing personnel, who will find themselves talking to one another more frequently in normal voices about variation, quality and performance issues. New departments and organizations will emerge in which both design and manufacturing are represented, working as a team.

As the final scene of my vision closes, I see an engineering designer, a manufacturing engineer, and a manager walking into a giant sunset, arm-in-arm, ready to compete in the world marketplace.

Perhaps it was only a dream after all. But, it could happen if industry and CAD vendors catch the vision of the tremendous opportunities and benefits that CAD-based tolerancing offers to those who pursue it vigorously.

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Barriers to the Future Success of Geometric Dimensioning and Tolerancing

The future success of GD&T will require many changes to the way many of us conduct our business. Barriers continue to exist that prevent GD&T from realizing its full potential. It continues to be seen as a "drafting standard." When applied properly at the right time, GD&T has a tremendous impact on cost, quality and time to market. Of all the tools available to a concurrent engineering team, GD&T is one of the most powerful. Despite this, proper use of GD&T continues to lag. The following is a list of areas where opportunities still exist to remove barriers and allow GD&T to realize its full potential. In all of these areas, there is a persistent need for individuals to become knowledgeable of GD&T and its benefits.

Management's Role - As more companies go about their downsizing or right sizing activities, the standards group is often the first to go. This results in corporate standards not being maintained. In addition, sponsorship of committee members to the national and international standards committees is not being supported. Without this representation on standards committees, companies no longer have input to the standards writing activities and will have to accept new and revised standards that may not work well for their particular industry. Without someone overseeing standards selection, use and training within a company, CAD files and drawings are generated that are unclear and destine projects to high scrap, rework, "use *as is* decisions," engineering changes, and increased cycle times.

Nearly all companies require that a design review be conducted by the concurrent engineering team. To avoid unnecessary drawing activity and expensive changes to drawings and CAD models, drawing "previews" rather than "reviews" should be held. Conducting a "review" is too late. Someone has already spent considerable time detailing the part drawing or file. Management should require that one or more design "previews" be held at the model stage. A preview gives the concurrent engineering team the chance to make suggestions and changes regarding the part geometry, datums, dimensioning and tolerancing. Changes resulting from a "review" require modifying the model and the GD&T causing added expense and increased total cycle time. Changes are an integral part of the iterative design process, but they must occur upstream.

Design Engineering - Since most engineers graduate not being able to read an engineering drawing, engineers must make certain they know what they are signing. They must seek out quality training in GD&T. They must also make the correct application of GD&T to their designs a priority. Since the output from their area (namely the CAD file and/or drawing) will drive the entire process, proper application of tolerancing is imperative. Also, they must seek manufacturing variation data and understand the impact of their specifications on the manufacturing process capability, product quality, and overall cost. Geometric tolerance is the numerator of the Cp and Cpk calculations.

Quality - There is a lot of inspection equipment and software available today that does not comply with the national and international standards. All capital investments should be for equipment that is compatible with the requirements of the design. Often equipment and software is justified by a return on investment. The ROI *(return on investment)* looks better if it can be argued that more parts may be inspected per hour and minimal or no fixtures will be required. This usually leads to greater uncertainty. When selecting equipment and software, make certain it complies with the Y14.5 and Y14.5.1 Standards. Expediency should not be at the expense of quality.

Production - GD&T does not dictate how parts are to be produced. In fact, process information should not be on drawings unless a particular process is required to assure that the part will function properly. Manufacturing may, however, make decisions about the order of operations and how in-process inspection may be applied to assure production of conforming parts. Also, when production understands and can distinguish between size, form, orientation, and location, it is easier to isolate sources of variation within the process. A thorough knowledge of GD&T can greatly assist with process variation reduction.

Software Manufacturers - There is a tremendous need for software that will automate the process of tolerance allocation and analysis. For over a decade we have been able to perform circuit analysis of electrical devices. We need a mechanical equivalent that is accurate, efficient, conforms to the Y14.5 Standard and most of all is user friendly. In addition, quality computer-based training (CBT) is needed in the areas of application, inspection, and tolerance analysis. Software developers—listen to the voice of your customer and everyone will win.

