AC 2010-752: POPPING THE TOP ON BASIC MACHINING INSTRUCTION

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Popping the Top on Basic Machining Instruction

Abstract

Learning manufacturing processes, particularly machining, is an important part of the education of mechanical engineering majors. In most universities' machine shops, there are typically many more students than any one type of machine tool. This situation, compounded by the fact that machining a part typically follows a strict manufacturing sequence, makes it difficult to have students create a single part that requires the use of more than one machine tool without forcing them to wait in line for one machine while other machines sit idle.

One solution to this problem that was used previously at the United States Military Academy at West Point was to have students create a separate simple part on each machine tool. This eliminated having a manufacturing sequence for any one part and allowed students to be split between the various machines. However, this approach also removed the important learning point of following a manufacturing sequence and thinking ahead to fixturing on the next machine in the sequence. Additionally, students were left with a series of relatively worthless trinkets that had little to no intrinsic value.

This paper describes the design and implementation of a simple bottle opener project that serves as the framework for an entry-level introduction to machining in an undergraduate manufacturing course. The bottle opener's design allows students to machine it using various manufacturing sequences, so they may start on any of several machines and end up with the same final product. This paper also provides an assessment of the effectiveness of the implementation of this project through the use of student grades and performance, an assessment of the quality of team products and prototypes in a follow-on project, surveys, interviews with students, and course-end student feedback. The results of this assessment should be useful to any program that incorporates metal part fabrication techniques into an engineering course.

"Just as one cannot learn to drive without getting behind the wheel; or to swim without getting wet; entry into the profession of engineering, particularly in the area of design, requires far more than sitting in a lecture hall."[1]

Introduction

Manufacturing processes are an important part of the curriculum for mechanical engineering majors. Industrial employers have long called for newly-graduated engineers to have both knowledge and proficiency in manufacturing, and they have expressed concern that many recent graduates of engineering programs lack these skills.[2,3] Hands-on assignments, such as learning to machine, are an effective way to impart these necessary skills to engineering majors. According to Lowman, these types of hands-on assignments also "enrich students' interaction with regular course content and help them see the course's relevance to real-world issues."[4] The growing movement to reemphasize hands-on learning in engineering has led many engineering schools to offer or require courses in basic machining for mechanical engineering majors.

The cost of lathes, milling machines and other machine tools as well as the amount of floor space they require typically dictates that there are many more students than any one type of machine tool in most universities' machining courses. At West Point, as is the case at many schools, the goal for the basic machining course is to spread the work load among the machines so that students are kept busy and not waiting for any one type of tool. This maximizes student participation and reduces the overall time that it takes for students to gain familiarity with all of the machines. However, since manufacturing a part in a machine shop typically follows a strict sequence (band saw first, then lathe, then mill, etc.), it is difficult to have students manufacture a single part that requires the use of more than one machine without forcing them to wait in line for one machine while other machines sit idle.

This paper describes the design and implementation of a simple bottle opener project that serves as the framework for an entry-level introduction to machining in an undergraduate manufacturing course. The bottle opener's design allows students to machine it using various manufacturing sequences, so they may start on any of several machines and end up with the same final product. The result of the project is a handsome, laser-engraved bottle opener that has value to the students. The authors hypothesize that having such a final product may provide additional motivation for the students to take their time, listen to instruction, and follow proper procedures in the machine shop since they are able to keep and use the final product at the completion of their instruction.

The Course

ME403, a one-semester course taught to juniors majoring in mechanical engineering at West Point, serves as an introduction to manufacturing and machine component design. Based on the fact that students at West Point are required to study more subjects than engineering majors at most other schools, they are on a very strict timeline and are required to take heavy course loads to cover the required material in four years. For this reason, ME403 is an intense, fast-paced course that covers a large amount of material in a short period of time. In fact, ME403 covers material that is typically spread across at least two courses at most other schools.

The objectives of this course are as follows:

- Apply manufacturing techniques and component machining processes to real-world applications
- Apply basic engineering science to the design of machine components
- Improve problem-solving and decision-making abilities
- Improve the ability to communicate orally and in writing

The first portion of the class is devoted to a review of fundamental engineering science as applied to machine components. These topics include load, stress, and strain analyses, impact, fatigue, and surface failure. The course then progresses to the study of machine component design to include fasteners, springs, bearings, gears, and shafts. Welding, soldering, and brazing techniques and equipment are introduced briefly in a hands-on laboratory setting, and then the course moves to five two-hour sessions devoted to a safe, hands-on experience working in a machine shop. Students have an opportunity to work with machines such as mills, lathes, grinders, belt sanders, drill presses, bandsaws, and a laser cutter in preparation for their final project. (This five-session machining portion of the course is the focus of this paper.) The course culminates with a team-based project that requires students to design and construct a water turbine using the techniques, tools, machines, and equipment that were developed and taught throughout the course. The teams then compete during the final lesson of the course to see which team can lift the most weight with their water turbines using a set amount of water.

