AC 2008-903: TEACHING APPLIED MEASURING METHODS USING GD&T

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Teaching Applied Measuring Methods Using GD&T

Abstract

Products are generally specified using the American Society of Mechanical Engineers' 1994 standard Y 14.5M on Geometric Dimensioning and Tolerancing, commonly known as GD&T. Engineering technology graduates who work in design, or manufacturing, or quality, need to have expertise in the principles of measurement science and practical interpretation of GD&T-based product specifications.

A new course on metrology has been recently introduced in an engineering technology curriculum where students apply the GD&T theory in to practice by inspecting parts using these GD&T tolerance specifications.

The paper describes the highlights of metrology course and some of the experiments that students do to measure using GD&T methods. The paper also discusses the lessons learned from the students' performance in class and laboratory, and gives their feedback on the extent of achieving the proposed course outcomes.

Introduction

All manufactured products require an accurate and precise scale of measurement to check their conformance to specifications. Much of today's industry and technology relies on accurate measurement. Manufactured products are measured by instruments to check their conformance to specifications based on GD&T standards. This need is all the more important in the present global economy as measurement error causes false fails and false passes both of which are expensive.

Understanding the practical principles of measurement science using GD&T should be an important part of engineering technology education which helps to impart the hands-on aspect of the subject area.

There is a basic metrology course at the freshman/sophomore level that teaches principles of hands-on measurements using common instruments such as vernier calipers, different types of vernier micrometers, gage blocks, dial indicators, and CMMs (Coordinate Measuring Machines). It was decided to develop the new higher-level metrology course at the junior/senior level that would supplement the material covered in the basic course. Also, students learn the GD&T theory in their freshman/sophomore level from the point of view of draftsperson and designer, and in this new metrology course they apply the theory in understanding and making correct GD&T measurements.

In this course, students learn the types and causes of measurement errors, perform measurement setups using most of the geometric tolerances such as, size tolerance, flatness, straightness, circularity, parallelism, angularity, circular and total runouts, concentricity, and position tolerancing. They also learn the concepts of functional gage design for both soft and hard gages.

To learn the principles of metrology, students use the standard inspection equipment such as micrometers, indicators, surface plates, right-angle plates, precision parallels, gage blocks, and gage pins.

The Industrial Advisory Committee recommended to add metrology concepts in the ET curriculum. The industrial interest was driven primarily because companies have realized the tremendous benefits of understanding the basic principles of measurement without which it is impossible to implement six sigma.

The course covers areas of metrology such as, gage R&R, bias, linearity, measurement uncertainty, inspection of size, form and orientation tolerances using 1994 GD&T standard[1]. In the initial development phase of laboratory experiments, students perform six laboratory experiments in teams. These experiments are on: (1) measurement of size, (2) flatness, (3) straightness, (4) parallelism, (5) runout, and (6) position tolerances including bonus tolerances.

The course includes a written report and oral presentation of student projects showing application of the measurement principles and practices. The assignments, experiments, and project work together allow students to integrate and apply the course material, and obtain sufficient breadth and depth of knowledge. The next section describes the course structure, including some examples of assignments done by the students.

Course Structure

This course is a 3 credit-hour or contact-hour per week, 16 weeks long course. Metrology theory and principles are taught in the first part of the semester and then students work in teams to do the experiments. The course content and learning outcomes are given in Table 1. Each student writes a separate laboratory report using and comparing the data obtained by all the members in the team.

Table 1. Metrology Course Content and Learning Outcomes.

Course Learning Outcomes	
Process and Measurement variation	Circularity
Gage R & R	Parallelism
Bias, Linearity and Stability	Perpendicularity and Angularity
Measurement Uncertainty	Circular Runout
Errors in measurement	Total Runout
Inspecting size tolerances	Concentricity
Flatness	Position Tolerancing
Straightness	Functional Gage Design

There are few universities that teach metrology concepts, for example, Cornell University, Arizona State, North Carolina State, Farmingdale State University of New York, to name a few. In many of the other courses, the metrology concepts are taught along with quality control or quality assurance, or with manufacturing. With this approach, the need is met by combining metrology concepts of GD&T measurements with emphasis on MSA methods for gage R&R and measurement uncertainty.