The Standards Committee - The Y14.5 Standard is a wonderful tool; however, proper use seems to elude most designers. Over the past fifty years as the need to express more complex design requirements has emerged, many concepts and symbols have been added. Many of these new concepts may obsolete or overlap earlier controls. The committee needs to consider streamlining the use of symbols to make the standard more user friendly with a shorter learning curve. In addition, the hierarchy of geometric controls needs to be emphasized to help designers understand the most efficient application of controls. To assure the Standards continued success, its users need to better understand application.

Seminar Leaders - Emphasis must be placed on the team building and communication aspects of GD&T. Too often GD&T is still being presented as a drafting standard. Although Y14.5 is a standard in engineering documentation, the language of GD&T has as much impact on the entire enterprise as Quality Function Deployment, Design for Assembly and Manufacturability, Total Quality and the other up-front tools in use today. Seminars should be filled with case studies, decision diagrams, solid models and other educational tools that help the students relate the concepts to their workplace. Whenever possible, the instructor should customize the training to the audience using their parts and prints. The support should not end once the course evaluations are collected. The instructor should be available for future questions and clarification of material that has been presented.

Academia - Engineering faculty need to learn what GD&T is all about. Although a few engineering colleges offer some education in GD&T, it is usually optional or a small part of a course in descriptive geometry or CAD. It is time to stop graduating engineers who cannot read the documents they are signing. Since many engineers do not understand GD&T, their analysis is usually based on nominal values. Rarely are parts engineered with all possible part variation taken into account. Engineering faculty needs to take responsibility for assuring that every mechanical, manufacturing, and quality engineer they graduate is capable of reading part drawings. GD&T should be integrated into the teaching of finite element analysis, design for assembly and other topics that deal with part geometry.

Manufacturing builds wealth for a nation. The one common thread throughout the entire manufacturing enterprise is the engineering drawing. If it is incorrect or incomplete, the entire operation will suffer. Communication is the key, and the key to communication on parts drawings is GD&T.

Paul Drake

The Future of Tolerancing

Historically, the method to communicate the allowable part feature variation from design to manufacturing has been with tolerances. As the design world migrates form using paper drawings to CAD models the role of tolerances will change. As manufacturing migrates toward statistical process control, the role of tolerances may change dramatically

The traditional approach to mechanical tolerancing follows what I call a *top down* process where requirements are “flowed down” from the customer to the manufacturing shop floor. In my business, this classical scenario looks something like this:

- The customer flows down requirements in the form of design specifications.
- A systems engineer allocates the customer’s requirements across the various “disciplines” in the form of mechanical design requirements, electrical design requirements, software requirements, etc.

- The mechanical design requirements flow down to subassemblies within the mechanical design.
- The mechanical subassembly requirements flow down to mechanical piece parts within the subassembly.
- The piece part requirements are flow down to manufacturing shops. One means of flowing down the subassembly requirements is with dimensional and tolerancing requirements on each piecepart.

In this process, the mechanical designer communicates to the manufacturing shops "this is what I need" to meet the mechanical performance requirements. A *significant drawback* to this process is that we have no way of knowing how well the manufacturing process(es) can build parts that meet these tolerances. As customer requirements become more difficult to achieve, there may not be enough "tolerance" available to manufacture cost-effective parts.

Historically, mechanical tolerances have been functionally driven. In general, mechanical design engineers are penalized if designs don't function, so they place a lot of emphasis on making sure their design works. As we know, the winning companies of the future will be the ones who can minimize the cost, while tolerancing systems to meet customer requirements.

Now the question arises, "How do we do this?" I propose that one method is to treat manufacturing requirements as *inputs to* the design process, instead of *outputs of* the design process. In the classical scenario we ask, "How well can we manufacture parts to meet system requirements." In this scenario we ask, how well can we meet system requirements, if we know the capabilities of the manufacturing processes.

In this scenario,

- The manufacturing requirements are flowed up to the pieceparts. One means of doing this is by incorporating manufacturing process capabilities into the design process. If we know the variation of the processes used to manufacture parts, we can calculate the expected variation of features on a part.
- The piecepart feature variations are inputs to the subassembly. If we know the expected variation of each feature on a part, we can mathematically calculate the expected variation of the subassembly.
- If we know the expected variation of a subassembly, we can mathematically calculate the variation of mechanical systems.
- If we know the expected variation of mechanical systems, we can mathematically calculate the impact this variation has on customer requirements. If we understand variation, we can assess the risk (probability) of meeting the customer's requirements.

