Spring 2020

Tabletop Mechanical Tester

Jamie Dombroski
jld183@zips.uakron.edu

Brian English

Richard Leffler

Andrew Shirk

Senior Design Project Report
Department of Mechanical Engineering
The University of Akron

Tabletop Mechanical Tester

Jamie Dombroski: Mechanical Engineering with Co-op, Honors, 4600:497
Brian English: Mechanical Engineering with Co-op, 4600:471
Richard Leffler: Mechanical Engineering with Co-op, 4600:471
Andrew Shirk: Mechanical Engineering with Co-op, 4600:471

Faculty Advisor and Sponsor:
Dr. Gopal Nadkarni

Project Completion and Submission:
Spring Semester 2020

Abstract

The need for hands-on and face-to-face experiences in the engineering classroom is very great. The equations, principles, and concepts can all be learned, but without the visual and tactile application, these don't always sink in or become concrete. A small-scale tensile test machine was designed, sourced, manufactured, and tested for the purpose of being applied in classroom settings to provide this experience to engineering students. Extensive research was performed concerning tensile machines on the market, the essential elements of which are the load cell, grips, crosshead, extensometer, motor, and frame. The raw materials for the frame were purchased and drawings were compiled for machining and manufacturing. Other parts were sourced and purchased for integration to the machine as a whole. The data acquisition system was researched and purchased to read, store, and output data from all machine systems as well as control the motor function. The machine was capable of testing aluminum wire samples to failure with the addition of some part modifications. The controls system was made compatible with the motor to allow it to run. More work can be and we have hope for the future of this project as well as the young engineering students impacted by it.

Acknowledgments

We would like to thank our advisor Dr. Nadkarni as well as Dr. Mahajan for his aid and encouragement through the project. We appreciate all the help we received from various community and outside companies-- R&J Cylinder and Machine, American Axle Manufacturing, Preformed Line Products, and Epsilon-- in supporting us through finances, knowledge, and resources. All of our hard work would have been much impeded and slowed without the help of our friends, family, and peers-- Kalen Bowen, the Dombroski brothers, Greg Hering, Jason Huey, Ross Klonowski, Matt Marsek, and Timmy Snyder. We also want to extend our thanks to all of the other major influencers in our lives who led us to engineering, creativity, and growth.

Table of Contents

Chapter 1: Introduction

1.1 Background

Material properties is one of the largest sectors of research and focus in the engineering community. The majority of engineering problems and solutions rely on material properties and one of the largest of these is the mechanical strength of materials. It is the basis of engineering principles and education. One of the first characteristics studied is the stress versus strain curve of a material. The general curve reveals many qualities about a material: the ductility, tensile and yield strength, and elastic and plastic behavior zones.

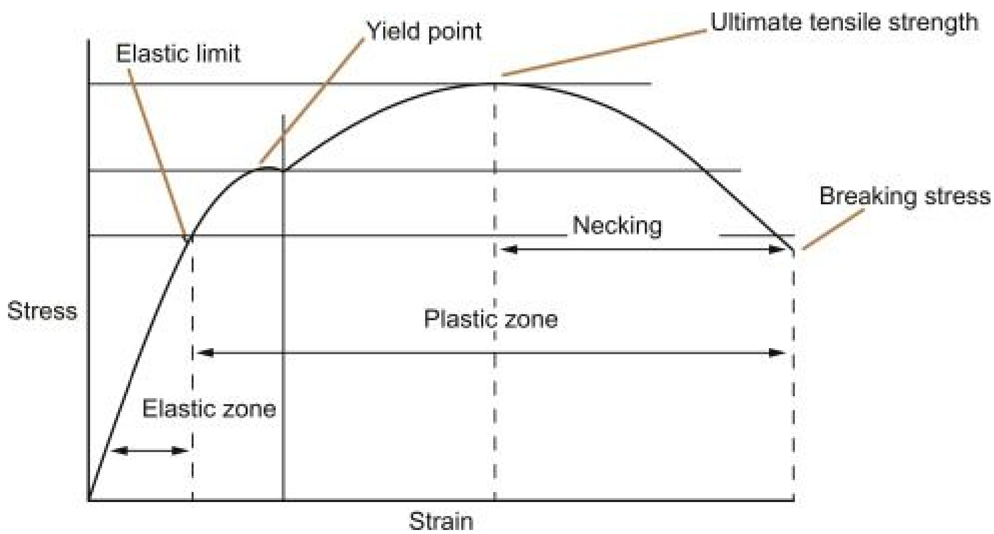


Figure 1: Typical Stress-Strain Curve [Stress-Strain]

