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Teaching Geometric Dimensioning and Tolerancing in a Manufacturing Program

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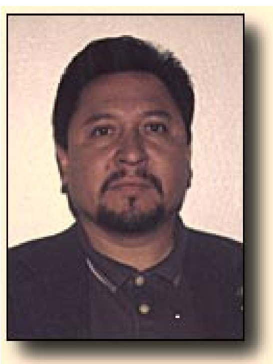

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Introduction

Geometric Dimensioning and Tolerancing (GD&T) is a universal design engineering language that is being used to faithfully capture and transmit the designer's intent through all activities in the product cycle. GD&T has been adopted by the International Organization for Standardization (ISO) and the American National Standards Institute (ANSI), as well as by many other national standards. This language has also been adopted by many U.S. manufacturing enterprises for their competitive well being. In addition it has also been suggested (Bakerjian, 1997) that GD&T be used as a standard or benchmark from which businesses may begin their continuous improvement (CI) processes. As a consequence, today GD&T is an essential ingredient of the industrial technology curriculum.

The impetus for developing GD&T was provided by the experiences of the munitions industry in the U.S. and Britain, which based their production operations on product data that solely relied on the "plus-minus tolerancing" or conventional tolerancing practice. Wartime production was hampered by the high scrap rates due to parts that would not assemble properly (Kurlikowski, 1991). Pioneering efforts by the British, the Chevrolet division of GM and the U.S. Army to remedy this problem led to the development of GD&T.

One of the principal avenues for introduction of GD&T into the technology curriculum are design graphics courses. While design graphics courses are a suitable medium for the introduction of basic concepts, the authors are of the opinion that GD&T should be revisited in manufacturing and quality assurance courses so that students may better internalize and apply these concepts. A sound understanding of GD&T principles would prove beneficial to the industrial technologist because they are involved in supervising and trouble-shooting production operations and should therefore have a clear conception of the design intent.

The intent of this paper is to discuss some limitations of GD&T instruction in design graphics courses and present teaching alternatives that might obviate these limitations. In particular this paper focuses on an approach that is being currently used at Southwest Texas State University (SWT) for instructing students in GD&T. This approach was a response to some problems that we were facing in terms of student interest, motivation and retention of GD&T concepts. The totality of material covered can be roughly divided into three parts. These include: (a) the Why's of GD&T (b) symbology, rules of legal application and interpretation and (c) GD&T implications for manufacturing and inspection. Currently these three parts are covered through a sophomore level machine drafting and senior level manufacturing class. The details of implementation follow through the rest of the paper.

Part I - Why Use GD&T ?

One of the first steps to be undertaken in teaching GD&T should be to enable students to understand the need for the same. This aspect of GD&T coverage occurs in TECH 2310 - Machine Drafting at SWT. Students enrolled in this class would have typically completed TECH 1413 - Engineering Design Graphics. TECH 1413 deals with descriptive geometry, orthographic projections, dimensioning and tolerancing (conventional) practices, sectional views and detail drawings. We felt that before GD&T can be presented to this audience, that it would be worth our while to discuss the shortcomings of conventional tolerancing and the resulting implications for design and manufacturing. Next a brief discussion of how GD&T solves these problems and lowers production costs follows. Our central idea was that students who have this background prior to learning the language will be well motivated and therefore are likely to better understand the applications.

The following are some of the reasons why GD&T is being used today and why it is discussed in our classes. The first three are due to Zied (1995).

1. Consider the part shown in Figure 1 . The drawing suggests that the two edges of one inch length that meet at the lower left hand corner maintain a 90 degree relationship. However this is not explicitly expressed. As a consequence the machinist will need to second guess the design engineer and decide whether this relationship is critical or not critical. There are cost and time based implications to either assumption. Thus conventional tolerancing does not explicitly control (except by the use of local notes) all aspects of part geometry, particularly the shape.

2. Again considering the lower left hand corner will reveal that the two edges of one inch length serve as datums for the location of part length, width and hole center . This fact is not expressed explicitly nor is there any indication as to the relative importance of these two datum planes.