Figure 1: The ME403 machine shop

The Problem

Originally, the machining portion of the course was five one-hour sessions rather than the two-hour blocks described above. Due to this extremely limited time available to teach machining and the fact that the students have only a small amount of time to work in the machine shop outside of class, it was extremely important to be able to maximize the use of the students' time in class. Having students waiting to use a machine wastes the precious time they have available and therefore, the original solution to this problem was to have students create a separate simple part on each machine tool. This eliminated needing a manufacturing sequence for any one part and allowed students to be split between the various machines as necessary. However, this approach also removed the important learning point of following a manufacturing sequence and thinking ahead to fixturing on the next machine in the sequence.

To reduce costs and increase the speed with which the students could machine, they were originally required to use machinist's wax for their parts. This left them with a series of relatively worthless wax trinkets that had little to no intrinsic value. Additionally, due to the fact that students only machined wax during this portion of the course, they had no hands-on experience with cutting metal or other materials on the machines. This method of teaching machining resulted in little retention of the material as was evident in their machining skills on the final water turbine project. Also, since the final project requires the students to machine several different types of material from acrylic to steel, their lack of experience with adjusting feeds and speeds led to many broken tools and parts during the final project.

The Approach

It was clear that ME403 needed additional time devoted to hands-on machining based on student performance on the final water turbine project and questions related to machining on the final exam. Seniors who had completed ME403 the year before were also relying heavily on additional instruction from laboratory technicians with respect to machining while working on their senior capstone projects. However, the ME403 syllabus was already so full that it was difficult to find time for more machining instruction without eliminating or reducing other very important subject matter.

The initial part of the solution was gaining approval to add a lab hour to the course. This allowed the course director to add seven additional mandatory hours of instruction to the course and it ensured that students' schedules would be set up so that they would be free during the hour following class even on days without a second hour of mandatory instruction. This improved the ability of students to stay after class to ask questions and work on assignments and it allowed the instructors to allocate additional time to hands-on machining. Five of the seven additional mandatory lab hours were added directly to the machining portion of the course. Additionally, in order to increase student motivation, the course director set about designing a new student project for the machining portion of the course that would allow students to make an item that they would value and keep following the basic machining instruction.

The first thought was to do away with the machinists' wax for the machining instruction. While it is easy to work with and does allow students to see what the machines are capable of doing, it does not allow students to gain a sense of machining actual metal, and it is perhaps too forgiving with students using incorrect feeds and speeds. Additionally, there is some intangible aspect of machining a 'real' part out of metal that helps motivate students. The authors decided to use aircraft-grade aluminum since it is durable, it machines well, parts can still be made fairly quickly, and it requires students to use proper feeds and speeds to be successful.

Figure 2: The ME403 machine shop includes five sets of lathes, mills, bandsaws, sander/grinders and drill presses

The resulting product needed to be simple enough to make in a short period of time, but it needed to be functional as well. It was also important to take the manufacturing sequence into account and this was perhaps the most difficult part of the design. The machine shop being used for this course consists of five sets of lathes, mills, bandsaws, sander/grinders, and drill presses. Since there would obviously always be more than five students in any given class, it was important to make a product that allowed students to start and finish on different machines in order to keep them busy at all times and not waiting for one of the machines to free up for use. This posed a problem that needed to be solved as well.

After considering several different potential projects – from magnifying glasses to models of small engines to coasters – the course director decided on bottle openers. A bottle opener seemed to be an ideal project for the machine shop. It would be something that the students would be able to take with them and use after the class, there was quite a bit of freedom for coming up with a simple design, and the tolerances for the 'mouth' of the bottle opener needed to be close enough to actually open a bottle. This would require students to pay attention to detail and do a good job if they wanted their finished product to actually work.

Figure 3: The author created several rough prototypes before settling on a final design

The course director set about coming up with a design during the summer. The goal was to make a bottle opener that was relatively simple to machine, but not too simple. The students should be required to change tools on the mill, lathe, and drill press, use all five machines in the machine shop, and not spend a very large amount of time on any one machine. Students should also be required to perform different types of operations on the various machines to include tapping, which would likely be required on their final water turbine project. An additional thought was to somehow incorporate the department's new 150 Watt CO_2 laser cutter into the project to give students some exposure to how it worked.