The stress σ, of a material is defined as the amount of force F, per unit area A, and strain ε, is defined as the change in dimension-- in many cases the length L -- or the elongation of a specimen.

$$stress,\ \sigma = \frac{F}{A},\ [N/m^2]\ or\ [psi] \tag{1}$$

$$strain,\ \varepsilon = \frac{L_{final} - L_{initial}}{L_{initial}} = \frac{\Delta L}{L_0} \tag{2}$$

Comparing these two values measures Young's Modulus of Elasticity E -- referred to simply as the modulus-- of the material, or in essence, the strength of the material, which is directly represented by the slope of the curve in the first region. This first area of the graph represents the elastic zone of the material, in which the material sample may deform or stretch, but when the load is removed, it will return to its original state. In this region, no failure will occur. The modulus can be applied to various other characteristics of a specific material as well as compared amongst materials in choosing the appropriate materials for different applications.

$$E = \frac{\sigma}{\varepsilon},\ [N/m^2]\ or\ [psi] \tag{3}$$

The second area of the curve represents the plastic region, in which irreversible deformation or failure occurs, and which is divided into multiple sections or stages. The sample will begin to yield, a phenomenon during which the strain increases without added load. An ultimate stress will be reached, after which necking occurs. During necking, the strain is again increasing, but now the stress applied is actually decreasing, not because the load is being removed but because the cross-sectional area of the sample is decreasing. Often a true stress-strain curve, which takes into account the decreasing area, is used to analyze the data in place of the engineering stress-strain curve.

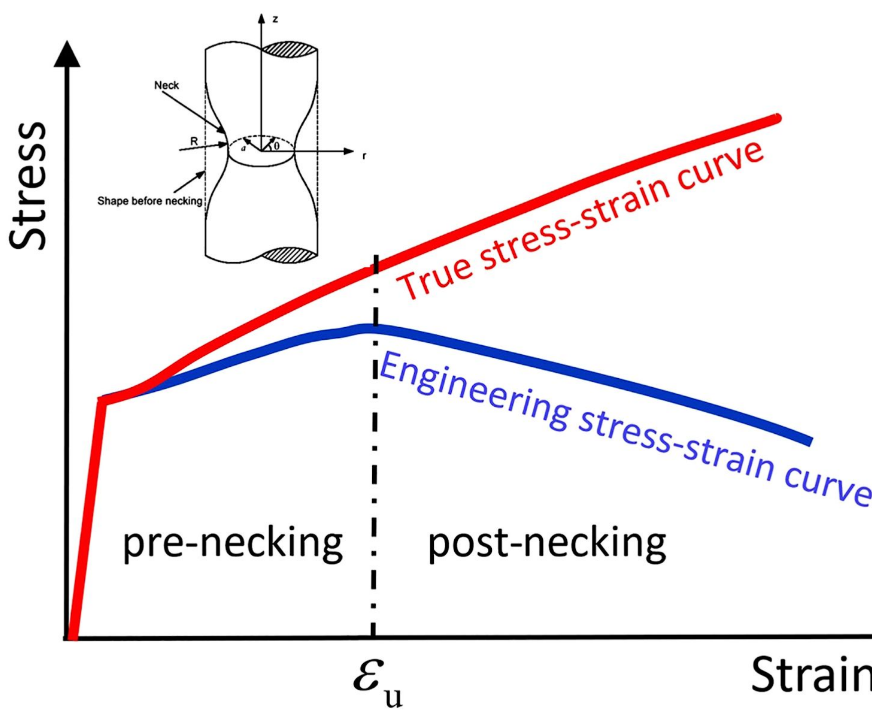


Figure 2: True Stress-Strain Curve in Comparison to Engineering Stress-Strain Curve with Visual of Necking [Tu]

In laboratory and industry settings, a basic tensile machine is the quickest, most accurate, and simplest way to acquire data concerning material properties. Typically, “dogbone” samples are used as shown in Figure 3 below, which are designed to fracture in the middle, or gauge, section.

