

## **Board 93: MAKER: Improving the Quality of Mechanical Engineering Senior Capstone Designs by Incorporating Geometric Dimensioning and Tolerancing During the Concept Design Phase**

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# **MAKER: Improving the Quality of Mechanical Engineering Senior Capstone Designs by Incorporating Geometric Dimensioning and Tolerancing During the Concept Design Phase**

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## **Abstract**

**MAKER:** We demonstrate that incorporation of Geometric Dimensioning and Tolerancing (GD&T) into engineering drawings in a Senior Design reduces the number of design iterations, increases design quality, and enables both the handoff to manufacturing and easier manufacturing. This demonstration is accomplished by a Senior design group manufacturing an Alpha style Stirling Engine out of 6061 Al using a manual lathe and mill and using GD&T. We will compare this engine to another Stirling Engine built by a Senior design group in 2015 that was based on the coordinate dimensioned design by Senft [1]. We compare the time it takes to manufacture both designs, as well as the design quality once they are fully manufactured.

The implementation of GD&T is not commonly taught in undergraduate mechanical engineering (ME) curriculums. More commonly, traditional coordinate dimensioning is used in the engineering drawings. If GD&T is taught in the curriculum, then it is not common the students get the opportunity to manufacture an assembly with tight tolerances that contained GD&T in the engineering drawings. For this Senior Design project, the students learn to machine all the parts to meet the GD&T specifications, and familiarize themselves with the necessary tools required to properly manufacture the Stirling Engine assembly.

For the Stirling Engine that is manufactured using traditional coordinate dimensioning, we demonstrate issues such as the piston jamming inside the cylinder, requiring a significantly longer time to manufacture the engine than when GD&T is used.

The ability to practice GD&T in student engineering drawings, as well as machining assemblies with GD&T specifications makes a more competent mechanical engineer, who knows how to reduce the total time and budget required to complete a satisfactory design project.

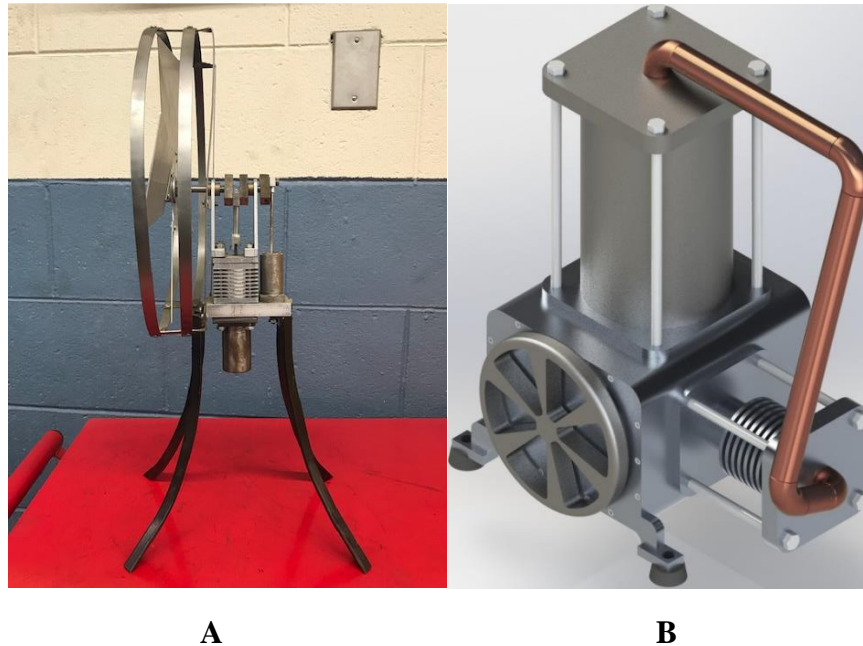
## **Introduction**

In the Fall and Spring semester of their Senior year, the Mechanical Engineering students are required to design and fabricate a machine for their capstone projects. A popular machine for the Seniors to design and manufacture is a Stirling Engine. In the Fall semester, each design group is required, among others, to create their designs using a Computer Aided Design software and produce engineering drawings for all of the parts they plan to manufacture. Prior to this academic year, all the design groups dimensioned their engineering drawings using the coordinate dimensioning system. In 2015, one group decided to make a Ringbom Stirling Engine according to the design by Senft [1].

All of the parts for this Ringbom Stirling Engine were machined to within the specified coordinate dimension tolerances. Four students machined different parts for this Stirling Engine. This Stirling Engine was made from 6061 Al and A36 Steel using a Jet lathe and Bridgeport Mill. Despite machining all the parts to within the specified tolerances, the Stirling Engine failed to operate properly. The crankshaft had too much runout and the position of the hot cylinder was incorrectly placed. When trying to rotate the fan by hand, the crankshaft would get stuck after ~45 degrees of rotation. This specific Ringbom Stirling Engine design is known to work [1] provoking

the question for the Seniors why their Stirling Engine didn't work if it was fabricated to the correct coordinate dimension specifications.

This academic year, one design group is fabricating an Alpha type Stirling Engine out of the same materials but including GD&T into their engineering drawings. The rationale for doing this is to ensure that whoever machines any of the parts, all of the Stirling Engine parts will assemble together perfectly. In addition, this would force the design team to focus not on just designing for theoretical operation, but also for ease of fabrication. Figures 1a and 1b shows the design for the Ringbom Stirling Engine and Alpha style, respectively.