The author made several prototypes and tested various machining sequences before coming up with a final design. The final product consists of two components: the main body of the bottle opener and a small threaded lug that allows a key ring to be attached and detached from the body. The resulting bottle opener requires students to use all of the machines in the machine shop and accomplishes the goal of allowing students to use several different manufacturing sequences.

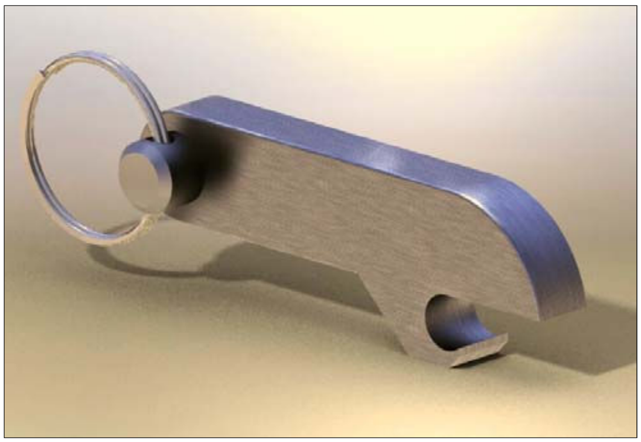

Figure 4: SoldWorks® model of the final bottle opener design

In order to confirm the feasibility of the design as a teaching tool, the authors first enlisted laboratory technicians who were unfamiliar with machining to each make a bottle opener. This initial test confirmed that the design was feasible, but pointed out some small glitches in the engineering drawings that were quickly corrected. The drawings were further adjusted so that they require students to do simple math to come up with some of the necessary dimensions. The thought behind this was that having this experience would motivate the students to get used to paying attention to detail as well as to writing notes on their own engineering drawings.

Once this initial beta test was complete, four mechanical engineering students who would be studying abroad during the semester were brought in to make bottle openers prior to the start of ME403. These students would be taking the course by correspondence, but were required to complete the hands-on machining portion prior to the start of their classes overseas. Following the machining instruction, they gave very positive feedback and were all able to complete their bottle openers in the required amount of time. These two tests allowed the instructors and laboratory technicians to become familiar with the bottle opener design and how the instruction would run.

Finally, after these tests were complete, the authors and laboratory technicians tried to incorporate the laser cutter by allowing students to engrave a picture or message of their choosing onto the sides of their bottle openers. It was quickly discovered, however, that aluminum does not engrave well on a laser cutter without first applying a special engraving spray to the aluminum part. While the first four students were unable to engrave their bottle openers, the laboratory technicians were able to test various sprays and laser settings prior to the machining portion of ME403 and students in the main course were able to engrave their bottle openers as planned. The technicians achieved the best results using TherMark® LMM-14 Black spray performed with the laser set to 20% power and a speed of 25 inches per second.

Once the semester commenced, the instructors began building excitement about the machining portion of the course early on by hanging poster-sized engineering drawings of the bottle openers on the wall of the classroom and passing around a finished bottle opener so students would be familiar with what they would be asked to make later in the semester. When the machining portion arrived, the students were excited to get started and seemed more motivated than in previous years.