3. The tolerances for hole location permit the hole center to “wander” by .010 inches along the X and Y axes, while at the same time permit a variation of .014 inches along the diagonal (please refer to Figure 2). This unequal variation does not stem from any functional consideration, and therefore is rather awkward.

4. The use of material condition modifiers allow bonus tolerances which in turn lead to great ease of assembly of mating parts and lowered production and assembly costs.

5. The notion of virtual condition permits functional gages to be developed. Functional gages lend themselves to mass production situations by speeding up the inspection process.

At this point the student is presented with the symbology, rules of legal application and interpretation of geometric tolerances. Without this prior background we feel that students get lost in a mire of symbology and syntax.

Part II - Symbology, Rules of Legal Application and Interpretation

The emphasis of TECH 2310 are machine elements and drafting practices. These concepts are practically applied through the use of CAD software such as AutoCAD. Topics covered include material designation, manufacturing processes, threads, fasteners, springs, GD&T, surface finishes, fits & clearances, assembly drawings and solid modeling. This class prepares manufacturing students for subsequent process engineering and tool design classes.

From a GD&T standpoint, after the Why’s of GD&T have been presented, symbology, rules of application and interpretation according to ASME Y14.5-1994 are covered. In order to actively engage students during the lecture, a workbook (Marrelli & McCuiston, 1997) is used. To reiterate the principles and concepts discussed during lectures, two major projects are assigned. In the first, the students are given a blueprint that is dimensioned according to conventional tolerancing practices. This print is accompanied by a sheet that contains information relating to specific features that are to be controlled with geometric tolerances. Students are to register datum features, affix feature control frames as appropriate and calculate bonus tolerances where applicable. In the second of these projects, students are