**Figure 1:** (A) A picture of a Ringbom Stirling Engine fabricated by a 2015 Senior Design Capstone group. (B) A rendering of the Alpha Stirling Engine the students are manufacturing this semester.

## Background

GD&T is an established system to assure that whoever and wherever a part is fabricated, it will fit perfectly into the assembly every single time [2]. Many of our alumni have requested that GD&T be taught in the CAD or Senior design courses. GD&T is most commonly taught at the community college level over one semester in machine tool technology programs or in on the job training in industry [3].

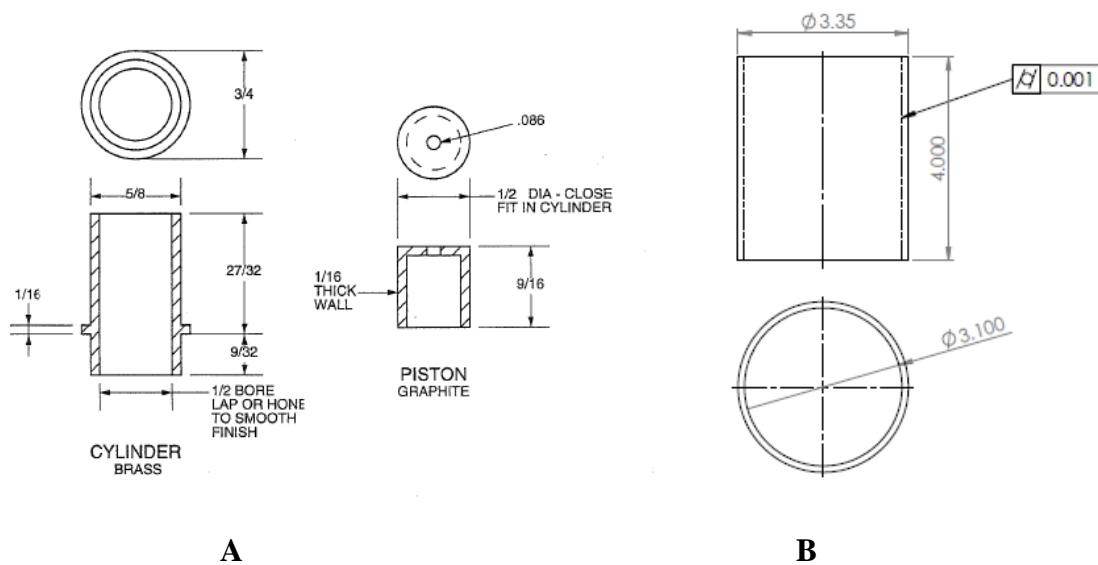
The incorporation of GD&T in mechanical engineering curricula is becoming a common occurrence [4-5]. Design engineers should ideally create designs that satisfy customer needs as well as make fabrication easy. The implementation of GD&T into the design drawings is known to provide clarity and ultimately reduce wasted parts and cost spent on fabrication [2].

The fabrication of pre-designed Ringbom Stirling engines as projects for manufacturing classes in mechanical engineering and machine tool technology curricula is also common [6-9]. The Stirling

Engine fabrication project provides a superb learning platform to better understand how different machined parts assemble together as well as better understand the basics of machinery design.

## Design and Manufacturing

This academic year, the Stirling Engine Capstone group has designed an Alpha type Stirling engine from scratch. In the Fall semester, they did analysis to size the pistons, cylinders, connecting rods, crankshaft, and flywheel for the required power output from a generator given that the hot cylinder is heated at a constant temperature. At the end of the Fall semester, the students created a CAD design and engineering drawings incorporating GD&T. Figure 2A shows an engineering drawing of the Ringbom Engine hot cylinder containing coordinate dimensions and 2B the Alpha Engine hot cylinder with GD&T.



**Figure 2:** (A) Ringbom Engine Engineering drawing for the hot cylinder containing coordinate dimensioning [1]. (B) Alpha Engine engineering drawing for the hot cylinder containing GD&T.

The engineering drawing in Figure 2A for the hot cylinder and piston appears to call out for a smooth sliding fit. However, if the two parts are to be machined according to those dimensions, there would be plenty of room for error. For instance, the drawings do not call out for a runout tolerance. If a 3-jaw chuck were used, there could be runout greater than five thousandths of an inch which would prevent a smooth sliding fit. The student machinist may eventually iterate machining the parts such that the sliding fit is ensured, but then material, time, and ultimately money is wasted.

If any student were to machine the parts shown in Figure 2B according to the dimensions and tolerances specified, the two parts will have a smooth sliding fit. The student machinist would know that in order to reduce runout to 1 thousandths of an inch, a 4-jaw chuck, turning between

centers, or 5C collet would need to be used. The students would be required to precisely determine the geometric dimensions and tolerances to ensure reduced manufacturing time and quality.

## **Conclusion**

During this current Spring semester, the Alpha Stirling Engine team are in the process of machining all the parts using a Jet lathe, Bridgeport mill, and Haas CNC mill and lathe. In order to machine all the parts to the required tolerances, they will learn how to use a 4-jaw chuck, tram the head of a mill, and how to use a dial indicator. By the end of the semester in April, they will have learned how to perform the correct theoretical analysis to size the Stirling Engine components, how to design and dimension the components to ensure proper function of the Stirling Engine, and how to use the correct tools to manufacture the Stirling Engine according to the GD&T tolerances. By doing all of this, the quality of their Senior Design Capstone experience will be improved.

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