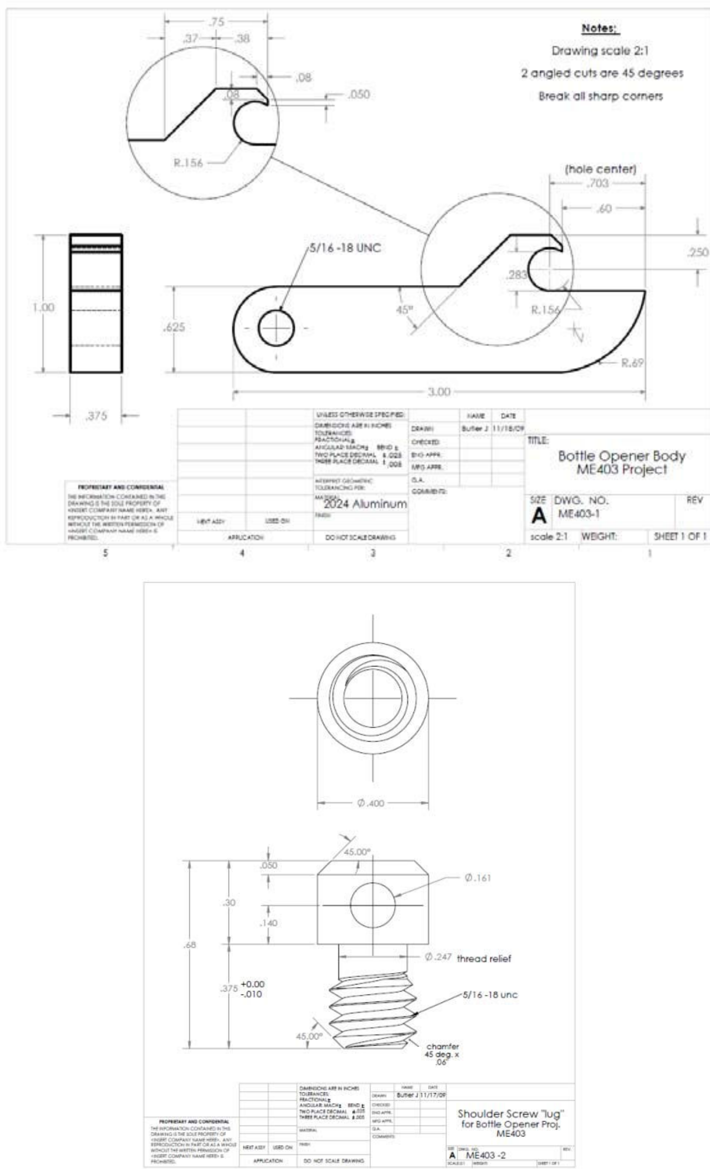

Figure 5: Engineering drawings of the bottle opener body and lug (larger views included in appendix)

Safety, as always, was a primary concern, especially with new machinists and the short period of time available for such an ambitious project. Prior to beginning the machining sequence, all students were required to watch a series of safety videos, some of which showed graphic images of accidents in machine shops. The students also received daily safety briefings from instructors and laboratory technicians while in the machine shop. Additionally, students were closely supervised by experienced laboratory technicians at a ratio of five students or less to one technician throughout the project. This focus on safety and close supervision by experienced machinists has resulted in a nearly flawless safety record over the previous three years of machining with the only injuries being two small superficial cuts.

In order to speed the machining, one hour was spent having students do a full layout of the bottle opener on the side of their aluminum billet. Students were provided with an approximately 3.5" long 0.38" x 1.00" piece of 2024 aluminum rectangular bar stock that was milled on one edge to provide an accurate staring reference for the students. The students first coated the billet with Dykem® layout fluid on one side and then scribed an accurate image of the bottle opener body using calipers, machinists' rules, squares, dividers and other basic layout tools. This forced the students to think through the dimensions and all of the operations they would be required to perform prior to touching any of the machines.

The students were assigned their machining sequences to ensure that there were never too many students on any one machine. Students were provided with a total of 13 hours of in-class instruction and work time. These blocks were broken down into a one-hour layout session and six 2-hour instruction/machining sessions. During the latter 2-hour sessions, students would receive a block of instruction from the laboratory technicians on the machine they would be using and then they would start their work on that particular machine. Since the bandsaw and sander/grinder portions were shorter than the other machines, they were put together on the same day of instruction. This opened up the final day in the machine shop as a 'free' day without formal instruction that allowed students to finish any operations that were not complete or that needed to be restarted due to an error. After all students were finished with the project, the instructors 'graded' them by providing cold bottles of soda that the students were required to open with their new bottle openers. This final test provided a festive atmosphere enjoyed by both the students and instructors.

The Results

The actual machining of the bottle openers went smoothly although the lathe seemed to be the slowest operation. This was primarily due to the fact that initial instruction on this machine took longer in order to fully familiarize all students with lathe operations including adjustment of the automatic feed system and speed settings. For that reason, the final 'free' day of machining did see a some students waiting in line to go back and complete their lugs on the lathe.

The new bottle opener project seemed to be effective based on several indicators. Course-end survey feedback was the first of these. Course-end feedback at West Point is collected using a 5-point Likert scale. Students respond to survey statements by assigning values from 1: Strongly Disagree to 5: Strongly Agree. Historically, it is rare for collective student ratings to drop below 3.0, so the main area of interest in this scale is the region between 3.0 and 5.0. Within this range, changes of 0.1 or greater are considered significant.[5] The following survey excerpt indicates that the new bottle opener project positively affected student assessment of the course's machining instruction, as demonstrated by a +0.17 delta in assessments from ME403 students from Academic Year 2008 (4.58) to Academic Year 2009 (4.76) for the question "This course increased my ability to apply manufacturing techniques and processes to machining components" and a smaller +0.06 delta (4.63 to 4.69) for the question "The Manufacturing/Machining Labs contributed to my learning in this class."