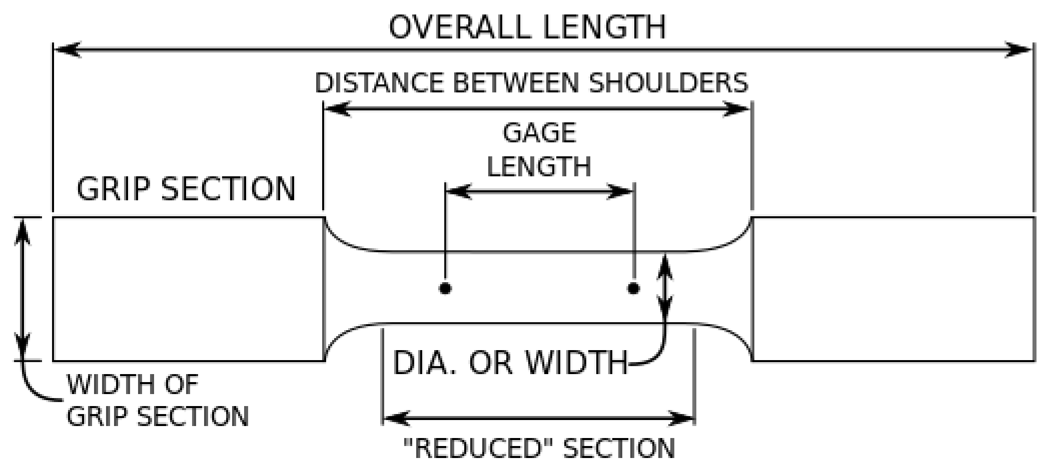


Figure 3: Typical Dog Bone Test Specimen [Tensile Testing]

The machine designed in this project is intended to pull mainly wire samples, with the potential to adjust grips in future improvement to use for dog-bone samples. The machine is intended to be lightweight and compact in order to be used for classroom demonstrations. It needs to be sturdy and robust enough to withstand the forces applied to it and including the basic components of a tensile machine, outlined in the rest of the chapter.

1.2 Research

Due to their significance, many tensile test machinery exists in industry today. Typically, machines are oriented vertically, powered electrically or hydraulically, where the two sample grips or jaws are oriented in the same plane, one above the other in order to avoid any bending forces on the sample. The main components are as follows: a motor to power the machinery, a load cell to read the applied load on the sample, an extensometer to measure the deformation of the sample, a crosshead which effectively shows the rate of movement of the top jaw, grips to hold the sample securely without significant damage, and a data acquisition system to record and display data from the experimentation.

Figure 4: Various Tensile Machines [What Is Tensile Testing]

From basic research and personal experiences with tensile and compression testing, our team understood that our machine types would vary in amount of support beams and orientation, whether vertical or horizontal.

1.2.1 Machine Research

While conducting a tensile test one of the more critical components of the machine is the gripping fixture used to hold the specimen in place while being pulled. There are two common problems that you encounter when selecting the right grip for the material you are testing, and both relate to the force applied. Firstly, too much force can cause the sample to break within the grip, providing inaccurate data about the material being tested. Secondly, too little gripping force causes the material to slip right out of the grip and not break at all during the test, in essence leaving any data, along with the entirety of the test, completely useless. During our research we tried to find a good balance of grip forces applied to the specimen in order to have an accurate test while keeping the dignity of the material.

For wire testing, snubbing grips are commonly used. According to Instron, "[snubbing] grips are typically supplied as a matched pair of grip bodies. Each body uses a spool to wrap the specimen around and a snubber (cam or clamp) to secure the free end of the specimen." [Mechanical Wedge]. These work great because they don't put an overbearing amount of force on the wire causing it to break at the gripping point, but are capable of holding it in place without slipping. After contacting a few companies for quotes for this style grip, our team came to the conclusion these were well above the desired price range.

Another commonly used grip for tensile testing is a wedge grip, which typically don't cause the specimen to break at the gripping point and can be used for wires. Instron stated that a "strong clamping force can be applied to materials that are difficult to hold through a high mechanical advantage achieved by the tightening mechanism." [Mechanical Wedge]. Again, upon getting quotes for these style grips it was made apparent that buying testing grade equipment grips would not be an option. Quotes for both the snubbing grips and wedge grips were estimated somewhere between $1000.00-$2500.00 each.

With the high pricing for testing grade equipment, a more creative approach was needed to both hold our specimen tight enough so it would not break at the gripping point and stay within our price range. We came up with several ideas but ultimately decided on using a small, threaded mount, keyed drill chuck to hold our wire. The threaded mount would make this very compatible with the frame.The three jaws that move inward ensure contact on multiple points on the wire. The chuck range allows compatibility with multiple wire sizes. Additionally, they were significantly cheaper than the snubbing or wedge grips, costing approximately $60.00 each. More information on pricing can be found in the cost estimates. However, since tensile testing is not the intended purpose of drill chucks, specification sheets lacked information such as gripping strength.

