To: Dr. Constantin Ciocanel
From: Matthew Batten, Cody Burbank, Thaddeus Grudniewski, Jonathan McCurdy, and Joy Weber
Date: April 18, 2014
RE: Design, Prototype Description, and Testing Results

The design for the MSMA Lateral Loading Device Project allows the user to impart a force on a magnetic shape memory alloy (MSMA) sample. Through the use of a force feedback system, the force remains constant as the variants within the MSMA change due to a magnetic field.

The final design uses a PAS015 piezoactuator and a Honeywell model 11 force sensor. These two units are fixed in place on the Instron machine being used for this test via stainless steel fixtures. As the actuator imparts a force on the MSMA, the force sensor records that force. This data is then fed to a computer program which was written in LabView. This program then tells the actuator to adjust accordingly if the force sensor receives an undesired change in force. Thus a constant force is achieved.

Through testing, several design changes were completed. These changes allowed a better fit of all the components as well as a better ease of installing the components. After the design changes were completed, the team was able to complete a more accurate testing procedure.

From these results, it was concluded that the goal of the project is a possible outcome. However, at the current time, these results were not achieved. Through more testing and refining of the design components, the end result should be what was originally sought after.

MSMA Lateral Loading Device

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Team 10

Final Proposal

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2014

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List of Contents

List of Figures

List of Tables

Abstract

The objective of this project is to design and fabricate a testing apparatus that is able to apply force in a lateral direction to an MSMA specimen. The specimen is already being subjected to a constant magnetic and a compressive force in a standard laboratory setting. The apparatus needs to be able to accurately apply a force of up to 200N to a 10mmx12mm area that is under a constant magnetic field. To this end a prototype was designed out of aluminum and stainless that would feature two towers, one with an actuator and one with a force transducer. The force transducer will be used to implement a force feedback system which will keep the force on the specimen constant despite the deformations in the material (increasing/decreasing force as needed).

In order to minimize deformation the towers are made out of 303/304 steel and the tips that are placed against the specimen are made of non-abrasive aluminum. The choice to use 303/304 steel presented some challenges during manufacturing which resulted in a few design changes.

The next major step after the initial fabrication was the development of a program that would allow force feedback. The decision was made to use LabVIEW as a means of creating a user interface. This program would take an inputted force and using force measurements from the transducer readjust the force output from the actuator.

A test apparatus was built so that tests could be conducted without the full testing setup in the machine shop located in building 98C at Northern Arizona University to facilitate easier programming. This test apparatus was designed to show how force would vary with the force feedback and then with the force feedback program running.

As testing was completed it was shown that the testing setup would eventually conquer the original goal. However, at the time more testing needs to be completed in order to refine the results.

Chapter 1. Introduction

This team has been asked to design an apparatus capable of adding an additional direction of force to the client's testing setup in Northern Arizona University's Machine Shop located in building 98C. The client, Dr. Ciocanel, is a member of the faculty at NAU who is researching smart materials and, in this particular case, an MSMA. MSMA's are materials that have properties tied to magnetic fields (they exhibit strain). The mechanical properties of the MSMA Ni_2MnGa are being determined in his experiments. More specifically, the magnetization vector rotation is what is being studied. This rotation occurs when the material is subjected to a constant magnetic force and a non-constant force in any other direction though, in this particular test the force is a compressive force pushing down vertically. This vertical force causes vectors to change direction and, in turn, the material to change shape. After the compressive force is released the MSMA will attempt to return to its original shape. There are three "variants" that an MSMA will progress through the fully vertical variant (where the sample is at its tallest), an in-between variant, and a horizontal variant (where the sample is at its widest). This project will attempt to constrain the sample in the in-between stage so Dr. Ciocanel can obtain test data from this variant.

Chapter 2. Problem Formulation

The Instron machine which Dr. Ciocanel uses applies a compressive load to the MSMA. He is able to use this setup along with a set of magnetic dipoles in order to discover the MSMA's mechanical properties. Even with his current setup, he is unable to run all of the tests required. There is a need for the MSMA to be constrained in a direction normal to the Instron's compressive forces in order to investigate its reactions. The goal for this project is to create a system which will allow him to carry out this operation.

The system designed must be able to apply a force of up to 200 Newtons to the MSMA, with a minimum resolution of 16.5 Newtons. This force is being held in order to constrain the MSMA from changing shape. Because the MSMA will attempt to change shape during testing, it will attempt to apply a load to the system. The system must be able to sense this load, and adjust accordingly so that a constant load is imposed on the MSMA. This system will be used in a lab environment.

The system must be effective, cost efficient, and precise, whilst interfacing with the current Instron setup. In order to achieve these goals, a set of constraints must be met. These constraints are listed below:

1) Full cost under $2,500:
    This includes all the parts and materials used within the design.
2) Capable of applying a constant force up to 200 Newtons:
    This is to hold a certain amount of strain in the MSMA.
3) All materials used must be non-magnetic:
    The test is run under a strong magnetic field. Therefore, the material selected must not be affected.

4) The width of the material in contact with the MSMA must be no greater than 10 mm: The distance between the magnetic dipoles is 10 mm. If our design has a width greater than the specified value it will not be able to make contact with the MSMA.
5) The height of the material in contact with the MSMA must be no greater than 12 mm: The distance between the electro dipoles is 10 mm. If our design has a width greater than the specified value it will not be able to make contact with the MSMA.

Along with constraints, there are requirements which must be met for this project. A Quality Function Deployment (QFD) compares the customer's requirements with the applicable engineering requirements. The QFD, Table 2.1, shows the relationships between these requirements and helps to highlight the importance of each.

Table 2.1: QFD Matrix

		Engineering Requirements							
		Length	Width	Cost	Weight	Magnetic Response	Strain	Material Strength	Voltage
Customer Requirements	1. Inexpensive			*X*					
	2. Withstand Force						*X*	*X*	
	3. Applied Force						*X*		
	4. Provide Feedback								*X*
	5. Limited Area	*X*	*X*						
	6. Portable	*X*	*X*		*X*				
	7. Non-magnetic					*X*			
	8. Adaptable with Current System	*X*	*X*		*X*				
	Units	mm	mm	$	kg	T	%	Pa	V
	* To be determined	10	10	2500	*	0	*	*	*
		Engineering Targets							

It is important for us to compare the engineering requirements to see how they affect each other. This helps make important engineering decisions during the design process. The House of Quality, Figure 2.1, represents this information.

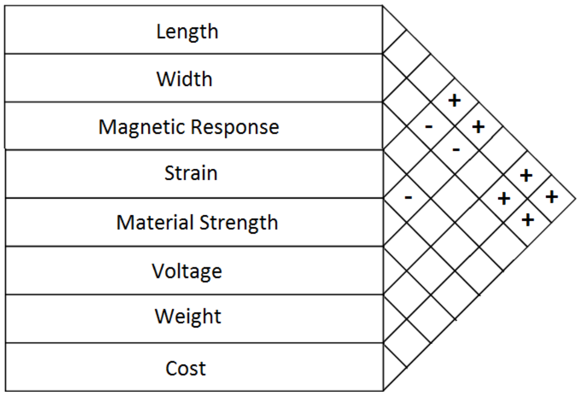

Figure 2.1: House of Quality

Chapter 3. Proposed Design

3.1 Final Concept Selection

When creating the design, the team focused first on the two identified subsections, actuation and force sensing, which were required to complete the problem requirements. Using the design constraints the team began to research available products. In the end, a piezoactuator and a strain gauge force sensor were selected, and a mounting setup was designed. This design can be seen in Figure 3.1 below.

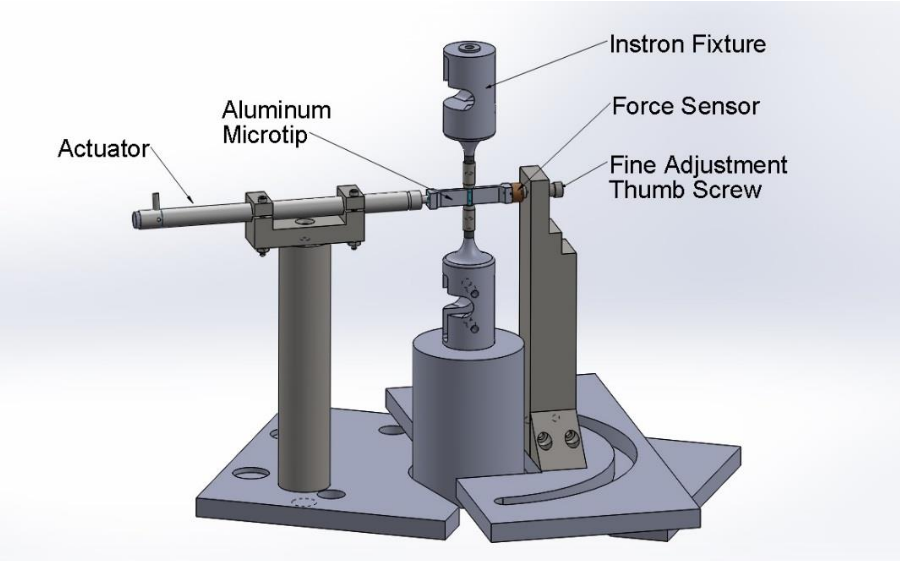

Figure 3.1: Full Assembly

The system consists of a force sensor and an actuator connected through a feedback control program on a computer. The force sensor is mounted on a rectangular steel column, and the piezoelectric actuator is mounted on a cylindrical steel column. The cylindrical column has a threaded end which screws directly into the aluminum bas plate. While the rectangular column is held in place by two custom-made triangular brackets. Two aluminum micro-tips that are in contact with opposite sides of the MSMA in the lateral direction are connected to the force sensor and actuator.