I call this a *bottom up* process. In the traditional design process, we ask: "What machines do we need to use to manufacture parts that will function?" In the process described above, we ask ourselves: "If we manufacture parts using certain machines, how well will they function? The key benefit of this method is that we can mathematically calculate how well the parts will perform an intended design function. We can capture design risk with metrics such as dpmo *(defects per million opportunities)*, probability of nonconformance, or "sigma."

This is a radically different way of designing systems. One thing that is unique is that this process doesn't use tolerances to drive manufacturing; it uses manufacturing machine capabilities to drive design. If we look at how we define quality in terms of Cp, this is exactly what we are measuring. The generic definition of Cp is "customer requirements divided by manufacturing process capabilities." (See Chapters 8 and 10.) Cp is a measure of the balance that we try to achieve between design and manufacturing. In order to increase Cp, we have two options: We can increase the (customer) requirements, or we can use better manufacturing processes.

Historically, this is what we have done. If we can't build *functional* parts with a certain manufacturing process, we go to a process that can hold a *tighter tolerance*. When we move from a milling process to a boring process, we are moving from a process that is less capable to one that is more capable. In general, if we use the best machines we have and we still cannot build *good* parts, we go to the customer and ask for relief on the requirements. Cp is a mathematical measure of what I just described.

This new product design process is difficult for many to understand because it is not tolerance driven; nor is it driven by the functionality of the design. I believe the following are barriers that keep us from adopting the second process:

- It is extremely difficult to change (product design) processes, especially ones that have been around for many years.
- How do I communicate (to manufacturing) the process capability that I used in my variation analysis? The statistical tolerancing symbol in ASME Y14.5 (see Chapter 11) is the first step in making this happen.
- Since there are no tolerances, we don't know what to *inspect*. The key to making this product design process work is to inspect manufacturing processes, not parts. The successful companies in the future will figure out how to verify statistical tolerancing requirements on the manufacturing floor.
- The new product design process works well, as long as the parts, assemblies, and systems function well. If we have problems, it's difficult to track down the culprit.
- Since this process is not tolerance driven, most standards do not support it.
- The new product design process uses statistical techniques (described in Chapters 11, 12, and 13). The language to communicate these requirements from design to manufacturing is not available. We try to force GD&T to do this with the statistical tolerancing symbol, but it doesn't work well. We need *another language* that is manufacturing (statistically) driven to make this process work.

As we enter the 21st century and tools become more sophisticated, we will be able to better support the *bottom up* method. The winning companies will be the ones who figure out how to make this process work. The winning companies of the future will be the ones who can eliminate the most waste (nonvalue-added activity) from the process. Imagine if we could build systems without using tolerances. Imagine how much time we could save if we went directly from a nominal design (CAD database without tolerances) directly to the shop floor. Imagine if we could build systems that meet our customers' needs without inspecting parts. The challenge for the winning companies of the next century is to figure out how to do this.

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The Future of Global Standards and Business Perspective

Worldwide harmonization of standards development initiatives must be a key focus. The world must work toward the development and acceptance of a single set of technically valid standards to eliminate global confusion. Throughout the world, national and industrial standards groups are developing technical standards in a shell. Meaning, in many cases they are not aware of past efforts or existing efforts on the same development topic. This duplication of efforts is burdensome due to lack of focus on understanding the baseline development as well as it postpones the advancement of related technical activities.

Communication or lack of worldwide communication is one of the reasons for this duplication of efforts. National and Industrial standards developers must put in place strategic objectives to work together to ensure common needs are accomplished with the least amount of burden that is optimization of resources to accomplish objectives at the least amount of total expense.

Funding of standards initiatives is a key problem within the US as well as other countries. We need a single standards initiative within the US that everyone throughout the US can count on and I believe we need the help of the US government to accomplish this. We also need to ensure we have key resources in place driving and managing the development initiatives as well as heading up the communication and integration of these development initiatives. These communication initiatives should have as its key focus the benefits of each standard to industry as well as recommended paths for the phase-out of existing standards to be obsolete.

The Future of Dimensioning & Tolerancing Standards

Dimensioning and Tolerancing is in a state of flux. The world cannot afford multiple systems that are all incomplete and we must drive toward a system of engineering precision in the form of advanced and simplified tolerancing expression. Product development has been on a fast track of miniaturization for years and parallel to this is the aggressive requirement of tolerance truncation. These two drivers alone are forcing a much greater level of precision then ever recognized or perceived in the past.