Our company sponsors were generous in allowing us access to equipment and tooling. Before purchasing two drill chucks for our machine we wanted to test the gripping strength. The engineering team at AAM worked with us to test the gripping strength of the drill chucks. For this trial, a Jacobs drill chuck held a Ø0.250" brass rod, and the opposite end of the rod was clamped into a vice grip attached to a heavy duty steel table. A chain was wrapped around the drill chuck and we proceeded to pull this chain upwards with a bridge crane. When lifted, the setup managed to lift the table off the ground before the rod slipped out of the drill chuck.

While looking for an extensometer, our team reached out to Jim Stuart at Epsilon. Epsilon specializes in building extensometers for different kinds of testing around the world as well as other testing equipment. They communicated various options and ultimately settled on a used extensometer (3542-010M-050-LHT) at a reduced rate. They offered to convert this into a 3542-025M-020-LHT which would be better suited for wire testing. The extensometer also required a single channel signal conditioner, and for this, AAM was generous to support us with financial funding.

1.2.2 Data Acquisition and Controls Research

The purpose of the machine is to be able to display a stress-strain curve along with the physical testing to have a side-by-side representation of the process. Thus, data must be acquired by the system and be easily accessible, preferably with the ability to be shown in real time.

Proprietary systems developed by machine manufacturers are the optimal route, but in order to keep costs down a Raspberry Pi 4B was used. The Raspberry Pi modularity proved helpful in the machine processes. The pins that were integrated into the tester were the 5V logic pins and General Purpose Input/Output Pins, or GPIO. These pins are especially useful for prototyping systems as external boards can be used alongside the Raspberry Pi system. For the purposes of the machine, the inclusion of a load cell amplifier, motor controller, and extensometer were vital, and were made possible through the use of the Raspberry Pi.

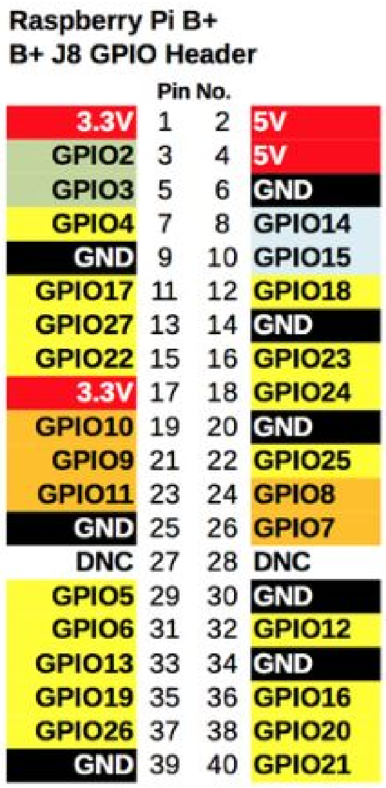


Figure 5: Raspberry Pi Pin Layout

The load cell amplifier, in this case an Hx711, along with an Hx711py Python code,made the voltage signals coming from the load cell compatible with the Raspberry Pi. The code streamlined the system by also calibrating the load cell. The motor controller ensures safety and is an intermediate phase between the motor and Raspberry Pi. It drives the motor forward when testing samples, but also has the capacity to drive backwards so the machine can be reloaded between testing. With the integration of the controller and Raspberry Pi, this system can also be used to start and stop the motor. The stopping function can be used manually, but also can be applied to limits such as a crosshead travel limit, a significant load drop limit, or a maximum load capacity limit. All of these increase the safety for the operator and the safety of the machine itself.

The extensometer measures the deformation or the strain of the sample being tested and the output allows this information to be recorded. Because of the small gauge length and overall compact quality of the machine, many extensometers on the market are not compatible. As mentioned above, Epsilon aided us in finding a usable extensometer that has the convenience of a USB connection which is easily made between the Raspberry Pi and the extensometer.