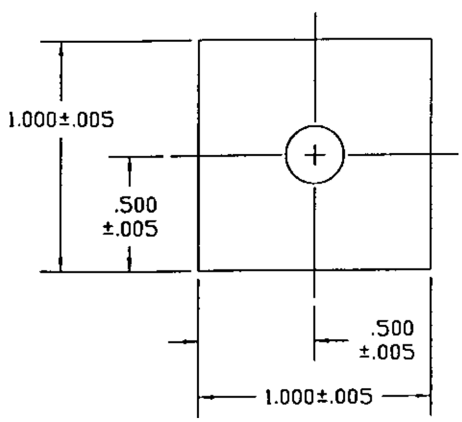

Figure 1. Conventional Tolerancing

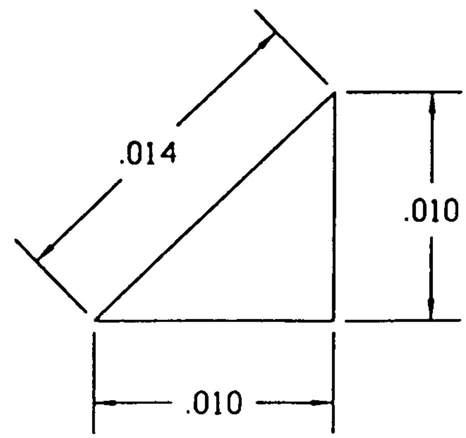

Figure 2. Unequal Tolerances

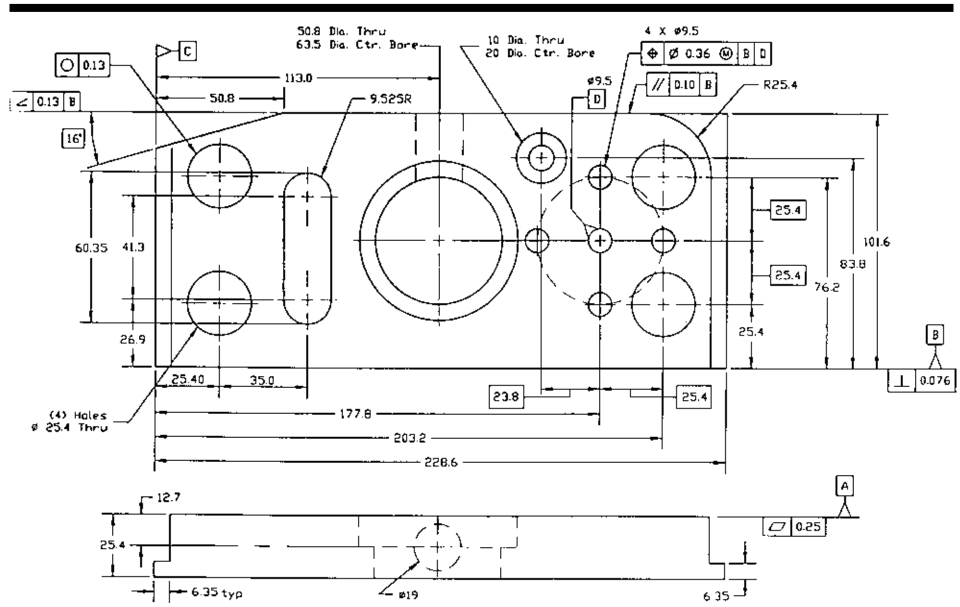

Figure 3. Sample Project

presented with a blueprint that is dimensioned according to ANSI Y14.5-1982 and features some poor applications of dimensioning & detailing practices as well. The students are then required to prepare a blueprint according to the ASME Y14.5-1994. Figure 3 is a sample result of the second project. We have found that these projects force students to think and reason about geometric tolerances rather than blindly apply them.

Once the second project has been completed, students are taken to our metrology laboratory which includes along with a host of common metrology tools, a Coordinate Measuring Machine (CMM). Figure 4 illustrates the CMM that is a Brown & Sharpe MicroVal PFx CMM. Students participate with the instructor in setting up and inspecting a physical model of the part shown in figure 3 on the CMM. These processes actively engages students and forces them to "touch" and "feel" datum planes. As a consequence, students no longer feel that GD&T concepts are merely theoretical. The next section deals with GD&T implications for manufacturing and inspection. This is an important aspect of GD&T education that may be overlooked at schools which present GD&T solely through the medium of graphics classes.

Part III - GD&T in Manufacturing and Quality Assurance Classes

In part III of instruction, the student is exposed to GD&T implications for manufacturing and inspection. This is an important aspect of GD&T instruction because an industrial technologist should not only be able to read and interpret symbology on a blueprint, but also use such information to determine machining setups, inspection setups and design gages where appropriate. At SWT, this part is conducted in TECH 4362 Manufacturing Processes I . The time required for GD&T applications based coverage in TECH 4362 was made available by de-emphasizing coverage on material removal theory. Material removal theory is covered in detail in an earlier class called TECH 2330 - Fundamentals of Material Removal. Students who enroll in TECH 4362 would have taken TECH 2310 Machine Drafting and would therefore be familiar with the Why's of GD&T and the basics (i.e. symbology, rules of legal application and interpretation). TECH 4362 focuses on manufacturing engineering functions such as producibility analysis, process planning, tool design and cost estimation. The relevance of GD&T to these functions is brought out at all appropriate points as described below.

The first application area for GD&T is producibility analysis. After instruction in basic concepts of producibility analysis, students are given drawings that contain besides conventional tolerances, geometric tolerances, surface finish and fits specifications. Students are then asked to critique the drawings from standpoint of producibility taking SWT's machine shop as the reference production facility. Students at this point are familiar with the machine shop capabilities because TECH 4362 has a laboratory component that requires 14 weeks of project related work. The key objective here is to educate students in : (a) studying the part specifications closely (b) determining part function based on the specifications and (c) relating these specifications to the shop capability and recommending design changes that would optimize the design for production.

The second application area is process planning. During this activity students determine the sequence of production operations, process parameters and tooling required to manufacture the part in our shop. GD&T specifications, especially the datum specifications and their precedence, drive the determination of part setups and the design of drill jigs and milling fixtures.