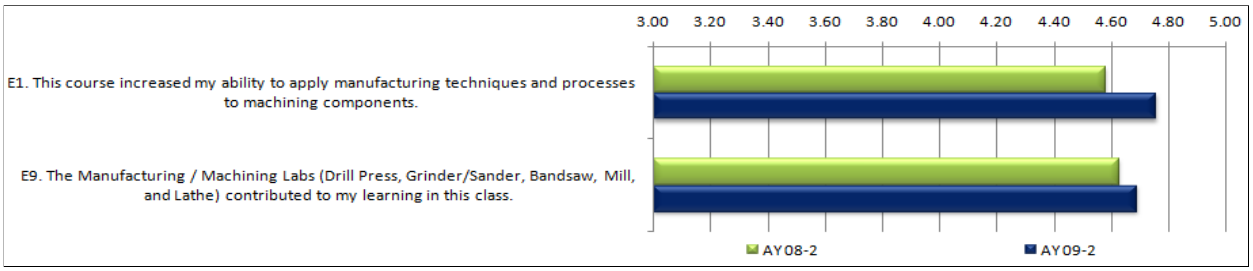

Figure 6: Course-end feedback showed an improvement in student assessment of the course's machining instruction

Students were also asked to answer the question "If you were course director, what would you keep in the course next year? Why?" on the course-end survey. The following comments were representative of those received with respect to the bottle opener:

- *The manufacturing/machining of a bottle opener because it effectively introduced all of the machines*
- *Bottle opener- I wanted to make the best product because I got to keep what I made*
- *Turbine project and bottle opener, I have confidence with the machine shop because of this project*
- *The bottle opener lab. It was cool and allowed people to get familiar with the machine shop*

Student performance on the final water turbine project also showed an enormous improvement over previous years. Several of the students' turbines set new records with respect to the amount of weight they lifted and it was apparent that the overall build quality and precision of the turbines was much better than previous years. However, it is important to note that only some of this improvement can be directly attributed to the additional machine shop training since incorporation of the department's new laser cutter also helped speed production of some of the students' components.

Finally, students also scored better on the term-end exam with respect to machining knowledge. An assessment of only those questions directly related to machining on the final exam showed that students earned a 6.53% higher average over the previous year's class on those questions.

There was also some room for improvement to the machining portion of the course, mainly with respect to having more time, as indicated by student answers to the question "If you were course director, what would you change in the course next year? Why? How?" The following comments were representative of those received with respect to the bottle opener:

- *Add more machining classes*
- *Provide one more class period for the bottle opener*
- *For the bottle opener classes, I feel that using each machine to[make] the part should be explained with a little more detail. I [felt] a little confused on how to use the lathe initially*

Also, it became obvious during construction of the water turbines that students needed more instruction on some techniques that were not covered by the bottle opener – namely, using the tailstock on the lathe both for drilling and with a live center to support long shafts. Students also did not learn how to use a boring head on the mill or how to press fit bearings when making the bottle opener – both of which were tasks that were important to know for the construction of the transmission for their water turbines. Additional class time had to be set aside to teach those techniques as students began working on their turbines.

Conclusions

Incorporation of a bottle opener project to help teach machining was an effective way to increase student motivation and learning in the hands-on machining portion of ME403. This increased involvement in the machine shop led directly to better performance both on the course's final project and on the final exam. Feedback from students was generally positive although several students said that they would like to have spent more time in the machine shop. The lathe was the most difficult machine for students to learn and will most likely need additional time for instruction in future iterations of the course. Although still too early to make any solid judgments, students who

Figure 7: The lathe was the most time-consuming machine for the students

made the bottle opener in ME403 last year have been showing increased confidence in using the machine shop during their senior capstone projects, requiring less additional instruction from laboratory technicians thus far.

Recommendations

Based on student feedback and observations of the class, the authors plan to allocate one additional lesson to the machining portion of the course which will focus specifically on covering those tasks related to the water turbine project that are not covered by machining the bottle opener. These tasks are mostly related to the lathe which seems to have been the most difficult for the students to grasp. The hope is that this additional block of instruction will help alleviate this problem.