Sample Assignments in Metrology

Some sample examples of work done by students as assignments are shown below. It gives a broad picture of learning that students go through in meeting some of TAC/ABET criteria requirements of use of ability to solve technical problems, use of math and statistics, application of technical skills learned in class. Some of the other books[2, 3] in this subject that have been found useful in GD&T measurement theory and applications are given in bibliography.

<u>On tolerance zones</u>: Before measurements can be taken, it is important to understand the type of applicable feature control frame. If flatness is to be measured, the symbol used in the feature control frame represents a surface. This implies the tolerance zone is defined as two parallel planes that are apart by the given flatness tolerance. The two types of straightness[1] that can be used are straightness of surface elements and straightness of axis, as shown in Figure 1. Again, the symbol used in the feature control frame indicates the tolerance zone within which the indicated edge or surface is to lie.

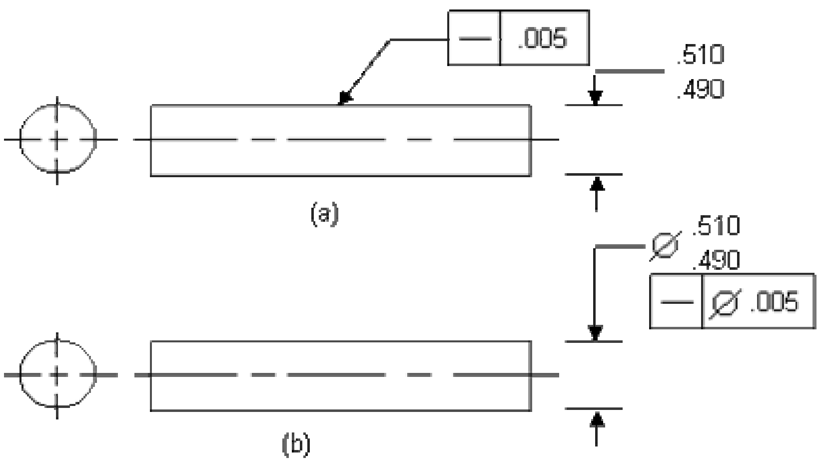

Figure 1. Straightness of (a) surface element, and (b) axis.

When tolerance is called out to at least one datum, the tolerance zone depends heavily on the type of datum and the controlled feature as is evident for parallelism[1] in Figure 2.

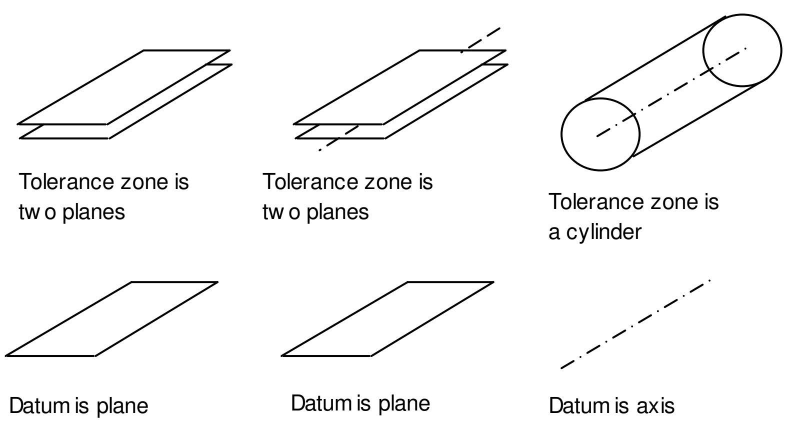

Figure 2. Parallelism tolerance zones.

On measuring size tolerances: It is important for the operator to understand that to properly and functionally inspect size tolerances both the boundaries at MMC (maximum material condition) and LMC (least material condition) should be inspected. Most measuring instruments such as, micrometers and calipers, cannot verify the maximum boundary of perfect form at MMC, and most g0/no-gages cannot verify the LMC boundary at any cross-section. Both types of gaging are required to measure size tolerances[1]. For cylindrical features as shown in Figure 3, the MMC boundary of perfect form can be simulated by a ring gage at MMC size. The undersize condition can be checked using a micrometer.

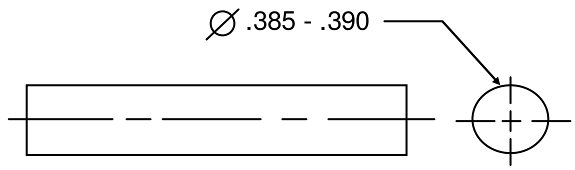

Figure 3. MMC boundary is the largest size.