3.2 Actuator

For the actuator, the THORLABS PAS015 Piezo-Actuator with the T-Cube Piezo Controller was selected. This product did not come with any custom mounting, therefore the team developed the design seen in Figure 3.2.

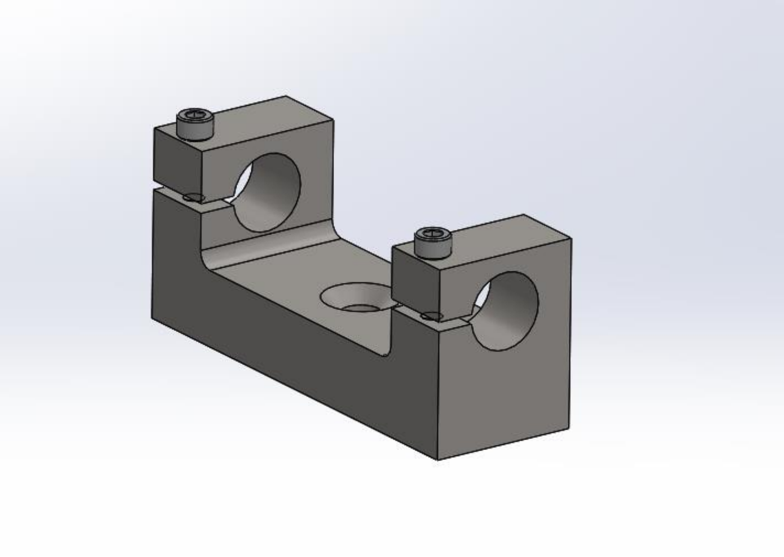

Figure 3.2: Actuator Mount

This mount works by creating a compressive force on the actuator’s cylindrical shell, through the tightening of two set screws. The mount is screwed into the top of the cylindrical column allowing the user to make slight changes to the actuator position prior to testing.

3.3 Force Sensor

The Honeywell Model 11 strain gauge was selected for this design. This strain gauge was selected because it is capable of measuring the forces that are expected for this project and the client already had this product. After verifying that the strain gauge could be used by the team, the force sensor mounting assembly was created. The cut-out view of this assembly can be seen in Figure 3.3.

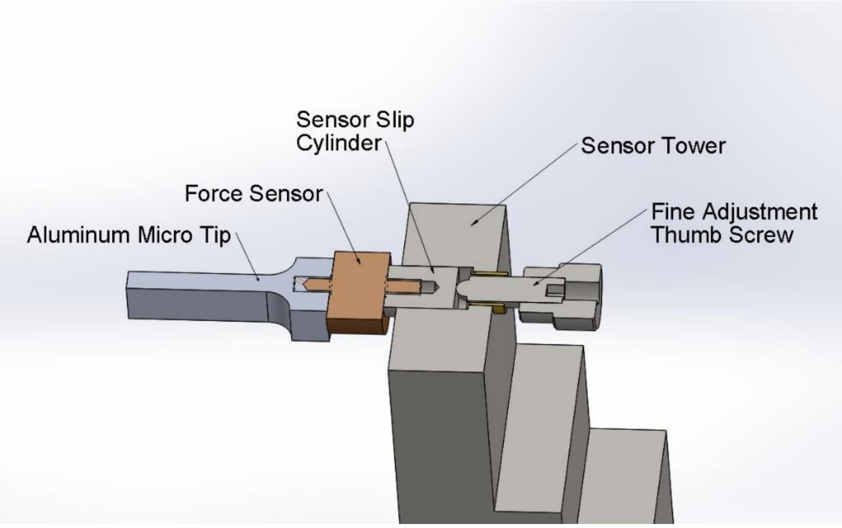

Figure 3.3: Force Sensor Configuration

With this design, the micro-tip will be able to move laterally toward or away from the MSMA without spinning and it is compact enough to fit under the magnetic dipole system. The force sensor screws directly into the micro-tip on one end and a slip cylinder on the other. The user can turn a thumb attachment which turns a high precision screw and pushes the slip cylinder. This design meets all the requirements while maintaining a reduced cost.

Chapter 4. Prototype Fabrication

4.1 Fabrication Background

The fabrication of the proposed design was done completely by members of the team in the NAU Machine Shop. Most of the machining was performed on a milling machine. However, some of the machining was machined using a lathe, namely that done on the actuator mounting tower. The material used was mainly 303 and 304 stainless steel, with some minor parts machined in aluminum.

4.2 Initial Fabrication and Threading Complications

The team machined the aluminum micro-tips first because of their easy machinability. This was followed by the actuator mounting bracket, due to the importance and complexity of the part. In the process of machining this component, the difficulty of machining in stainless steel became apparent. This is mostly because this particular machine shop is not equipped to handle such a material very well. As such, there was a limited cache of carbide end-mills, the appropriate tool for this material. Unfortunately, this deficiency extended to the supply of taps as well. In designing this product, the team did not take these limitations under consideration. The threaded hole in the actuator mounting bracket was simply too small to be tapped with the resources at hand, a realization the team came to while braking a tap and end mill in the process.

4.3 Design Revisions

The problems that arose due to the threading led to a necessary impromptu design change in order to maintain schedule. Instead of trying to thread such a small hole in the bracket, the team decided to drill a through-hole (now on the other side of the bracket) to allow the use of a nut and bolt setup to accomplish the same task. This design change can be seen in Figure 4.1.

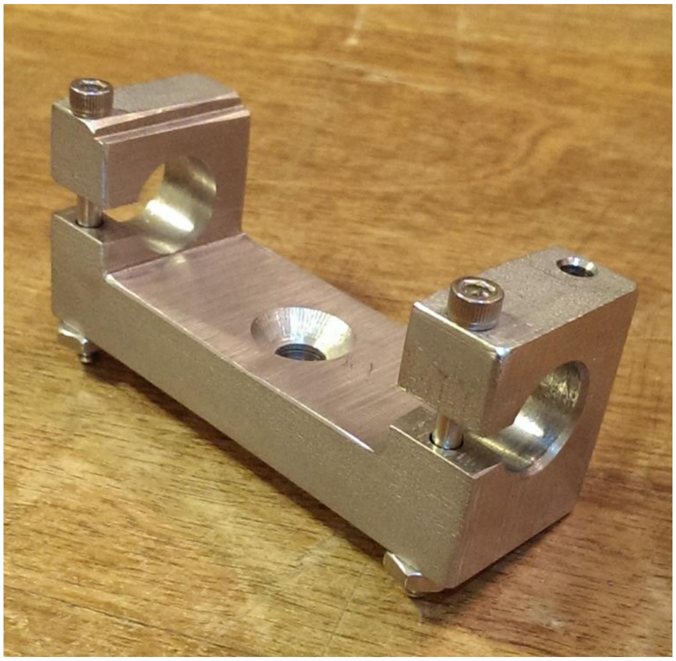

Figure 4.1: Actuator Mount with Design Revision

With these new limitations in mind, the team examined all the other designs and revised them where necessary, so as to preclude this problem in the future. The only other design change was that of sensor tower mounting system. Where originally, the design involved tapping four holes into the bottom of the tower, where the triangle brackets would be clamped using a four separate bolts. In the updated design, two through holes were drilled in the bottom of the tower, and two threaded holes were tapped into only one of the triangles. Two bolts would run through one triangle and tower to be threaded into the triangle on the other side, as seen in Figures 4.2-4.

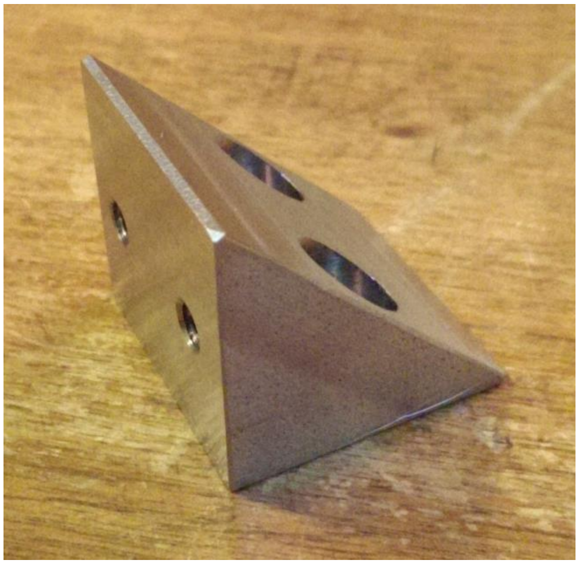

Figure 4.2: Triangle Bracket

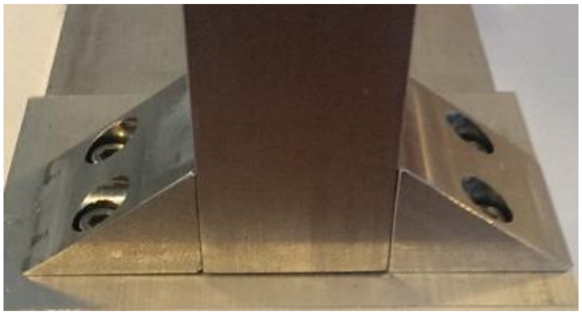

Figure 4.3: Triangle Brackets Attached to Tower (1)

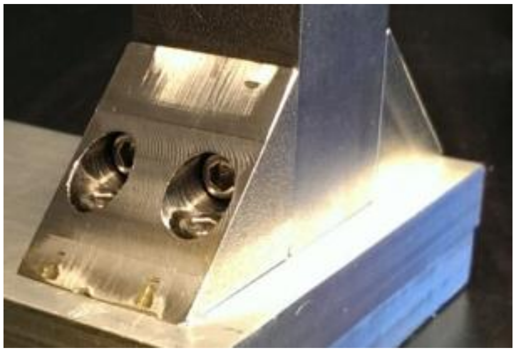

Figure 4.4: Triangle Brackets Attached to Tower (2)

4.4 Initial Assembly

The machining of the remaining components proceeded smoothly. After the triangle brackets and the sensor tower were completed, only the actuator tower and a few smaller miscellaneous parts remained to complete the setup. The complete setup can be seen in Figure 4.5.