Figure 8: Final 'testing' of bottle openers was conducted on bottles of soda

Based on the considerable amount of time spent planning and testing the bottle opener design described in this paper, the authors recommend that any programs wishing to incorporate a similar project conduct at least one or two test runs with inexperienced students or others to help iron out problems and prepare the instructors for what they can expect during a full-sized class.

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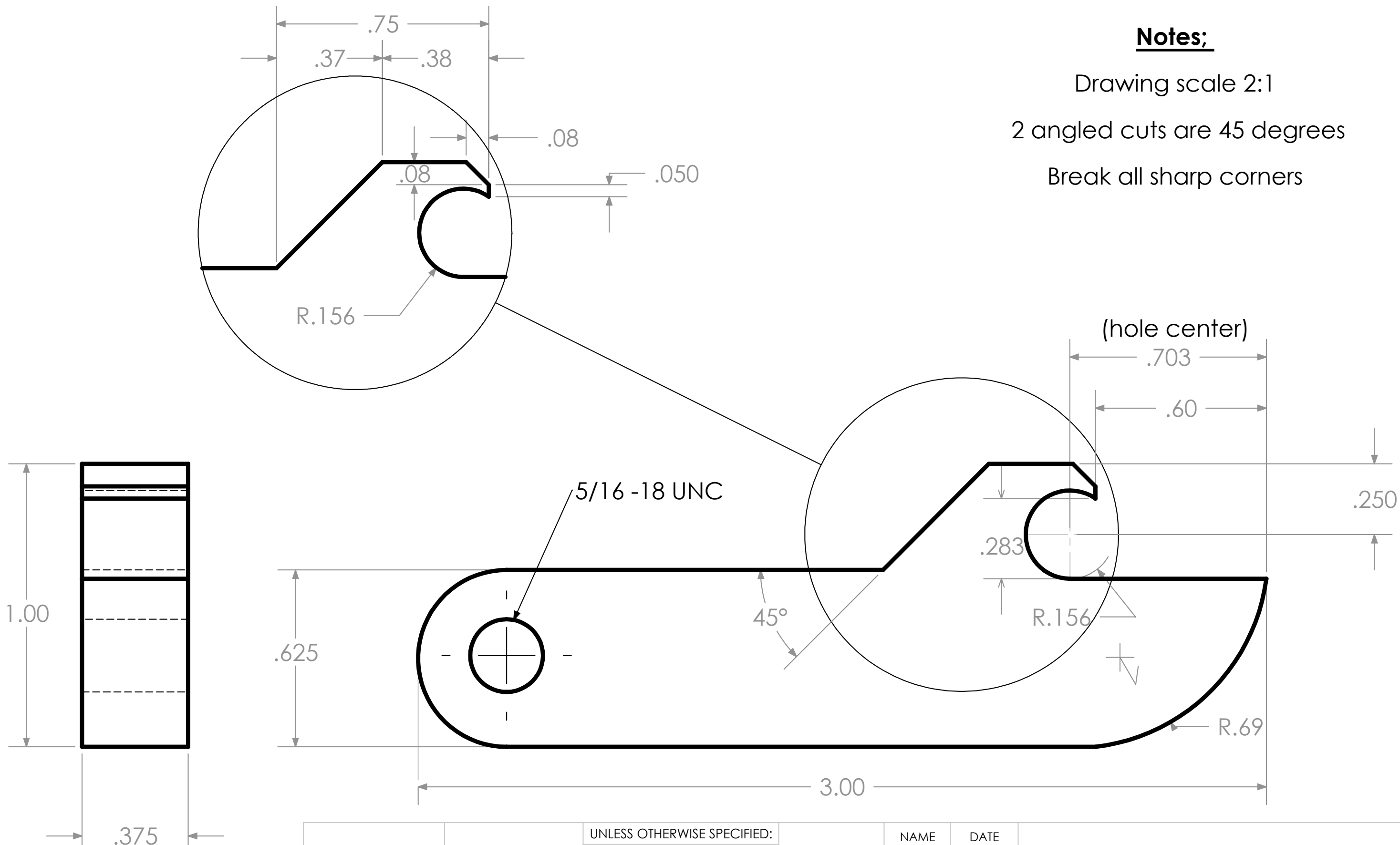

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
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FRACTIONAL ±
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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL 2024 Aluminum

FINISH

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APPLICATION

DO NOT SCALE DRAWING

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Bottle Opener Body
ME403 Project

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scale 2:1 | WEIGHT: | SHEET 1 OF 1