On sine and cosine errors: These two errors are of importance in understanding measurement principles. An example of cosine error[2] is shown in Figure 4. This error occurs when the indicator stem is not perpendicular to the axis of the measured part. A typical example given to students can be to determine the error or to determine the actual size of a workpiece given the data as: An indicating probe is at a 10 degree angle to the horizontal when set to 0 on a 2.000" gage block stack. It reads +.070" on a work piece. What is the actual size? This example uses the cosine function of trigonometry to determine the measurement error.

Figure 4. The concept of cosine error.

Similarly, the sine error that occurs when a part is not aligned perpendicular to the axis of the measuring standard.

On straightness: For measuring straightness of an axis as called out on a round shaft for example, the measurements need to be taken along a single line element at different lengths of the shaft, and this measurement repeated again for another line 180^0 apart. The differential measurements obtained can be used to measure straightness of an axis, as shown by the following Table 2.

Table 2. An Example of Straightness Measurement Data.

Distance on the part	0	0.5"	1.0"	1.5"	2.0"	2.5"	3.0"
One line element (inches), x	0	.002	.004	.006	.004	.002	0
Opposite element (inches), y	0	.002	.004	.006	.004	.002	0

These measurements and simple calculations for axis deviation, (x-y)/2, show that the even though the part is barreled-shaped, its axis is straight with 0 deviation. An equal rise in the opposing elements means that the axis is straight. If all the "y" measurements had been negative, then the shaft would be bowed.

On positional tolerances: Measuring positional tolerances uses a number of principles of measurement, especially if MMC modifier is included in the feature control frame as shown in Figure 5. The tolerance zones for the hole axes are cylindrical located at the basic dimensions.

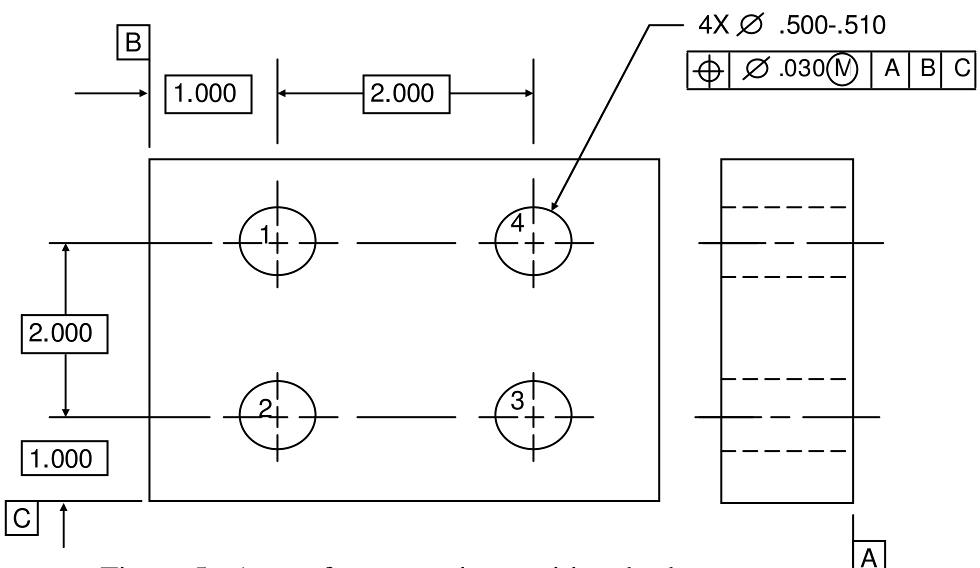

Figure 5. A part for measuring positional tolerances.

The hole sizes need to be measured first using gage pins. If the holes are within the .500-.510 size, then measurement of position tolerances become meaningful. The tolerance zones for the four hole axes will vary depending on the bonus tolerance given to each hole due to the MMC modifier. For example, if a gage pin that fits hole 3 is .503", the tolerance zone for hole 1 is a cylinder with .033" diameter.