Simplification of our global system must be a focus item for standards developers. Linear tolerancing strategies are ambiguous and clearly a duplicate dimensioning and tolerancing methodology from its parallel and less ambiguous system of Geometric Dimensioning and Tolerancing. The complete system requires aggressive development as well as simplification. Eliminating or de-emphasizing the duplicate, more ambiguous system of linear tolerancing would be a positive start on this simplification path. A second step would be in the reduction of symbology that reflects duplicate representation of tolerance boundaries. If the full scope of boundary representation can truly be represented by few geometric symbols, as I predict, this would truly be a form of simplification due to less for the user to learn and it would be an intuitive language. Additional benefits would be less computer variations at the CAD level, reduced training, better understanding of requirements, less mathematical representations for the accumulative symbols, and less algorithms required for the analysis of each geometry class.

Significant development efforts are required to close existing gaps in the arena of tolerance expression to ensure we have a robust system that is unambiguous. Development of “extension principles” in the following areas must be key focus items to eliminate the existing gaps.

- Separation of surface roughness and waviness parameters from form tolerances
- Definitions and flexibility’s related to datums
- Complex geometries and tolerance boundaries
- Statistical analysis of geometric tolerances
- Assembly level tolerancing
- Statistical tolerancing
- Tolerance analysis
- 3-D modeling

The current state of ISO *(International Organization for Standardization)* initiatives related to dimensioning and tolerancing is in a state of turmoil. Key individuals involved with the development lack the core technical understanding and sensitivity of past and current dimensioning and tolerancing practices and are driving change which will clearly have a negative impact on industry throughout the world.

An incorrect perception exists throughout the world: in that it is believed that for a standard to be considered international, it must be labeled ISO. This is clearly incorrect and we must change this perception. ASME Y14.5 is the most broadly used dimensioning and tolerancing standard in the world today and will clearly continue to be the most solid basis for industrial use. Development initiatives with the Y14.5 committee, as well as other related committees such as ASME Y14.5.1, Y14.41, and others, are on a much more aggressive development path to achieve a sound basis to meet worldwide industrial needs. Our challenge within the US is to establish strategic initiatives that will ensure effective integration of these documented initiatives throughout the world.

The Future of Metrology Standards

One of the most strategic initiatives being kicked off within the industrial metrology community is the development and integration of advanced analytical tools used to better understand the uncertainty related to task specific measurements. Understanding which error sources contribute to task specific measurement uncertainty and understanding the analytical methodology is the key to the advancement of understanding measurement uncertainty within industrial applications. For years, national physical laboratories such as NIST *(National Institute of Standards and Technology)* have been using such tools for a number of years. The basis for this and the tool developed to ensure standardization across all laboratories is the "**G**uide to the Expression of **U**ncertainty in **M**easurement," commonly referred to as GUM.

The industrial challenge we now face is in the development of tools (Technical Reports, Standards, and user-friendly guides) to help industry effectively integrate these advanced tools and understand the magnitude of global benefits in doing so. The primary benefit is in having the level of analytical tools required to confidently ensure a controlled understanding of measurement uncertainty when determining conformance to requirements of product produced and shipped.

ASME subcommittee B89.7 has been recently established with the mission to support US manufacturing industry in a smooth, economical transition to the requirement of using measurement uncertainty. The motivation for the establishment of B89.7 and for its mission and scope of work lies in the growing importance of measurement uncertainty in international trade. Over the next 3 to 10 years, critical development and integration of these tools will be a critical basis for advancements in the metrology community and will be recognized as a sound tool by manufacturing and design engineering groups that they will grow to count on to ensure needs are being met with confidence.

Industry will find these advanced analytical tools will also be beneficial in understanding process uncertainty as well as design uncertainty. In all the task specific uncertainty analysis I have been involved with, I find it important to note that there has been more uncertainty related to the engineering requirement (tolerance specification) than there is in the delta of the targeted uncertainty and the actual uncertainty derived. It's important to understand the meaning of this statement so it is not taken out of context. I'm stating that the tolerance defined for any of the features or feature characteristics on an engineering drawing is or should be the key parameter with the greatest opportunity to scrutinize which will yield a benefit. There is more opportunity analytically to evaluate the possibility of tolerance reallocation or new tolerance expression, which will yield greater allowable tolerance to the feature or feature characteristic in question. It is critical these tools are used to direct all advanced development initiatives in a manufacturing environment.