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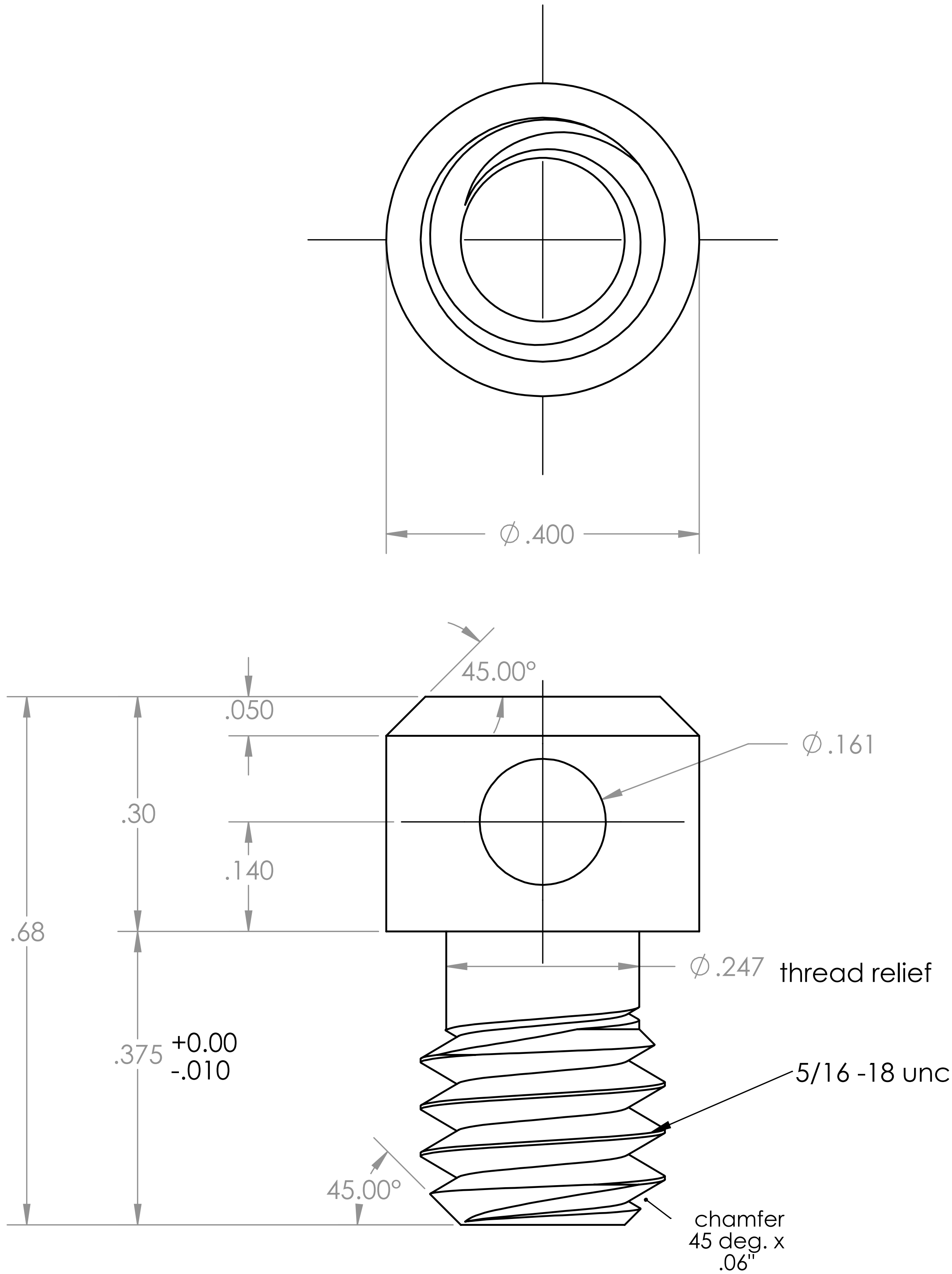

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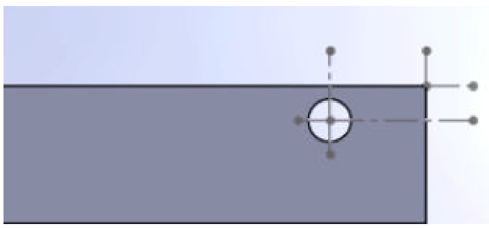
Shoulder Screw "lug"
for Bottle Opener Proj. ME403

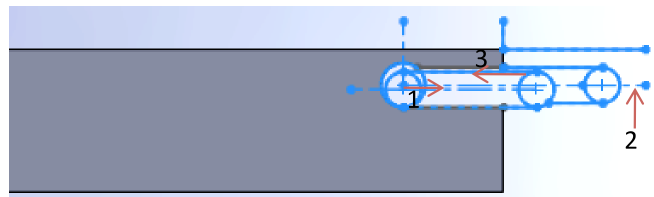
SIZE A | DWG. NO. ME403 -2 | REV.