Using the same gage pins in the holes, the hole axis of each hole needs to be located in x and y directions These x and y coordinates of actual hole axis location has to be converted to cylindrical zones that should be within the tolerance zone of each hole. If the hole 3 axis is located at 1.006" from datum C and 3.015" from B, the x and y coordinates are .006" and .015" giving a cylindrical zone of .0323" for the axis which happens to be within the tolerance zone of .033" and is therefore acceptable. The surface plate setup of this experiment generally requires planning and ingenuity in successfully performing the laboratory. Students are amazed by the step-by-step approach required to work with each hole, and record the data in a tabular format to check if the part is acceptable or not.

GD&T principles have great technical relevance in the modern methods practiced in industry as is evident from the published literature. Ignoring the GD&T specifications creates inaccuracies in the inspection process which can generate a misleading impression of manufacturing and lead to its negative effects[4]. Requirements for measuring and inspecting medical device components, implants and prosthetics are driving manufacturers toward more nontraditional measurement and inspection technologies using GD&T methods of reporting[5].

Assessment

As part of the course requirement, students complete a learning outcome survey immediately after their final exam when they are expected to have assimilated maximum of the course material. For the survey students are asked to rate how well they learned a given learning outcome on a 0 to 10 scale, with 10 being 'very satisfactory' and 0 being 'not satisfactory at all'. Table 3 contains the summary of their feedback for Spring 2007 class.

Table 3 Assessment Evaluation of the Metrology course.

No.	Learning Outcomes	Program Outcomes	6*	7	8	S/NS**
1	Inspecting size tolerances	b, c, g		1	3	NS
2	Flatness	"		1	2	S
3	Straightness	"		1	2	S
4	Circularity	"		1	3	NS
5	Parallelism	"		1	1	S
6	Perpendicularity and Angularity	"		1		S
7	Circular and Total Runout	"		1	2	NS
8	Concentricity	b		2	1	NS
9	Position Tolerancing	b, c, g		1	1	S
10	Functional Gage Design	a, b, f			2	S
11	Function effectively in teams	e		1	1	S
12	Communicate effectively through oral presentation	g		3	2	S
13	Communicate effectively through technical writing	b, d, g		2	3	S

* The number of students who gave scores of 6, 7, or 8, the least scores obtained on the 0-10 scale. Respondents=12.
** S is Satisfactory and NS is Not Satisfactory. Based on the spread of responses, learning outcomes that should be improved in the next offering of the course are given NS.

The learning outcomes also include their feedback on (a) functioning as a team in laboratory and (b) on use of effective verbal and written communication through project work that they present to the entire class and in a written report. Students are also given an opportunity to give general written comments on the survey sheet as well. Students commented in general that they liked doing the laboratory experiments. The only consistent suggestions for changing the course had to do with (1) sufficient practice of the instruments before labs are formally conducted, (2) more experiments on variety of parts using GD&T, and (3) to include profile tolerance. Some also suggested to cover CMM programming in the course.

Experiments on thread wire methods, gear measurement, design of gage pins and rings, and use of paper gaging are not included at this stage, even though theoretical discussion on the design of functional gaging and paper gaging is covered in sufficient detail.

Conclusions

Based on the course assessment, there are some significant changes planned for teaching the metrology course: initial practice on instruments as a review of the introductory course, more example parts, and to do basics of profile tolerance. Overall the course appears to be meeting its objectives and learning outcomes according to the student feedback and assessment evaluation. Instructor feedback is that students have been engaged in the course, with satisfactory exposure to the theoretical and practical aspects in the field of applied GD&T measurements. The structure of first grounding in basic theory and then hands-on measurement setups with some demonstrations, and finally with an independent project work appears to have worked well.

Bibliography

1. Geometric Dimensioning and Tolerancing: Applications and Inspection, by Gary K. Griffith, 2nd edition, Prentice Hall, Inc., 2002.
2. Fundamentals of Dimensional Metrology, by Ted Busch, Roger Harlow, and Richard Thompson, 3rd edition, Delmar Publishers, 1998.
3. The Metrology Handbook, Jay L. Bucher, Editor, American Society for Quality, ASQ Press, 2004.
4. Wearing, Colin and Karl, Dennis, “Impact of Ignoring GD&T Specifications”, SME Technical Paper MS91-542, 1991.
5. Tolinski, Michael, “When Inspection’s a Matter of Life and Death,” Manufacturing Engineering, Society of Manufacturing Engineers, May 2006.