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Dimensional Tolerances: Back to the Basics

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Abstract

Students often have difficulty grasping the principles of dimensional tolerances and frequently fail to recognize that dimensioning practice has a significant impact on the tolerance of part features. This observation may be attributed to several factors, not the least of which are changes in prior student education and life experiences and increasing pressure in academia to add course content to cover new technologies, sometimes at the expense of fundamental concepts. This paper presents some back-to-basics instructional methods designed to help students improve their understanding of tolerances, including a description of some hands-on instructional activities that were implemented in the Engineering Technology program at Illinois State University.

Introduction

The focus of the Engineering Technology program at Illinois State University (ISU) is to prepare technically-oriented management professionals for work in a variety of manufacturing-related careers. Few of our graduates are expected to make decisions regarding the appropriate tolerances for a given product, although many are expected to interpret part prints that include tolerance specifications. Accordingly, our focus is to provide instruction to help students develop the ability to interpret dimensional tolerances and help students develop an understanding of the relationship between dimensioning and tolerancing practices and the cost to manufacture a product.

In years past, many students came to the Engineering Technology program at ISU with prior hands-on shop experience obtained by working on the farm or in K-12 technology education classes. Today, however, seemingly few students come to ISU with experience physically making things with their hands, resulting in a student population that often has difficulty finding meaning in textbook discussions of tolerances. For example, a textbook discussion of full indicator movement (FIM) has little meaning to engineering graphics students who have never seen a dial indicator. Similarly, some students have difficulty appreciating the meaning of a tolerance callout of +/- .005" because they have never used a measuring instrument capable of measuring at that precision. Topics such as tolerance stacks and datum reference frames are abstract concepts to many students who often simply learn these concepts by rote rather than develop an understanding and appreciation for the tolerance-related messages expressed on part prints.

This paper describes several hands-on group activities that have been added to an intermediate engineering graphics course at Illinois State University. The group activities require students to interpret a variety of dimensioned part prints and physically measure the parts they describe. Although all groups measure the same physical parts, different dimensioning practices were used on the part prints, frequently resulting in the parts being "good" for some groups but "bad" for other groups. Each group created inspection reports for their parts and was required to explain and defend their report to the other groups in the class. In some cases, the part prints were intentionally over-dimensioned to help students discover that this practice leads to conflicting tolerances and multiple interpretations.

Background

The ISU Engineering Technology Industry Advisory Board is comprised of 12 professionals working in a variety of manufacturing-related industries throughout the Midwest. One consistent theme discussed by ISU advisory board members is the importance of print reading and tolerance interpretation skills in the manufacturing workplace. Similarly, the literature is replete with work indicating that engineering and engineering technology students should receive instruction in the area of tolerancing concepts. For example, Meznarich, Shava, and Lightner (2009) presented the results of a study that indicated print reading and tolerance interpretation were seen as important topics by both industry professionals and educators. Lamb and Kurtanich (2007) describe the rationale and structure of a new course they developed at Youngstown State University to help improve instruction in various areas of print reading including tolerance interpretation. Evans (2004) describes an innovative approach to use standard CAD tools to "virtually" inspect products based on geometric dimensioning and tolerancing (GD&T) callouts. Sriraman & DeLeon (1999) describe their use of a coordinate measuring machine (CMM) to help improve instruction in the area of GD&T. In summary, based on input from our program constituents, as well as support from the literature, the engineering graphics curriculum at ISU was modified in 2010, allowing new instructional activities to be added in the area of dimensional tolerancing.

ISU Curriculum Changes

ISU Engineering Technology students are required to take two courses specifically dealing with engineering graphics and technical drawing. Until recently, the TEC116 course, Introduction to Technical Drawing, introduced students to the fundamental principles of technical drawing using primarily hand-sketching and 2D AutoCAD™. This former TEC116 course was designed to accommodate students from primarily two technical areas: engineering technology and construction management, and therefore had broad course content. Engineering Technology students then took a second required course, TEC216 Computer Aided Design and Drafting, in which they were introduced to the principles of constraint-based solid modeling, and a variety of manufacturing-related technical drawing topics including ASME dimensioning and tolerancing principles. The former TEC216 course schedule included two days of

discussion dealing with traditional tolerancing topics and two additional days of introduction to GD&T.