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The Future of Dimensional Management

I see that the concept of dimensional management will become more important in the future. Dimensional management incorporates form, fit, function, inspection, assembly, manufacturing, and variation into the tolerancing scheme. We are still in the early stages of understanding tolerancing. Dimensional management is a living process and is constantly evolving. As dimensional management becomes more important, it will also become more complicated.

There will be another division of labor. I believe that successful companies will develop a separate group of tolerancing engineers who are experts in tolerancing. In fact, some companies are doing it now. These tolerancing engineers understand it all. They specialize in tolerance analysis and applying tolerances to parts and assemblies. If we pay attention to history, we have already seen this progression. In the beginning, engineers did everything. They designed the parts, drew the prints, did stress and fit up calculations, ran the prints, machined the parts, inspected the parts and assembled the parts. This is too much for one engineer to do.

Tolerancing is becoming more complicated. We now realize that tolerances and part definition is much more complicated than we originally thought. The most important document we have in a company is our product drawing. Without a clear definition of our product we have nothing. We need experts that specialize in tolerancing.

When you think about it, the general population should know something about tolerancing but they do not need to know everything. In the future, CAD operators will draw the pictures of the parts and do general part design. Afterwards, tolerancing engineers will take the design and make it work dimensionally.

Manufacturing people must have a general understanding of tolerancing. The specialized manufacturing tolerancing engineer will set up all the fixtures and processes and machines to meet the GD&T specifications. The manufacturing personnel will operate the machines based on the tooling set up by the manufacturing engineers. They will work to the process plan developed by the manufacturing engineer.

Inspectors don’t have to understand it all either. There will be special quality tolerancing engineers to do this. They will define the gages and the inspection procedures to follow to meet geometric requirements. The inspection personnel will work the dimensional measurement plan that is developed by the tolerancing engineer. The general population will still have to have a basic understanding of tolerancing, but the intricacies of the tolerancing stackups and analysis will be done by the tolerancing engineers.

The Future of Tolerancing in Academics

Tolerancing must be part of basic education. It must start at the high school and trade school level. More people are becoming more serious about geometric tolerancing. They used to apply the tolerancing because they were told to do it or it was the “in” thing. More colleges and university professors are becoming involved in tolerancing and looking at it from a higher level than in the past. This will help deploy tolerancing in the business environment, because businesses won’t have to spend the money they have invested in the past to develop this expertise.

The Future of GD&T

Geometric tolerancing will increasingly become more prevalent. Many companies are using a combination of plus/minus tolerancing and geometric tolerancing. More geometric tolerancing, primarily profile and positional tolerancing, will be used. Positional tolerancing locates features of size such as holes, slots, tabs, and pins. Profile tolerancing is used to locate nonfeatures of size such as surfaces. Plus/minus tolerances are used for the size of features. The location, form, and orientation of the features are done with geometric tolerances.

Tolerancing needs to be 3-dimensional (3-D). The parts are 3-dimensional, drawn in 3-D solids in CAD; the manufacturing process is 3-D; and the inspection process is 3-D using coordinate measuring machines. The old plus or minus system only gave us 2-D tolerancing. We need to think in 3-D. Everyone must understand that geometric tolerancing is the basic communication tool among engineers. Historically, people have used GD&T for the so-called "important features." I see geometric tolerancing not just for "important features" but for *all* features.

The Future of Software Tools

I see computers doing more tolerancing stacks. In the future, we will do more and more tolerancing within the solid model. Since tolerancing will be imbedded in the solid model, we will have a closer integration between inspection design (CAD), inspection CMMs *(coordinate measuring machines)* and manufacturing CNC *(computer numerical controlled)* machines. CMMs and inspection equipment will read the imbedded design specifications in the model. There will also be a database in the CAD systems to provide more integration of the manufacturing process information in the tolerancing. I anticipate a larger emphasis on reducing and understanding variation. This will promote more statistical tolerancing of parts.