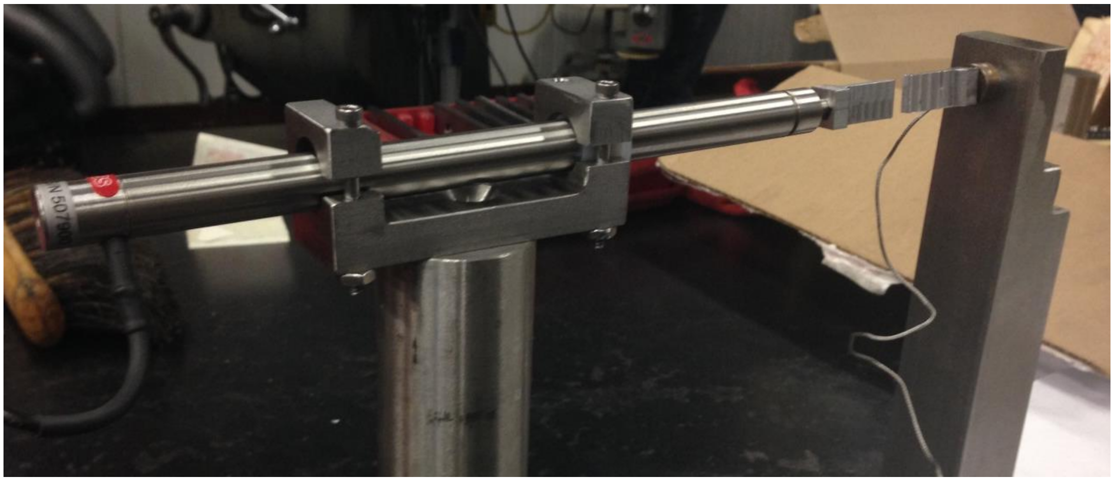

Figure 4.5: Initial Assembly

4.5 Mobile Setup Base and Final Design Modification

Additionally, the team desired some way to easily test the design without installing it in the client's existing system every time. This task was accomplished by machining an aluminum base with the same relevant dimensions. This allowed the team to test the actuator and load cell together without being in the client's lab. In testing with this base, another issue became evident. When the actuator was running at maximum force, the force sensor read only a value of 2.5 N. The team believed this to be a problem with the design of the actuator mount; specifically, the plastic bushings holding the actuator were either allowing it to slip, or were compressing. Either way, the actuator was not allowed to apply its full stroke upon the load cell.

In an effort to fix this flaw, a design was drafted up to restrict the unwanted motion of the actuator. After buying material and two days in the machine shop, this component was finished. This finished part as well as the final assembly can be seen in Figures 4.6-7.

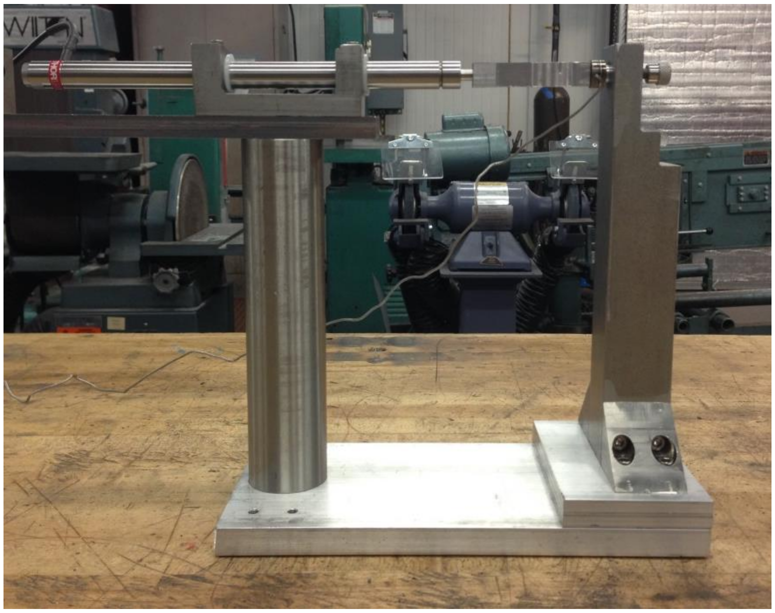

Figure 4.6: Final Testing Assembly (1)

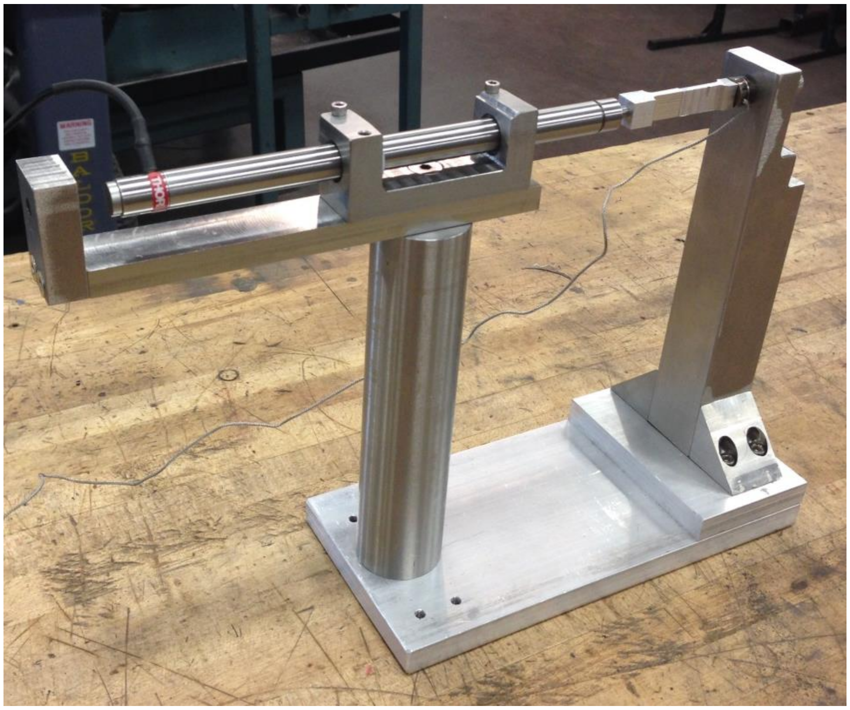

Figure 4.7: Final Testing Assembly (2)

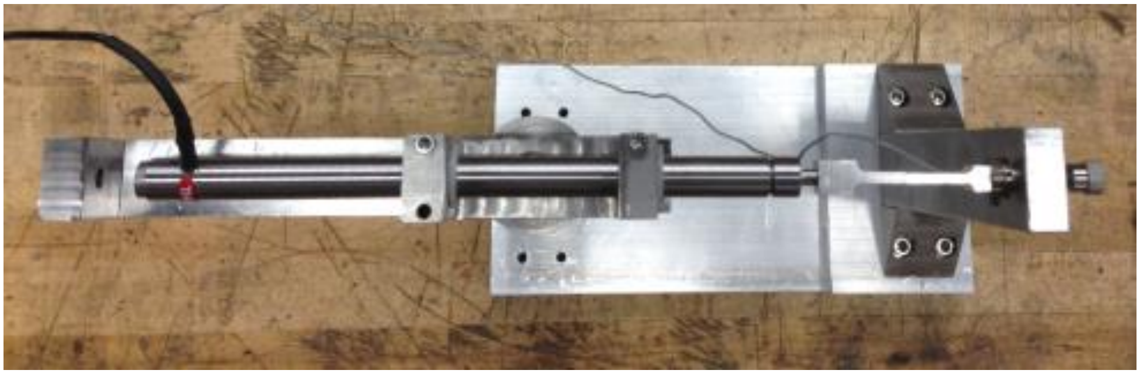

Figure 4.8: Final Testing Assembly (3)

Chapter 5. Testing and Results

5.1 Testing Environment

The testing environment for this product is in a room temperature laboratory setting. In this setup the MSMA specimen is variably loaded vertically using an Instron machine, has a constant magnetic field being applied in the horizontal direction, and is loaded by a feedback controlled force in the lateral direction. A close up of the specimen setup can be seen in Figure 5.1.