Based on recommendations from our industry advisory board and program alums, several curriculum changes were implemented in 2010. A new introduction to construction graphics course was implemented to serve the specific needs of construction management students, and the TEC116 course, which is still required for engineering technology students, was significantly modified. The most notable change in TEC116 was the deletion of content dealing with 2D AutoCAD™ and the addition of 3D solid modeling content using Autodesk Inventor™. TEC116 students now receive a comprehensive introduction to constraint-based solid modeling during their first engineering graphics course. This change has had a dramatic effect in the TEC216 course because much of the time spent in previous years introducing students to the principles of solid modeling may now be spent covering other topics. The TEC216 course now includes expanded coverage of dimensional tolerancing principles. The remainder of this paper presents some of the instructional activities that have been added to the revised TEC216 course.

Activities to Support Basic Tolerance Concepts

Dimensional tolerance instruction in the TEC216 course begins with a discussion of tolerancing terms and concepts such as tolerancing formats, limits of size, and fits. The main focus of instruction at this point is on the fundamental concepts of traditional (+/-) tolerancing. After several calculation sheets and sample part prints had been worked through together in class, students were divided into small groups and given a simple machined part, partially dimensioned print (Figure 1) and a dial caliper. Students were then asked to use the dial caliper to measure several part features, complete an inspection report (Figure 2), and make definitive statements about whether the part features were in tolerance. Finally, groups were randomly selected to present their inspection results to the class. When opinions from the groups differed, the students were required to defend their findings.

To make things a bit more interesting, several features on the part prints were dimensioned differently and given to the groups. For example, the slot feature size and location (dimensions D, E and F in Figure 1) were intentionally dimensioned using different methods, resulting in students using different inspection methods to measure the slot. In some cases, several groups concluded the slot feature met specifications while other groups did not. Using different dimensions on the part prints resulted in several discussions regarding dimensioning practice and the designer's true intentions.

After physically measuring two parts in small groups, students were required to complete several tolerance calculation exercises using only part prints. Although these exercises have been completed in the TEC216 in previous semesters, a noticeable improvement in student performance was observed, and in-class discussions on these exercises involved more students this semester. This semester, a simple part print that

was intentionally over-dimensioned was given to the students (Figure 3). This problem created quite a bit of discussion as students discovered there was more than one way to calculate the limits of size for this part. While students had previously been told that over-dimensioning is poor practice, several students commented that the exercise helped them understand why this practice is not acceptable, especially when they were pressed to complete the simple tolerance table that accompanied the print.
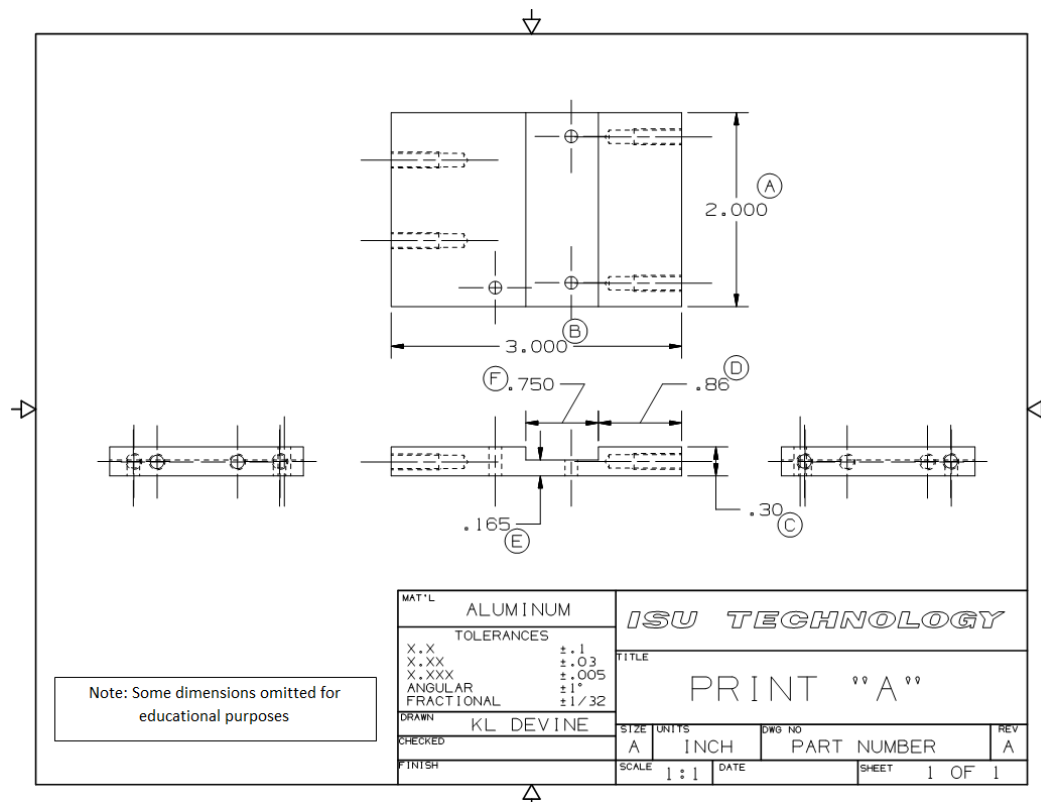

Figure 1. Sample part print.