The third application area, and the one where we place significant emphasis, is inspecting geometric tolerances. Inspection activities involve the use of conventional instruments such as dial indicators, vee blocks, surface plates, angle plates, optical comparators, functional gages and gage pins as well as the use of a CMM. We start with the conventional approach. One key concept covered is the distinction between measuring and gauging a geometric tolerance. For example, consider the part shown in Figure 5. The feature of interest is the bore whose axis has a perpendicularly tolerance specified at MMC. It is possible to measure this geometric tolerance using a snug fitting gage pin and dial indicator. However, depending upon the "as manufactured" bore size, bonus tolerances as indicated in Table 1 apply. Measuring a part at random involves determining the exact size of the hole, finding a snug fitting pin and then consulting table 1 to determine the applicable tolerances. Such a method would prove very intensive in terms of time and cost in a mass production environment. The concept of ***virtual condition*** (defined in Figure 6) proves very useful in such situations. Since a virtual condition exits for the part shown in figure 5, it is possible to design a functional gage that is an attributes type instrument. Functional gages represent the geometric worst case boundary and declare a "pass" or "fail" result. Thus, it is possible to gage rather than measure, an option which would be preferable in mass production. Figure 7 illustrates a functional

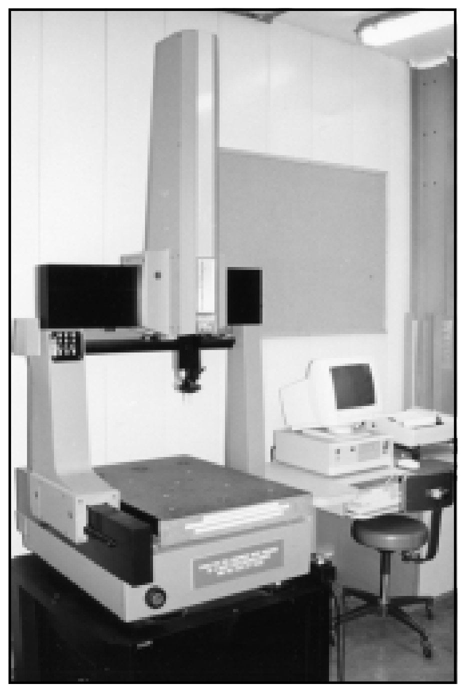

Figure 4. Coordinate Measuring Machine

gage that would be used to gage the part shown in figure 5. Unfortunately, not all geometric controls permit the application of functional gages; which leaves measuring as the only option. The rules for determining when and where these gages may be applied are stressed in the lecture.

After conventional approaches to the evaluation of geometric tolerances have been presented, students are introduced to the CMM. The CMM, when one may be afforded, is an extremely versatile tool for the inspection of size and geometric tolerances. It is also fast, consistent and reliable. Students learn how to program a CMM for subsequent measurements by "teaching" the CMM to measure a master part. Once this inspection program has been proofed and saved, it may be rerun for the automatic inspection of subsequent parts. Students are able to very readily appreciate the productivity gains in inspecting a part of moderate complexity with a CMM as compared to other methods of evaluation. Such gains increase in those industries that require 100% inspection.

There are several side benefits to using a CMM for inspection in the classroom. These include: (a) students appreciate the fact that CMMs eliminate the need for many functional gages for inspecting features with a virtual condition, (b) students are introduced to automated inspection methodologies which are important in the context of automated manufacturing systems, (c) students become conversant with programming a CMM and the several procedures used in this process such as homing, probe qualification and part alignment and (d) provides more opportunities for practically dealing with GD&T concepts such as datums, their precedence and material condition modifiers.

Results

Procedures outlined in Parts I, II, and III of this paper have been implemented for the past few years at Southwest Texas State University. Our experiences in the classrooms may be reduced to the following significant observations: (a) the addition of laboratory activities in TECH 2310 as a supplement to lecture coverage of GD&T has resulted in improved student interest and participation and (b) the inputs to TECH 4362 were found to retain basic GD&T concepts that were covered in TECH 2310. Prior to the implementation of our methodology in TECH 2310, a good portion of GD&T coverage in TECH 4362 involved refreshing the basics. This permitted very little time for coverage of advanced topics involving GD&T applications. Also, students upon completing TECH 4362 will have been exposed to all aspects of GD&T, i.e.