Chapter 2: Conceptual Design

2.1 Expanded Design Brief

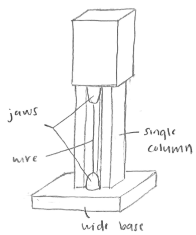
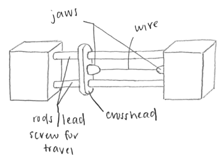
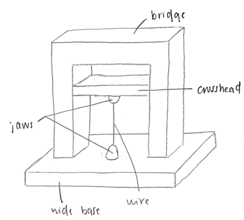
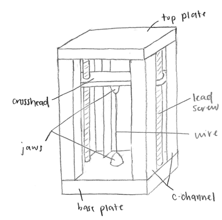
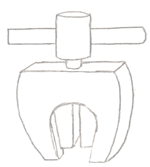
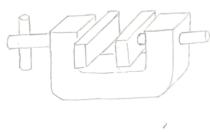
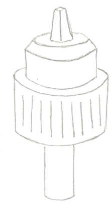
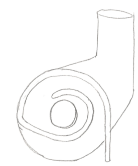
There is a desire for a small-scale tensile tester, no larger than two and a half feet in height and weighing no more than 40 pounds, for use in classroom demonstration applications. The tester should be able to accomodate metal wire samples consisting of aluminum and copper and with diameters ranging from 0.075" to 0.200". These guidelines could of course be expanded to steel, dogbone samples, and various diameters if possible. The average test specimen will not exceed a breaking strength of 1000 pounds with a factor of safety in account. Preferably, the machine will be powered by means of a DC motor modified to provide a load rate capable of pulling the samples slow enough to be able to observe necking, but not so slow that the testing was extensive.

Concerning the data acquisition of the machinery, a Raspberry Pi or Arduino system should read, store, and display data from a load cell and extensometer as well as control the motor through various limits and regulations. The machine must be stable and able to withstand buckling forces and must be large enough to accomodate for the deformation of samples between 0.5 to 2 inches in gauge length. Ideally, the tester would cost no more than $3500 including parts, assembly, and peripheral costs.

2.2 Morphological Chart

The function of a morphological chart is to aid in the choosing and optimization of sub-functions within an assembly. The largest design factor our team had to consider was that of the configuration of the main frame. Although we originally had considered a horizontal layout, ultimately, a four support beam style was chosen for its stability and ease of configuration for the lifting mechanism. The second largest contributor to the chart was the selection of a gripping device, as explained previously. The placement of the motor was originally at the base of the machine for sake of center of gravity and balance, but during the first phases of design the spool storage made more logical sense below the bottom grip, and so the motor was moved to the top of the machine, and ultimately the center of gravity was not affected negatively and the machine was very stable. The spool storage was moved from below the machine to the side for ease of accessibility and the compartment included beneath the bottom grip was converted to an area for the data acquisition equipment.

Table 1: Morphological Chart

Components	*Function Solutions*			
Frame	Single-Column Vertical 	Single-Column Horizontal 	Bridge 	Four-Column 
Grips	Wedge Grips 	Vise-Type 	Drill Chucks 	Snubbing Grips 
Motor and Controls	Top Motor	Bottom Motor	Side Controls	Separate Controls
Spool Storage		Below Tester	Side of Tester	

2.3 Objective Tree

The purpose of an objective tree for use in a design process is to assign weights to each and every factor that is deemed important as a project outcome. Each respective branch grouping sums up to one. Then, a weighted decision matrix is used to consolidate this information and determine how each factor is weighted in comparison to all the other factors as shown in the following section.