SCALE:2:1 | WEIGHT: | SHEET 1 OF 1

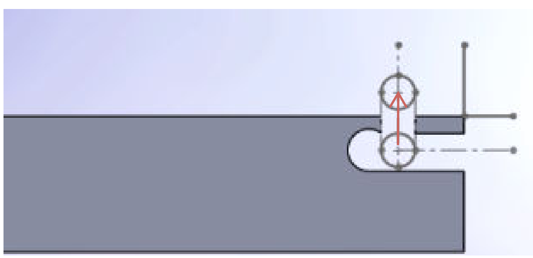
Mill Operations



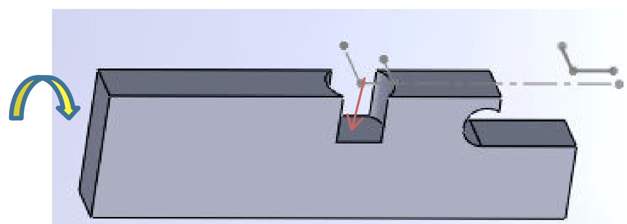
(1) **Plunge Mill** 5/16” end mill



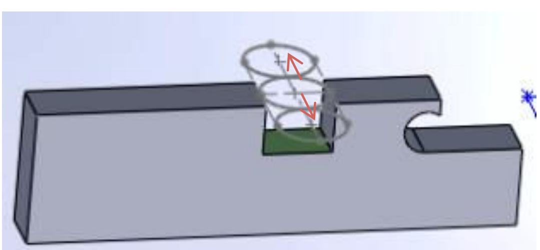
(2) Slot Mill ¼” end mill **Peripheral Milling** (2 passes offset)



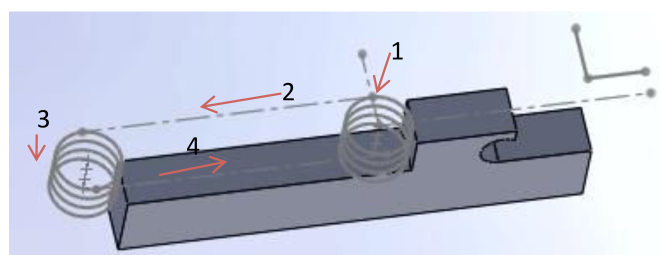
(3) **Slot Mill** Cut off ¼” end mill



(4) Rotate part 90 deg. about X axis, Plunge ½” end mill

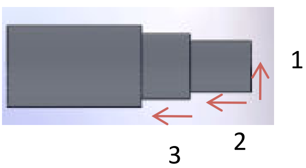


(5) Slot Mill (sharp corner at base) ½” end mill

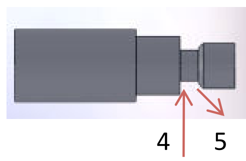


(6) **End Milling** to depth (multiple passes)

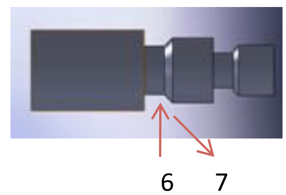
Lathe Operations for Lug (Top View)



(1)Facing, (2&3)Turn & Shoulder face

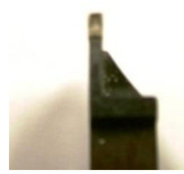


(4)Groove, (5) back chamfer

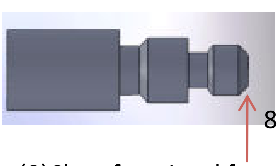


(6)Groove to (7) chamfer Head of Screw

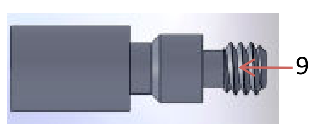
Tool used



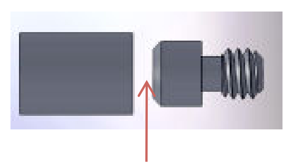
Note; take very light cuts for steps 5&7 when using cutoff tool.



(8)Chamfer – Lead for Threading



(9) Threading – Die used



(10) Cut-off (parting)

Tool used