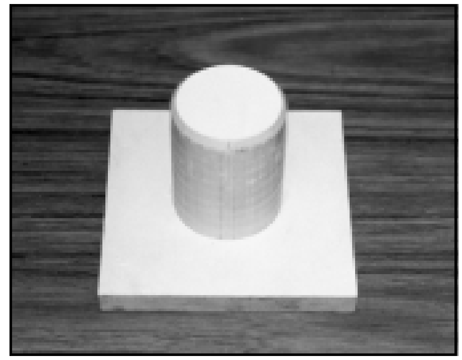

Figure 7. Functional Gage

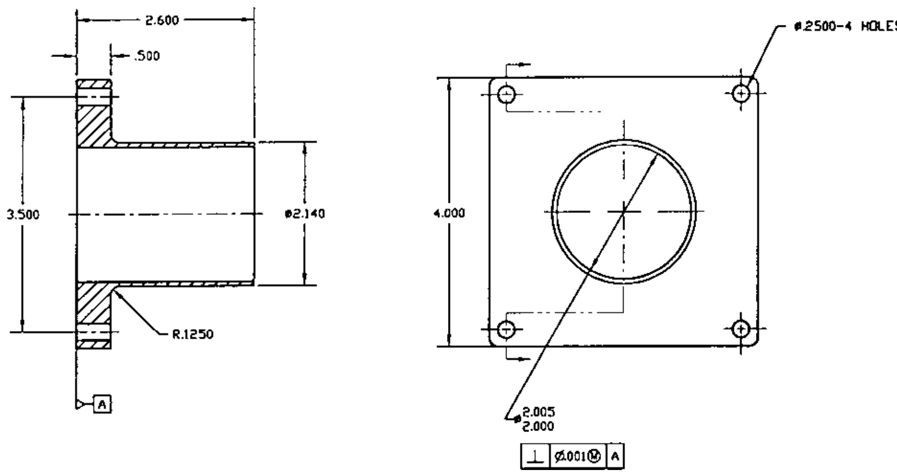

Figure 5. Perpendicularity Control.

Virtual Condition (external features) = MMC + Geometric Tolerance

Virtual Condition (internal features) = MMC - Geometric Tolerance

Figure 6. Virtual Condition Defined

As Manufactured Size	Bonus Tolerance	Total Tolerance
2.000 (MMC)	.000	.001
2.001	.001	.002
2.002	.002	.003
2.003	.003	.004
2.004	.004	.005
2.005 (LMC)	.005	.006

Table 1. Permissible Geometric Tolerances

symbology, rules of application, interpretation and applications to manufacturing and inspection.

Conclusions & Recommendations

Today GD&T is an essential component of the manufacturing and mechanical technology curricula. Typically, most all GD&T coverage in such programs is through the medium of design graphics courses. Unlike conventional tolerancing which may be easy to understand, GD&T features some very seemingly abstract although important concepts such as datums, their precedence and material condition modifiers. At SWT this problem was resolved by involving students in a sophomore level drafting class in laboratory inspection activities that help students "see" these concepts in practice. Our recommendations are that: (a) traditional GD&T instruction in design graphics courses be supplemented with laboratory activities such as those outlined in Part II of this paper. While we had used a CMM to implement laboratory activities, these activities may very well be implemented using surface plates, precision angle plates, sine plates, etc. and (b) the practical applications of GD&T in manufacturing and inspection should be illustrated through both lecture and laboratory activities in subsequent manufacturing and quality assurance classes. Such practices would enable students to apply and internalize GD&T concepts better. The value of producing manufacturing professionals with a background in GD&T will be undermined unless we implement means to provide students practical "hands-on" opportunities for applying these principles. Such experiences where students can learn from their mistakes will train them well on the use and abuse of GD&T.

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