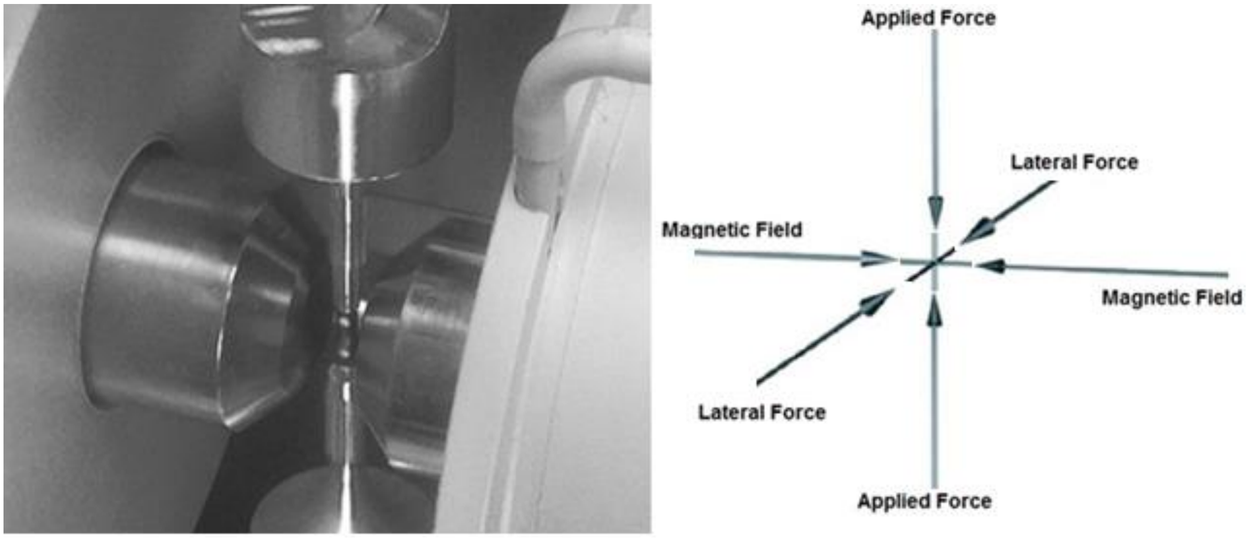

Figure 5.1: MSMA Specimen Setup

5.2 Feedback Control

The feedback system was constructed using THORLABS APT System Software emulated within LabVIEW. LabVIEW is capable of using ActiveX technology to communicate with the APT T-Cube Piezo Controller. The LabVIEW Block Diagram for this feedback setup can be seen in Figure 5.2.

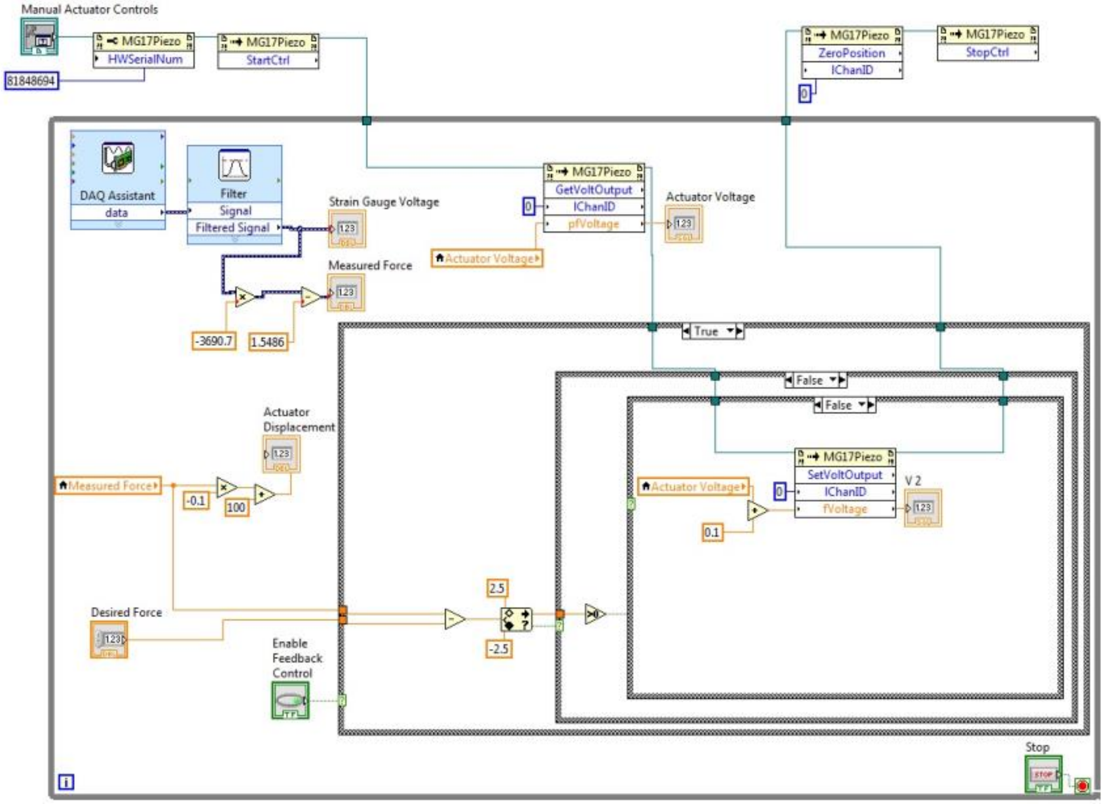

Figure 5.2: Block Diagram for Feedback Control

In this diagram LabVIEW is able to control an APT motor or Piezo Controller depending on its serial number. A full list of code definitions can be found in **Appendix C** and explains what each component of the block diagram does. The front panel, where the user will be interacting can be seen in Figure 5.3 and contains manual actuator controls, and various value displays.

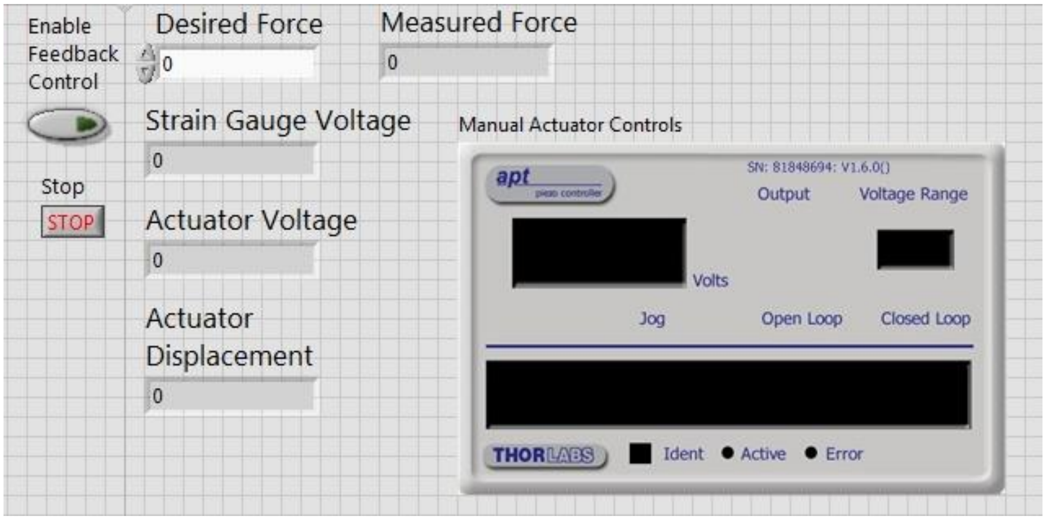

Figure 5.3: Front Panel View for Feedback Control

The logic of the feedback control is as follows: The user can start the program and then manually adjust the actuator voltage and screw placements on the system to set the required initial force. For comparison purposes the user must input a value in the “Desired Force” indicator on the front panel. After the force has been set by the user the “Enable Feedback Control” Boolean can be activated and the vertical loading test may begin. During this test the program will compare the “Measured Force” registered by the NI USB 6210 Data Acquisition Device with the user’s “Desired Force.” If these forces differ by a value of ±2.5N the output voltage of the actuator will be adjusted to alleviate the difference and create a constant lateral force on the MSMA specimen. After the test, the user can press the stop button on the front panel and the actuator’s voltage will be reset to zero and the controller will power down.

5.3 Results

Through unrecorded data it can be shown that the lateral strain applied to the MSMA specimen can be controlled through feedback control for strain above or equal to 2 MPa. The millivolt change for a strain of that magnitude has been corrected via the actuation range of the piezoactuator. Further feedback control could be possible through further testing and adaptations of the product. However, at this time the testing procedure is limited.

Chapter 6. Cost Analysis

6.1 Bill of Materials

The majority of the budget was spent on our actuation devise. The Thorlabs PAS015 cost $2370.26 for the entire system. This system included the actuator and the T-Cube controller. The next costly item is the Honeywell Model 11 force sensor at $771. This item is not represented in the final bill of materials because the client already had the sensor in his possession and approved of its use in the system. The rest of the materials used were nowhere near as much as the actuator costs. The final cost for the entire system is $2498.80, which is $1.20 below the allotted budget. The list of materials and their individual price is below in Table 6.1.

Table 6.1: Bill of Materials

Material	Cost
1.5" dia (1' length) 304 SST	$25.00
1" x 1.25" (3" length) 303 SST	$19.14
1.125" X 1.125" (11" length) 303 SST	$12.50
0.5" x 0.5" (3" length) 6061 extruded Alum.	$2.90
3/16 and 1/4 Fine Adjustment Carrier and Bushings	$3.75
KB187-100 Knob	$4.00
TS187-100-625 3/16-100 TPI Screw	$4.35
6-32, 3/4" long Stainless Steel Socket Head Cap Screw	$0.86
1/4" 9/16" long Stainless Steel Flat Head Socket Cap Screw	$1.18
10-32 1/2" Low Profile Socket Head Cap Screw	$9.44
UHMW Bearing, Flanged, for 1/2" SD, 5/8" OD, 1/2" Length	$15.96
THORLABS PAS015 Piezo-Actuator (entire system)	$2,370.26
Sales Tax	$4.96
Shipping	$24.50
Total	$2,498.80

6.2 Manufacturing and Manpower Costs

The entirety of the manufacturing was completed by the team members at Northern Arizona University. Because the team completed the manufactured the entire system, there was absolutely no additional cost. Therefore, the Bill of Materials introduced in Table 6.1, is also the total cost analysis.