The Future of Tolerancing Standards

Standards will become more important in the future, although I do not see a complete union between ISO and ANSI (ASME) standards any time in the near future. There are a lot of cultural and philosophical differences that must be worked out. International standardization will get closer but there will be no complete union for some time. It is important that ASME or ANSI standards keep up with the technology, as we may find a commercial computer software program becoming the de facto standard because it's easy and simple to use.

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The Future of Dimensioning and Tolerancing*

Changes are rapidly taking place in the field of dimensioning and tolerancing. A quick look at recent and ongoing changes will help to understand what the future is likely to hold.

The manufacturing world has started associating many terms with various aspects of this wide and complex field. Names such as Geometric Dimensioning and Tolerancing (GD&T) emerged as dimensioning and tolerancing became more sophisticated. It was as if the improvement in our comprehension of the subject and ability to more clearly define requirements somehow required a new name. Computer programs were developed to assist in the calculation of tolerances and to assess the assembly variation caused by applicable factors. The use of these tools for dimensioning and tolerancing was called dimensional management. Dimensional management expanded to include manufacturing process controls

*Reprinted by permission of Bruce A. Wilson in more progressive companies. Manufacturing process control was not always called dimensional management, but was sometimes made a separate initiative called variability reduction.

The variety of names used for various aspects of dimensioning and tolerancing were tied to company names, so each company that began a similar effort tried to come up with a unique name that identified the process. At least one major company has multiple groups working nearly identical efforts to implement improvements related to dimensioning and tolerancing along with the appropriate manufacturing controls. Internal power struggles result in different names used for the similar initiatives. The proliferation of names does not indicate progress or the number of advancing initiatives.

The point of the above description is that many names are being applied to doing the job of calculating and defining dimensions and tolerances for detail parts and assemblies. The associated manufacturing process controls are seeing the same proliferation of names for the process improvement methods. Names should not become an issue in determining how things improve, so the picture of the future that I will paint does not depend on the terminologies that are used for such a wide array of efforts in industry.

Chapter one of Design Dimensioning and Tolerancing states that dimensioning and tolerancing requirements are likely to become part of the CAD data file and no longer require a paper drawing to communicate those requirements. That prediction was first written in 1988. This prediction has to some extent taken place. Computer programs exist in 1999 that permit tolerances for a feature to be associated with an entity in a CAD file. However, the way in which the tolerance requirement is stored and associated with the entity is not yet standardized. This means the information is not as universally readable as a paper drawing that shows the tolerancing symbology.

At least three companies are hotly competing to achieve a superior tolerance application and analysis program. Many other companies are involved in efforts, but they may find the competition so fierce that they will not have the resources to stay in the race.

Progress has been rapid over the past few years. The first tolerance analysis programs did not operate within the CAD program. They were stand alone. Data was output from the CAD model to the analysis program and then the analysis completed. Any updates to the CAD model were made manually. It is likely that future development of computer programs will permit work within the CAD model (some currently claim this capability) and information from the analysis will be updated in the CAD model automatically.

One problem with the current analysis software has been the amount of effort to become proficient in its use. Inexperienced users can output results that look accurate but be filled with errors. Reviewers have less experience than the person who made the errors, so nobody catches the mistakes. Efforts are being made to make the software more user friendly, and this will reduce the learning curve.

Attempts to produce a software package that speeds up the modeling process are introducing risks that may be easily overlooked. The software is permitted to select points on surfaces that later get used for determining part locations in an assembly. The automated point selections are made on the basis of routines written in the computer program code. If the user does not understand how the software makes the point selections, then a needed decision to override the program might not be made. The result will be an inaccurate analysis.

Many problems exist and a few have been described above, but progress will be made and the problems overcome. The future will eventually include CAD systems and the associated manufacturing equipment that do not require any paper drawing. There probably will not even be a drawing in the CAD system. It is likely to contain only a 3-D model with all the requirements attached to part features in such a way that either humans or compatible machines can read the data.

Caution is recommended in using the emerging software tools to ensure they are properly used, and that any outputs are accurate. Many of the new products available today are very high quality, but the results obtained by inexperienced people can be extremely misleading. A well educated and experienced mind is still superior to the best available computer and software package.

Reference

1. Wilson, Bruce A. 1996. *Design Dimensioning and Tolerancing*. South Holland, Illinois: The Goodheart-Willcox Company, Inc.