Feature	Nominal	Actual	Deviation	Tolerance	Upper Limit	Lower Limit	Out Of Tolerance Amount	In tolerance?
A								Yes / No
B								Yes / No
C								Yes / No
D								Yes / No
E								Yes / No
F								Yes / No

Figure 2. Sample inspection report.

After spending two class periods measuring parts using dial calipers and completing print reading exercises and calculations sheets, students were required to measure two parts using a coordinate measuring machine (CMM). Working in small groups, the students were guided through the process of measuring various part features to create

a computer-generated inspection report identical in format to the report illustrated in Figure 2. These CMM measuring activities helped students better understand concepts of measurement accuracy and helped set the stage for some future GD&T measurement activities.
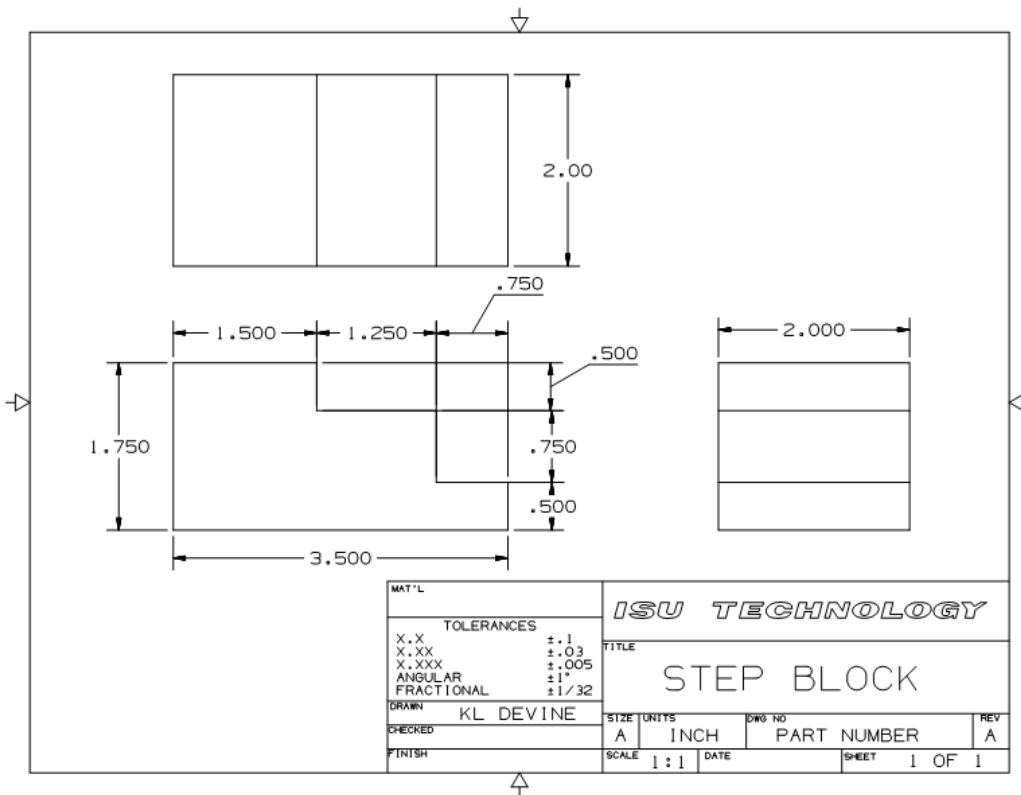
Based on the print above, complete the following table:

Feature	Nominal size	Tolerance	Maximum Limit of Size	Minimum Limit of Size
Overall length				
Overall height				
Overall width				

Figure 3. Sample over-dimensioned print.

Hands-on Activities to Support GD&T Concepts

Instruction in GD&T principles took place after students had completed the activities described above. By this point in time, students had been exposed to basic concepts such as maximum material condition (MMC), least material condition (LMC), fits, and the like. The students had also experienced print reading and simple part inspection using a dial caliper and a CMM.

GD&T instruction started with an introduction to feature control frames and symbols, tolerance zones, and the datum reference frame. Several textbook exercises and in-class feature control frame exercises were conducted to help students learn about the basic language of GD&T. Several hands-on activities and demonstrations were added using hand-measuring instruments to augment the textbook-based instruction. For example, students were shown how to use a dial indicator, height gage, and surface plate to measure a part surface. By using these tools, students gained a better understanding of the tolerance zones being described by various feature control frames. Other instruments demonstrated included gage blocks, sine bars, and vee-blocks.