Chapter 7. Conclusion

The goal of the project was to seek a new means for testing the specimen of MSMA in the third dimension so as to more thoroughly test a sample of Manganese, Nickel, Gallium, a magnetic shape memory alloy. The proposed solution was to pair a piezoelectric actuator with a strain gauge force sensor. These components would be held up to the MSMA sample by means of non-magnetic stainless steel towers. These two components work together through a program in LabVIEW to control the force imposed laterally upon the MSMA, while the MSMA itself attempts to increase this force through a change in cross-sectional area. While facing some difficulties due to machining complications and component constraints, the team was able to produce a prototype thought to be capable of applying a lateral force, while keeping it constant within an acceptable range of 5%. However, at the time of writing this report, no concrete data has been collected to support the functionality of this device. This lack is due to complications that arose during the testing of the device externally using a separate testing base. The complications that arose seem to stem from factors relating to the external testing setup but would not be present in the client's existing system. Therefore, the team is confident that the device will perform as desired when actually in place.

Appendix A. References

[1] Garcia, Matt, Randy Jackson, Jeremy Mountain, Qian Tong, and Hui Yao. *Material Testing Fixture*. *Material Testing Fixture*. Dr. Ciocanel, 2012. Web. 15 Nov. 2013. <http://www.cefns.nau.edu/capstone/projects/ME/2013/DFMTM/index.html>.
[2] Leo, Donald J. Engineering Analysis of Smart Material Systems. Hoboken, NJ: John Wiley & Sons, 2007.
[3] "Model 11." *Model 11*. Honeywell International Inc, 2013. Web. 6 Nov. 2013.
[4] "Replaceable Tip Piezo Actuators." *Thorlabs*. N.p., n.d. Web. 15 Jan. 2014.