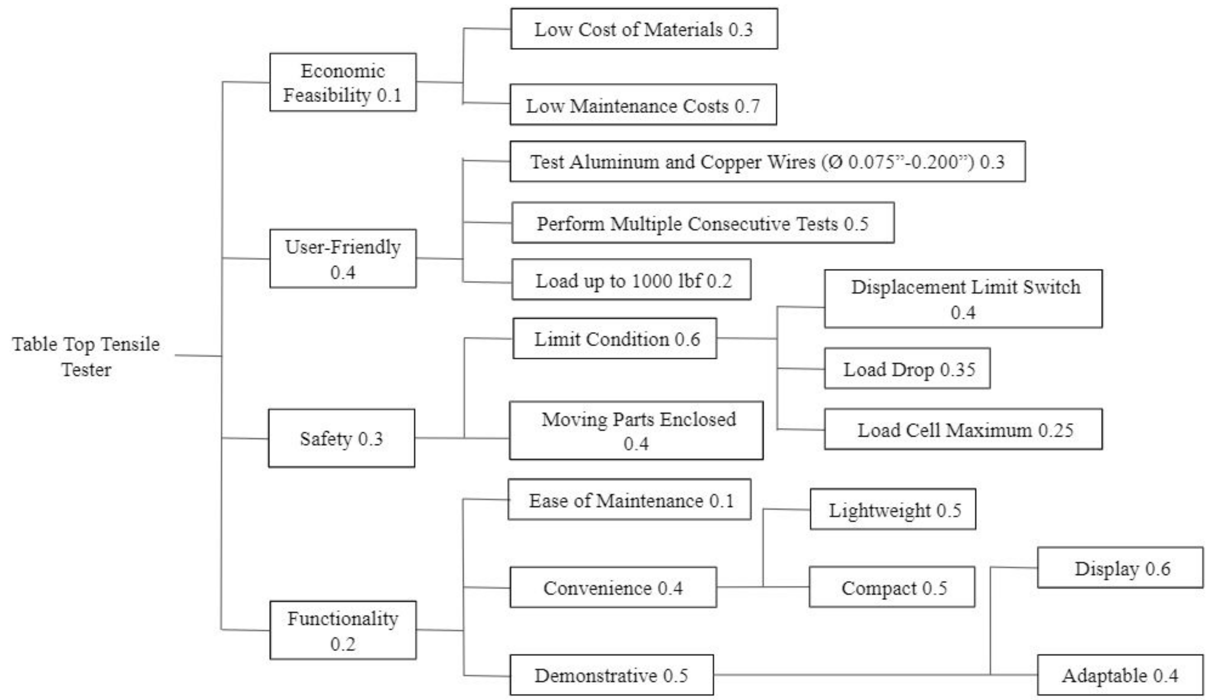


Figure 5: Objective Tree

2.4 Weighted Decision Matrix

In order to decide which frame design to pursue, a weighted decision matrix can be created. The decision matrix uses the most influential and important criteria-- namely, mass, size, strength, cost, and power-- along with weighting factors to quantify the quality of each possible design. Below is the decision matrix based on the frame design options shown in the morphological chart, four-column, bridge, single-column horizontal, and single-column vertical.

Table 2: Weighted Decision Matrix

Evaluated Criteria		Weighing Factor, W	Four-Column		Bridge		Single-Column Horizontal		Single Column Vertical	
			Rating, V	VxW	Rating, V	VxW	Rating, V	VxW	Rating, V	VxW
1	Machine Mass	5	3	15	4	20	3	15	4	20
2	Machine Size	3	5	15	3	9	3	9	4	12
3	Frame Strength	2	5	10	3	6	2	4	2	4
4	Cost of Materials	4	2	8	2	8	4	16	3	12
5	Power Transmission	1	3	3	3	3	2	2	2	2
			51		46		46		50	

Chapter 3: Embodiment Design

3.1 Product Architecture & Configuration Design

The architecture design of a product is the process of arranging the physical elements such that the intended functions can be successfully executed. Grouping can be made which are commonly called modules which are then connected in the overall system. In our design, not many modules were implemented. For the intended purposes of this machine, a basic four-column vertical frame was chosen, as mentioned in the above morphological chart. This design allowed for stability and provided four individual c-channel legs to distribute the forces. Lead screws were placed in the space between the c-channel pairs on either side of the base plate. These are the mechanisms on which the crosshead is able to move and having two also distributed the forces and torques. The gears were meshed together in order to achieve the gear ratio needed and to confine all gears into as small of a volume as possible to keep the design compact.

In configuration design, general shape and dimensions are constructed without as much regard to the exact dimensions and tolerances which will be established later in the design process. As one of the main goals of the design is to create a small and compact piece of equipment, general machines were one of the first parameters to be set. The general height limit was set at two feet and the footprint was initially intended to be 8x3". These parameters were intended to keep the machine small and easy to transport. The height took into account the space needed for the actual testing. Ideal gauge length for the samples is two inches, so, incorporating the general dimensions of the grips and any extension this test section was set to approximately . This area needed to be large enough for a visual demonstration but optimized such that it didn't occupy more space than necessary.

3.2 Embodiment Rules and Principles

The most important aspect in design is properly achieving the intended function. This machine is designed to be able to destructively test the mechanical properties of a wire specimen. A tensile force is transmitted onto the gripped wire. The wire is inserted into the grips when they are set at the approximate gauge length and then they are tightened down on the specimen for testing. The top grip is attached to a crosshead that is mounted on two threaded nuts. In order to generate the force that is needed to pull the wire, an electric motor was mounted on the top of the tester, and was meshed with a gear train used to transmit the force at the appropriate gear ratio for the proper rotations per minute, or rpm, to generate the appropriate linear velocity for pulling the wire. At the end of the gear train are two sprocket and chain assemblies that have a 1:1 rotation ratio to rotate the two lead screws in unison. The lead screws are threaded into the nuts that are mounted to the crosshead.