Students were then given simple machined parts and prints containing GD&T callouts. The students were first required to interpret the datum reference frame and feature control frame callouts (limited to true position). Tolerance zones specified by the feature control frames were hand-drawn on the print and a CMM inspection plan was created to measure the required physical part features. Next, a sample part was loaded on the CMM and students were instructed how to use the CMM software functions to implement their inspection plan. The graphics capabilities of the CMM software allowed a CAD solid model of the part to be opened and displayed. This feature proved to be very helpful when establishing the datum reference frame because the software displayed the frame using the same coordinate system triad (XYZ axes) used by most CAD systems. Figure 4 illustrates a simple part that was measured by the students.
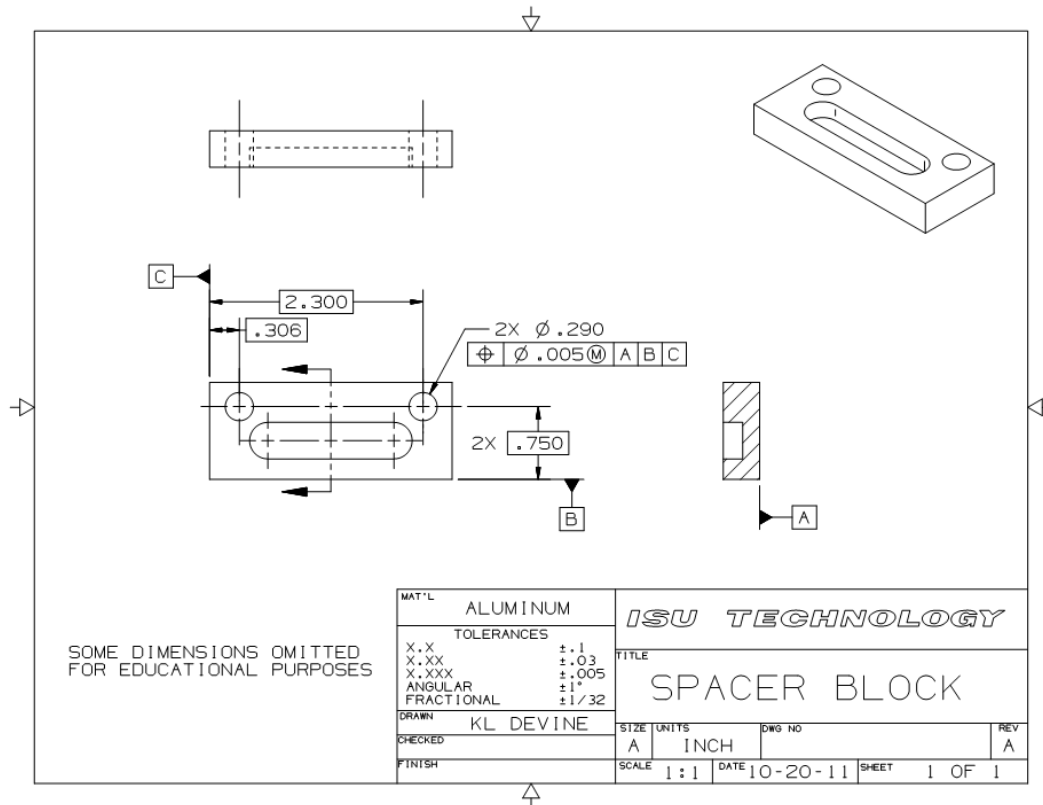

Figure 4. Sample GD&T print.

Conclusions

Although the changes to the engineering graphics courses describe above were implemented at ISU during the Fall 2010 semester, the impact of the changes were not seen in the TEC216 course until the Fall 2011 semester. As expected, the curriculum change freed up some time in the TEC216 course to allow for additional instruction in several areas including dimensional tolerancing.

Engineering Technology students seem to learn best by putting theory into practice. Therefore a priority was placed on adding hands-on activities in the TEC216 course in the area of dimensional tolerances. The hands-on measuring activities added in TEC216 seemed to help ground the abstract tolerance concepts into knowledge that students can better understand and use. The activities were not difficult to design and implement and although the activities described in this paper included the use of a CMM, other activities utilizing less expensive measuring instruments could be developed in their place. While the activities themselves seem somewhat simple in nature, they proved to be very beneficial to student learning. Anecdotal comments from students as well as overall performance in the class suggest the activities were well received by the students and helped improve student understanding of dimensional tolerances. In a time when educators are often pushed to add new technology to their courses, sometimes a back to the basics, hands-on approach should be considered.

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