Appendix B. Engineering Drawings

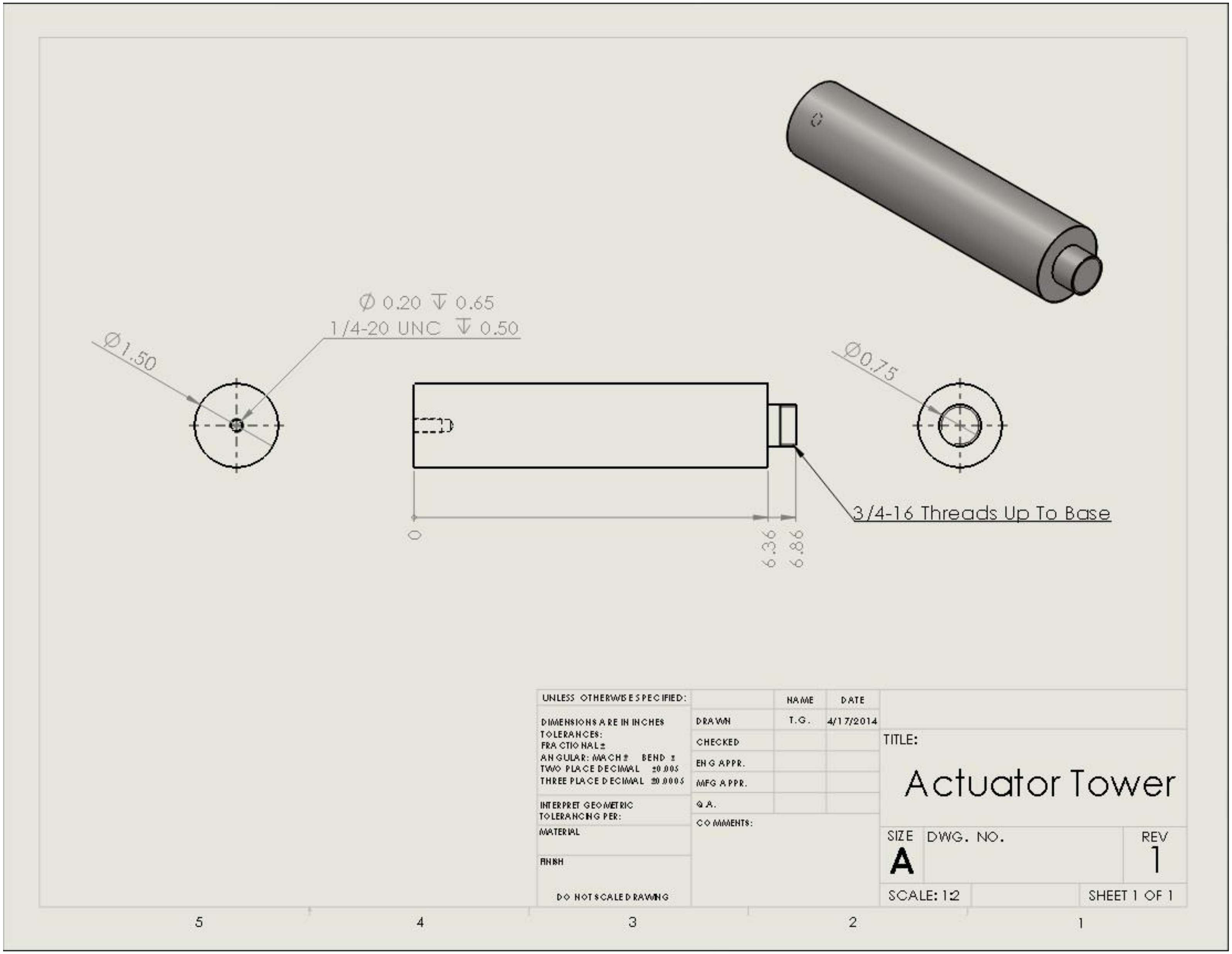

Figure B.1: Engineering Drawing of Actuator Tower

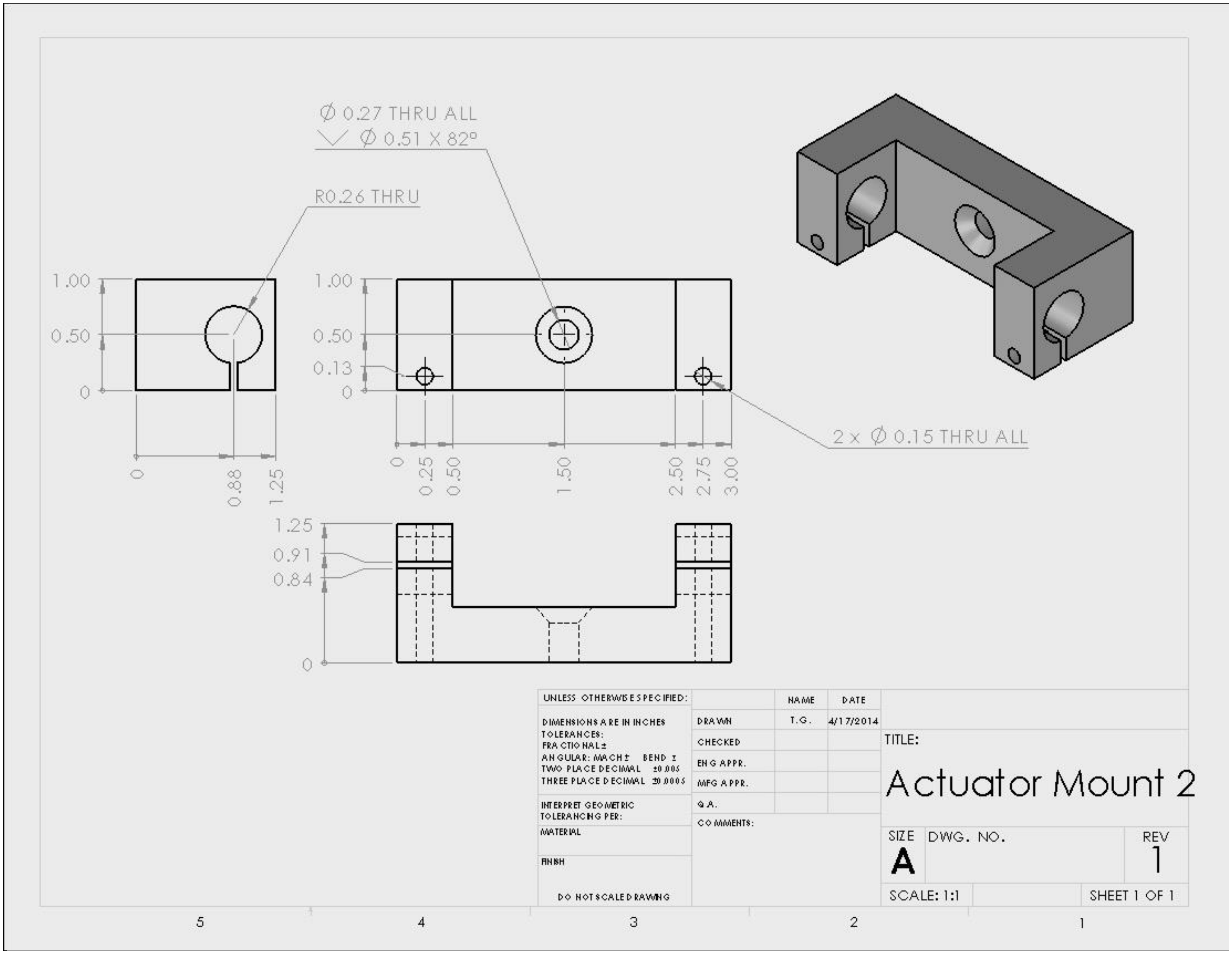

Figure B.2: Engineering Drawing of Actuator Mount

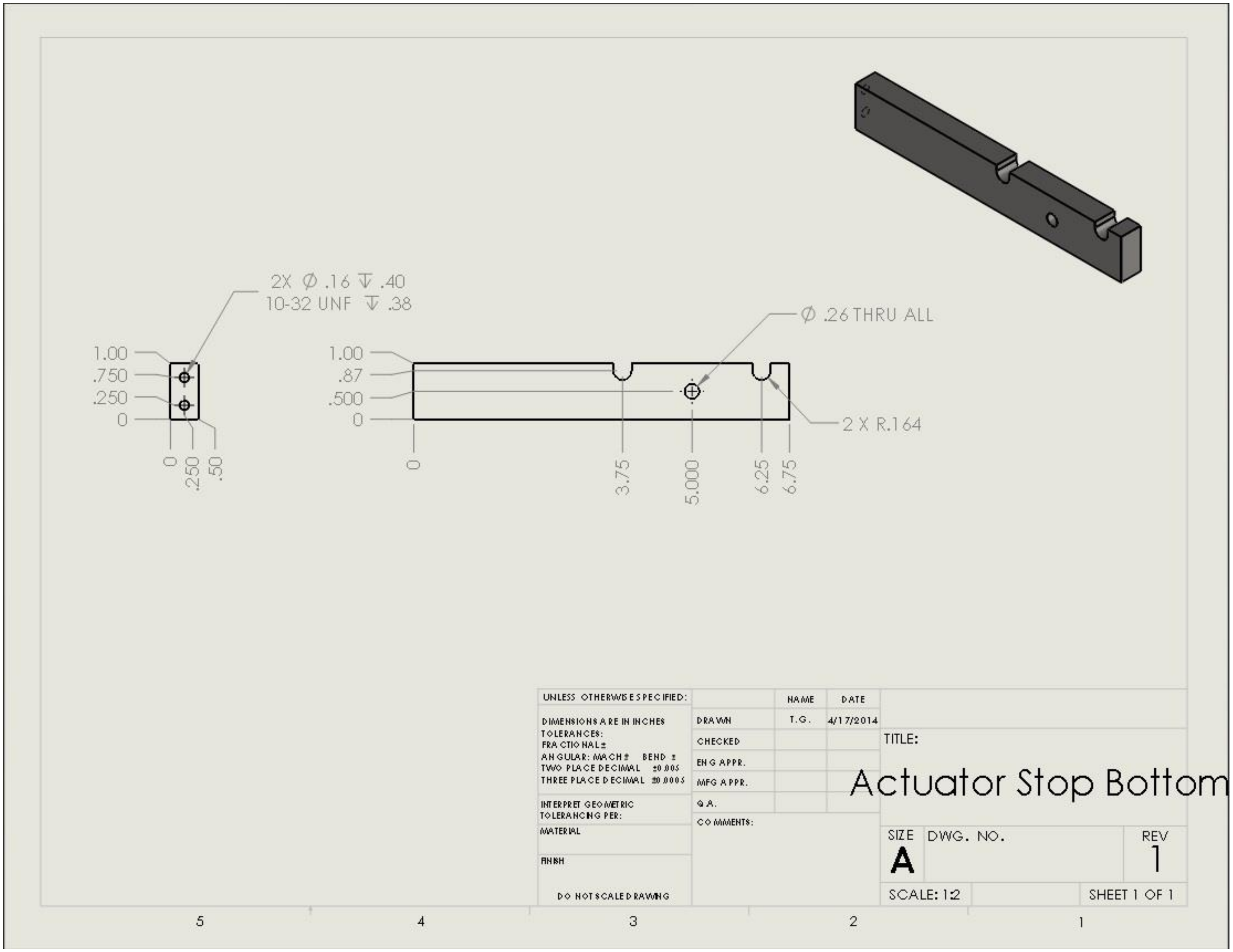

Figure B.3: Engineering Drawing of Actuator Stop – Bottom Plate

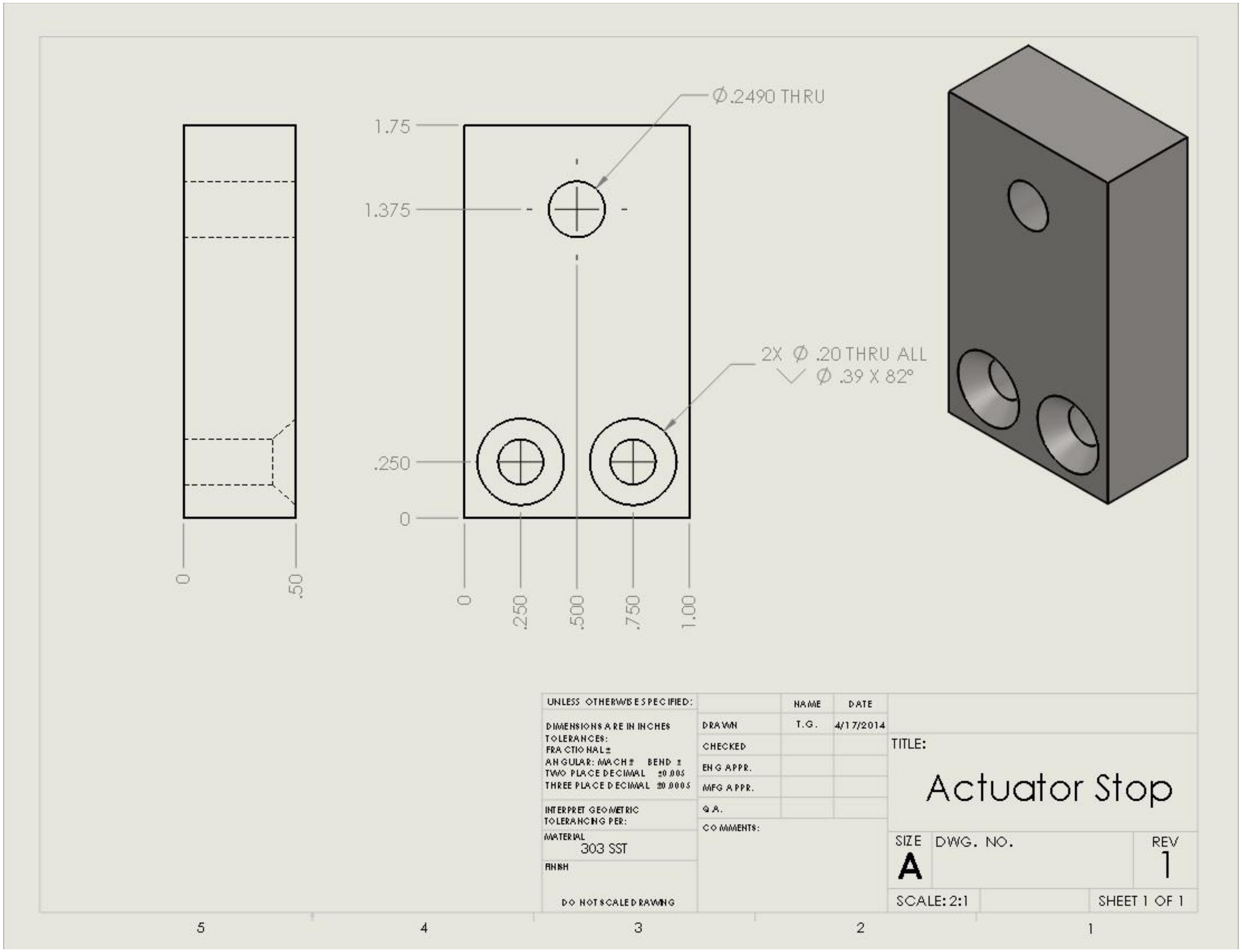

Figure B.4: Engineering Drawing of Actuator Stop

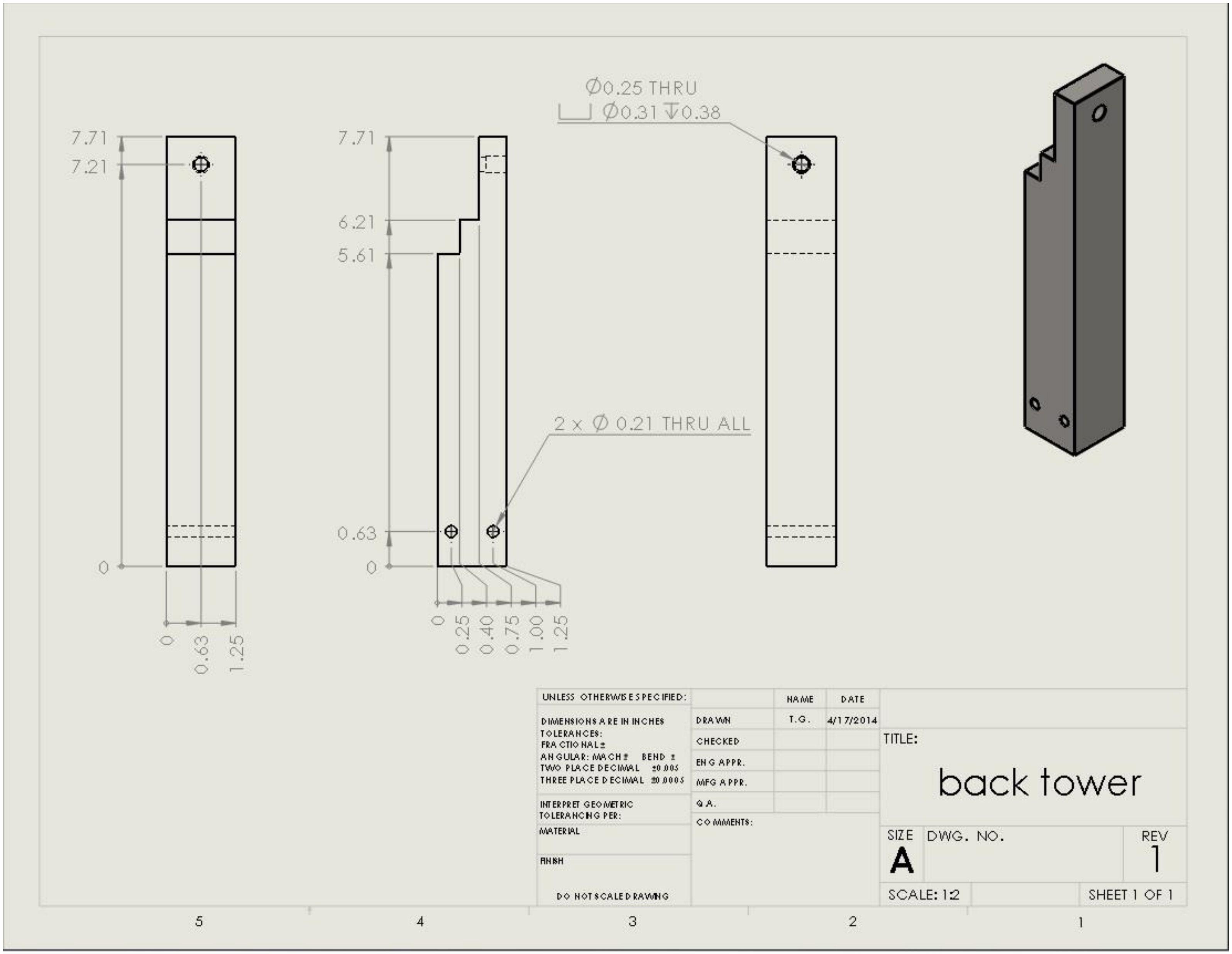

Figure B.5: Engineering Drawing of Force Sensor Tower

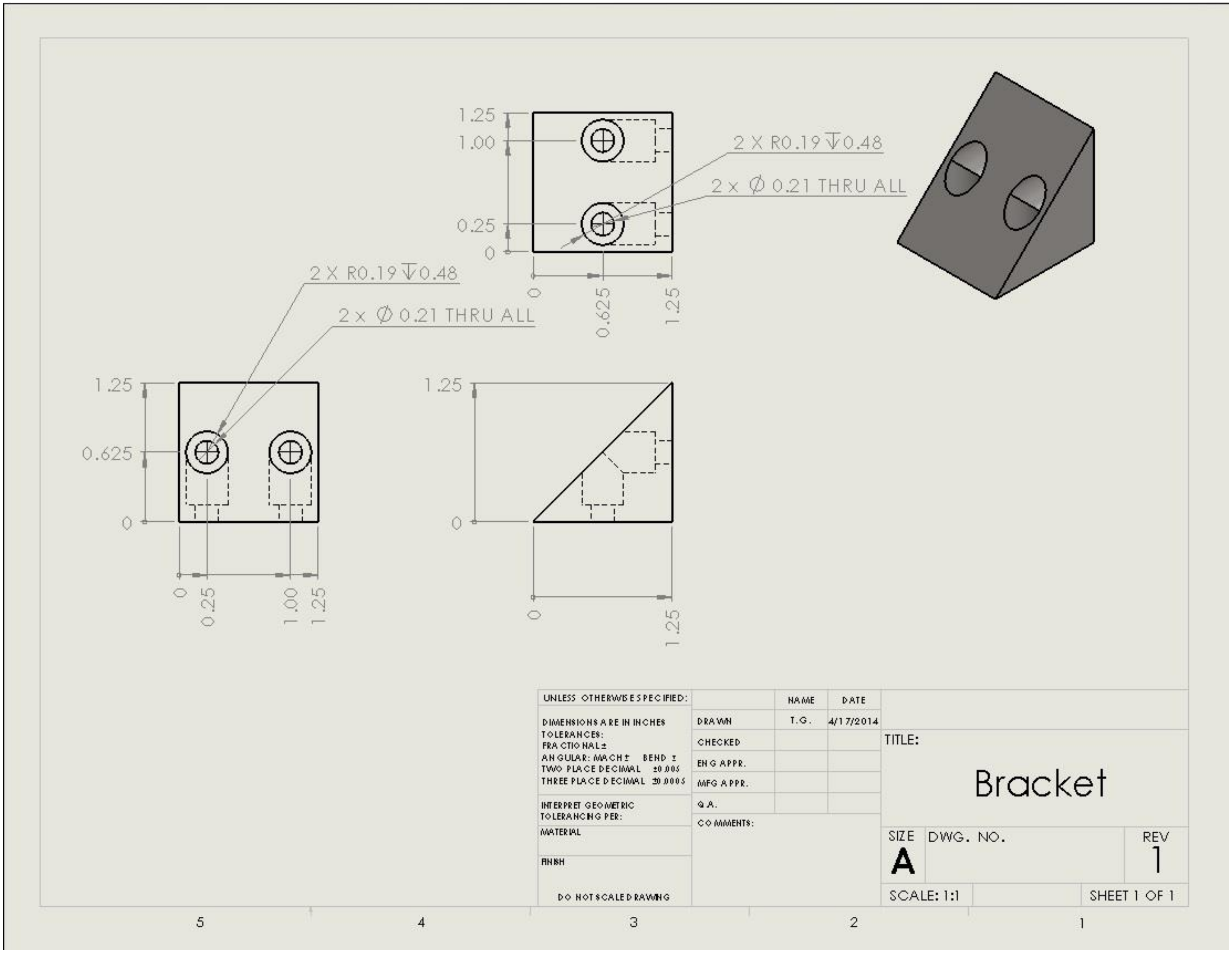

Figure B.6: Engineering Drawing of Triangular Bracket

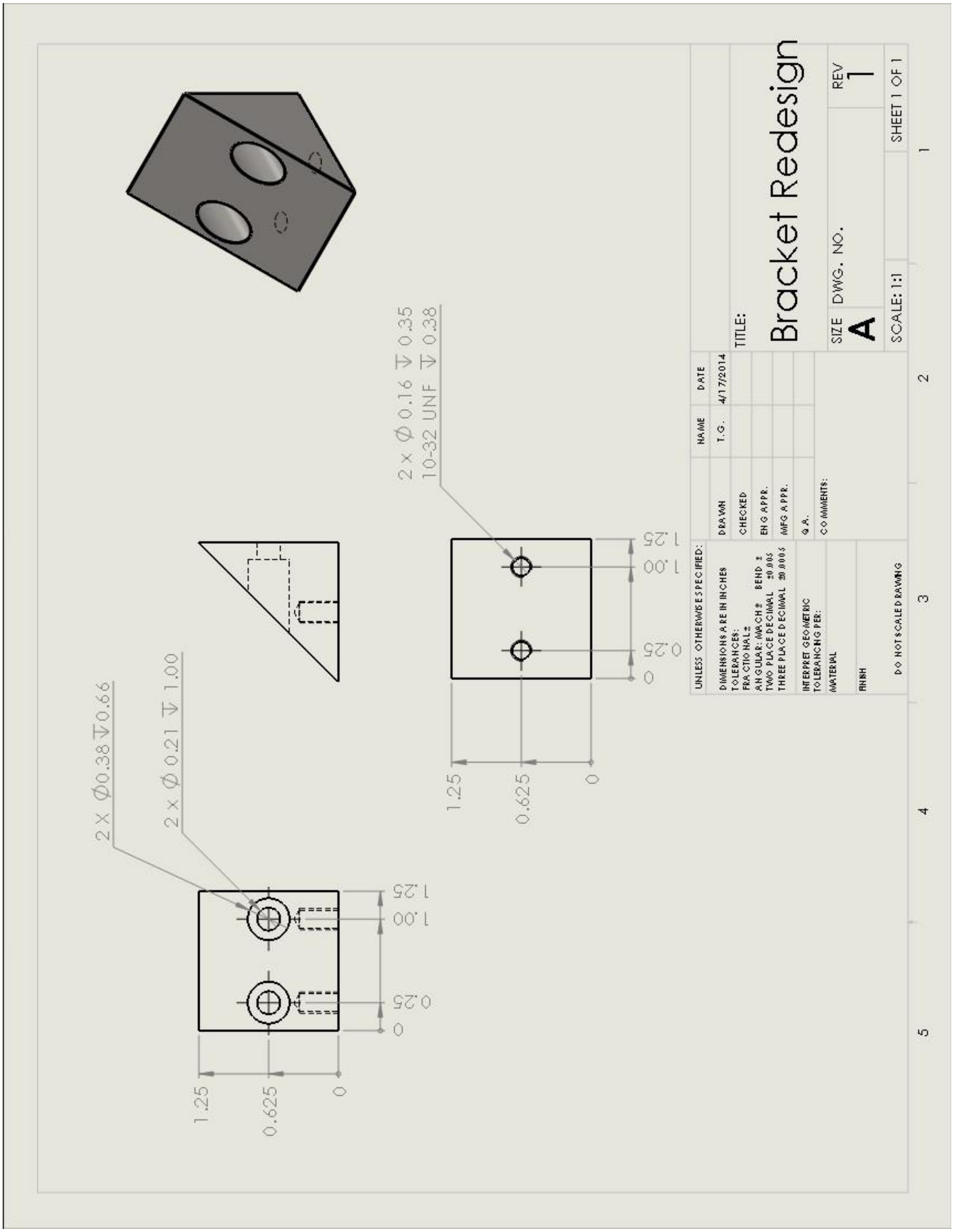

Figure B.7: Engineering Drawing of Triangular Bracket Redesign

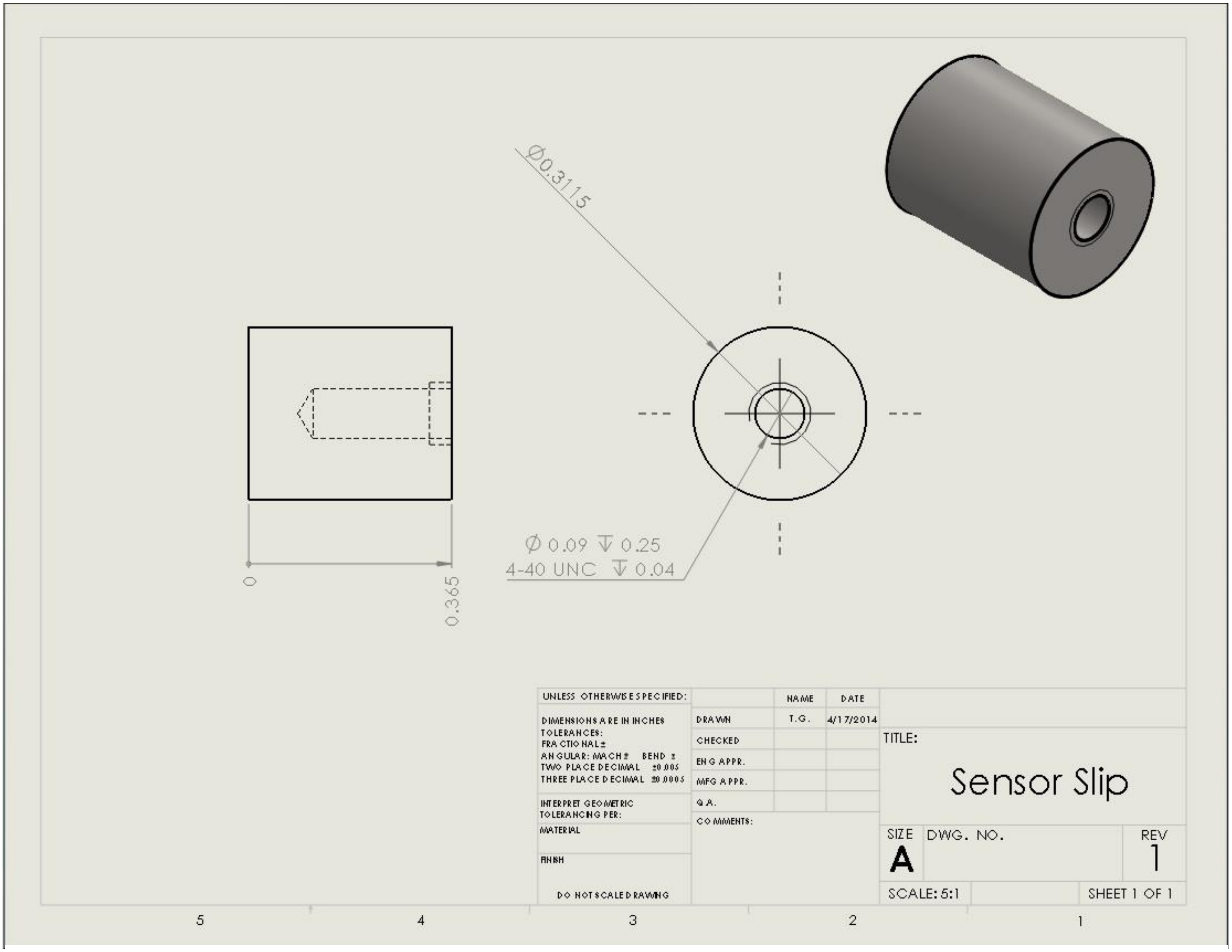

Figure B.8: Engineering Drawing of Sensor Slip

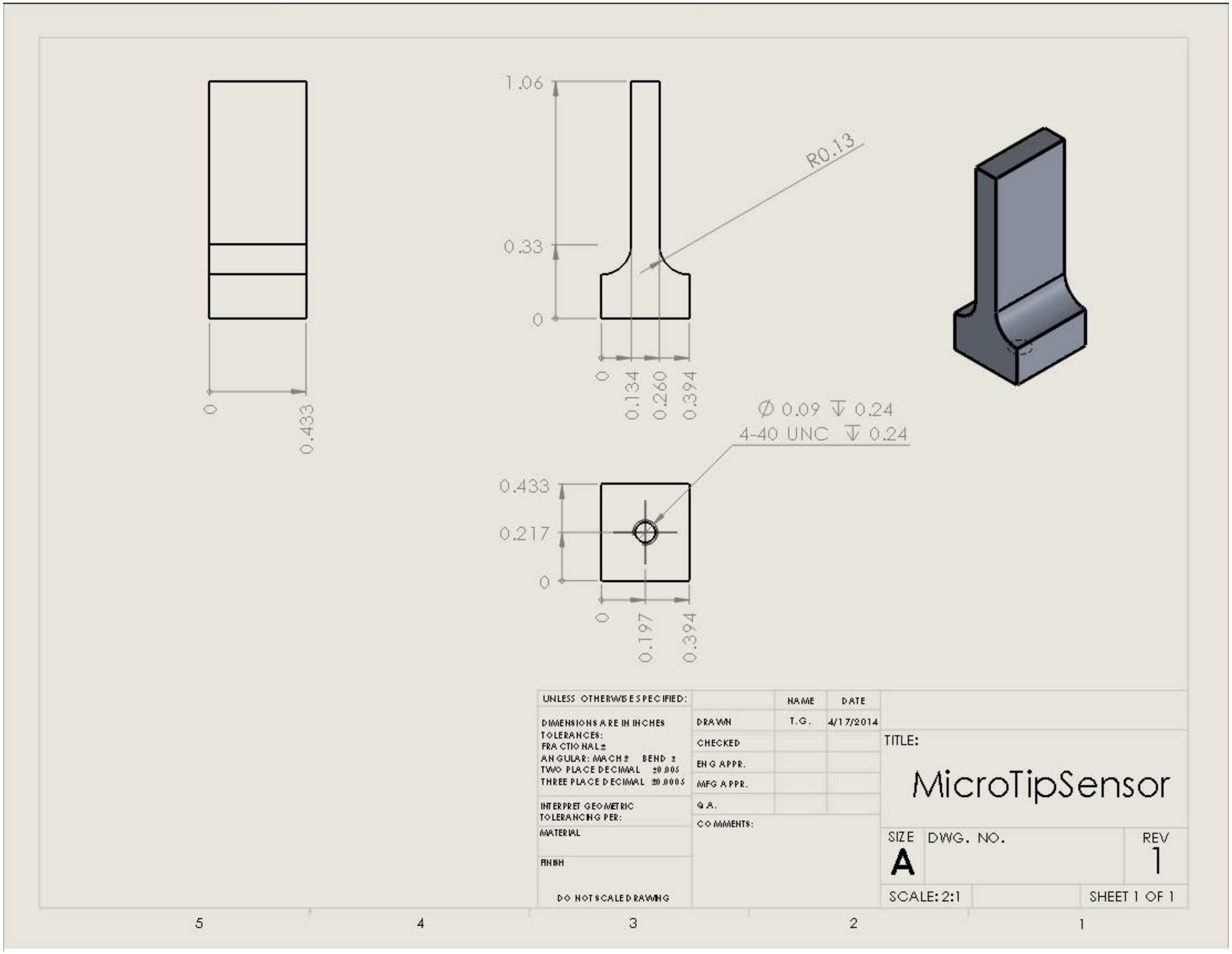

Figure B.9: Engineering Drawing of Micro-tip Sensor