To make sure the crosshead can move properly, the lead screws needed to be secured at both ends so tension could be maintained on the sprocket chains. This prevents the chains from jumping links and causing the crosshead to rise or lower unevenly. To perform this task, we designed the lead screws to have radial ends that would be mounted in cups thus securing the rotational axis of the lead screws in parallel to the crosshead movement. Because the joints between the ball ends of the lead screws and the cups is a kinetic joint, the cups are made from 954 bronze to act as a lubricant for wear. The same concept was used for the gear shafts in the gear housing. Each end of the shaft was designed to have a pilot and a flange keeping them from sliding up and down. The ends were also housed between two bronze bushings to act as a lubricant to reduce wear.

One of the more important features of the tensile tester is performance, in that it must endure repeated tests done quickly for classroom demonstrations. A middle plate was installed and used as a mounting structure for the bottom grip. It was designed to be able to feed a spool of small diameter wire through a hole drilled in the mounting connection so that between tests, the wire could be pulled through and attached to the top grip without a need for cutting samples prior to testing. To ensure safety, the bottom plate and the middle plate were welded to the four vertical supports as permanent joints. Because none of the moving components were mounted between these plates, there would be no need for this part of the assembly to be repairable or accessed through disassembly. This also acted as a way to gain more structural strength to the vertical supports by having three positive connections to the framework.

To keep the manufacturing of the tensile tester as simple as we could, the remainder of the joints contained removable fasteners. This helped reduce the amount of manufactured or machined parts, but also allowed for maintenance or repair should any of the components fail. Using standard components also helped reduce the cost, since machining unique parts can become costly.

3.3 Failure Mode and Effects Analysis

Failure mode and effects analysis, commonly known as FMEA, is a method used to identify and acknowledge potential problems and issues in a product design. Each individual component is analyzed in order to have a broad view of the assembly as a whole and determine where the majority of the risk is. Three main factors are considered-- severity, probability, and likelihood of detecting the issue-- and each are rated on a scale of one to ten as shown in the following figures.

Rating	Severity Description
1	The effect is not noticed by the customer
2	Very slight effect noticed by customer; does not annoy or inconvenience customer
3	Slight effect that causes customers annoyance, but they do not seek service
4	Slight effect, customer may return product for service
5	Moderate effect, customer requires immediate service
6	Significant effect, causes customer dissatisfaction; may violate a regulation or design code
7	Major effect, system may not be operable; elicits customer complaint; may cause injury
8	Extreme effect, system is inoperable and a safety problem; may cause severe injury
9	Critical effect, complete system shutdown; safety risk
10	Hazardous; failure occurs without warning; life-threatening

Figure 6: Rating for Severity of Failure

Rating	Approx. Probability of Failure	Description of Occurrence
1	$\leq 1 \times 10^{-6}$	Extremely remote
2	1×10^{-5}	Remote, very unlikely
3	1×10^{-5}	Very slight chance of occurrence
4	4×10^{-4}	Slight chance of occurrence
5	2×10^{-3}	Occasional occurrence
6	1×10^{-2}	Moderate occurrence
7	4×10^{-2}	Frequent occurrence
8	0.20	High occurrence
9	0.33	Very high occurrence
10	≥ 0.50	Extremely high occurrence

Figure 7: Rating for Probability of Occurrence

Rating	Description of Detection
1	Almost certain to detect
2	Very high chance of detection
3	High chance of detection
4	Moderately high chance of detection
5	Medium chance of detection
6	Low chance of detection
7	Slight chance of detection
8	Remote chance of detection
9	Very remote chance of detection
10	No chance of detection; no inspection

Figure 8: Rating for Likelihood of Detection

These three criteria are then multiplied together to formulate the risk priority number, RPN, which ranges from 1 to 1000 and quantifying the perceived risk of each component.

$$RPN = (severity) \times (probability) \times (detection)$$

Table 4 belows shows the components that were seen as the most likely to fail under different circumstances. These components were considered and the failure modes were determined. Each failure mode was assigned a potential cause and the variables discussed above were given values. The most influential failures would be an untimely shut off of the motor due to a short circuit from the controller and failure from the Raspberry Pi due to an overload of current and/or voltage. It should be noted in the table below, severity is represented as ‘S’, occurrence as ‘O’, detection as ‘D’, perceived risk as ‘R’, and change as ‘C’. The items are numbered with motor being (1), lead screws (2), load cell (3), extensometer (4), Raspberry Pi (5), and frame (6).