Appendix C. LabVIEW Code Definitions

Manual Actuator Controls: Creates the APT controller which is emulated on the front panel for user interaction within LabView.

HWSerialNum: Uses the controller serial number to apply the proper APT controller to emulate.

StartCtrl: Powers on the APT controller

GetVoltOutput: Displays for the user the current voltage being applied to the actuator

SetVoltOutput: Provides the APT controller with updated output voltages, increasing or decreasing the force the actuator exhorts.

ZeroPosition: Sets the actuator output voltage to zero.

StopCtrl: Turns power off on the APT controller.

DAQ Assistant: Uses a voltage range of ±1V and continuous sampling to read the output voltage of the Honeywell strain gauge.

Filter: Takes a moving average of the strain gauge output voltage and provides a more stable reading.

Measured Force: Converts the Strain Gauge Voltage into associated force in Newtons using a calibration curve for the Honeywell strain gauge.

Actuator Displacement: Converts the Measured Force into associated actuator stroke in microns using a calibration curve for Stroke vs. Block Force.

Actuator Voltage: Displays the voltage applied to the actuator for the user, and is used to increase/decrease the voltage during the feedback control.

Desired Force: User input for force desired on MSMA specimen that is used to monitor feedback control.

Enable Feedback Control: Boolean button that controls whether the feedback loop is running.

Acknowledgements

Throughout the design and fabrication of the system, the team sought the help of several individuals. These individuals include: Dr. Srinivas Kosaraju, Isaac Nelson, and Professor John Sharber. The team would like to extend a special thank you to the client and technical advisor Dr. Constantin Ciocanel.