Table 4: FMEA Chart

Item	Function	Potential Failure Mode	Potential Effect(s)	S	Potential Cause(s)	O	Prevention Controls	Detection Controls	D	R	Action(s)	Revised Rankings				
												S	O	D	R	C
1	Control loading/unloading speed and direction, transfers torque to lead screws through gearbox	Failure to operate	No testing	7	Internal failure	1	Know motor specs	Visual inspection	4	28	N/A	7	1	4	28	0
		Untimely shut off	Discredit test data	6	Motor controller or power supply disfunction	5	Maintenance and controls troubleshooting	Analyze output readings	4	120	Troubleshoot and improve on control system	6	2	2	24	96
		Fail to provide enough torque	Ultimate motor failure, no test	8	Incorrect gearbox or motor connection	1	Maintenance	Visual check	2	16	Implement a more appropriate motor and gearbox	6	1	2	12	4
2	Lift and lower crosshead with upper grip to load sample	Total failure	No testing or failure mid-test	9	Buckling	1	Correct part selection	Visual check	3	27	N/A	9	1	3	27	0
				9	Stripped threads	1			2	18	N/A	9	1	2	18	0
3	Detects, measures, and outputs the force experienced by the sample	Total failure	No testing or failure mid-test	5	Excess loading	1	Automatic shut-off at load max	Load monitoring during test	1	5	Source a load cell with larger load range	4	1	1	4	1
		Output failure	Incorrect data	4	Bad connection to Raspberry Pi	6	Troubleshooting systems	Visual check of output reading	2	48	Improve on control system	3	4	2	24	24
		Poor data output	Incorrect data	3	Force out of calibrated range	4	Test proper samples	Visual check of output reading	2	24	Source a load cell with larger load range	3	1	1	3	21
4	Measures and outputs deformation of sample	Total failure	Incorrect data	5	Physical break of part from excess force	2	Machine care and proper use	Calibration and output checks	1	10	Calibrate extensometer and implement safe storage	5	1	1	5	5
		Output failure	Incorrect data	4	Bad connection to Raspberry Pi	5	Troubleshooting systems	Visual check of output reading	2	40	Improve on control system	4	2	2	16	24
5	Records, stores, and displays data and controls motor function	Complete failure	No testing capabilities and repairs needed	6	Excess current or voltage draw from power supply	8	Power shut-off	Voltage and current readings	2	96	Use proper power sources and controller hats	6	3	2	36	60
6	Supports the machine	Complete failure	No testing and failure of entire structure	9	Buckling under excess forces	1	Design with safety factor	Visual check of frame	2	18	N/A	9	1	2	18	0

3.4 Materials and Manufacturing Processes

Although many components could be purchased, many were also manufactured for the sake of costs and for the freedom or uniqueness and an ability to be applied specifically as designed. The greatest factor for part sourcing was the stresses and strains involved during normal operation of wire testing. Most of the components in the assembly are not subjected to movement so A36 structural steel was chosen for any plate components. The shafts were made out of 1045 HR steel because of its superior mechanical properties. Any place that movement within a joint occured, it was designed to have a bronze interface between steel components to reduce the wear of the parts, and resist galling. Most of the bronze pieces were purchased parts made from 660 bronze, but the cups for the lead screw ends needed to be manufactured to mount to the frame, so we chose 954 bronze.

Machining is an important part of the design process and can determine if a design will be successful. Using unnecessary machining processes can add costs, such as choosing to grind a surface that could have been achieved by lathe turning and polishing; the same goes for milling operations. For all of the shafts that needed manufactured, they were designed to only require lathe turning so that costs could be avoided where tighter tolerances were not needed.

Welding aided in cost control when it was applicable, by welding joints together instead of resorting to subtractive manufacturing, starting with a large raw material mass and removing material. This is how we chose to achieve our frame structure. Standard C-channel was welded to a plate to create a rigid framework. The more consideration given to material sourcing, the more cost reductions that can be made. For example, for a frame, strength is necessary but there is little impact on functionality, so a structural steel can be used for the best application. Below, Figures 9 through 14 show the assembly process in detail.

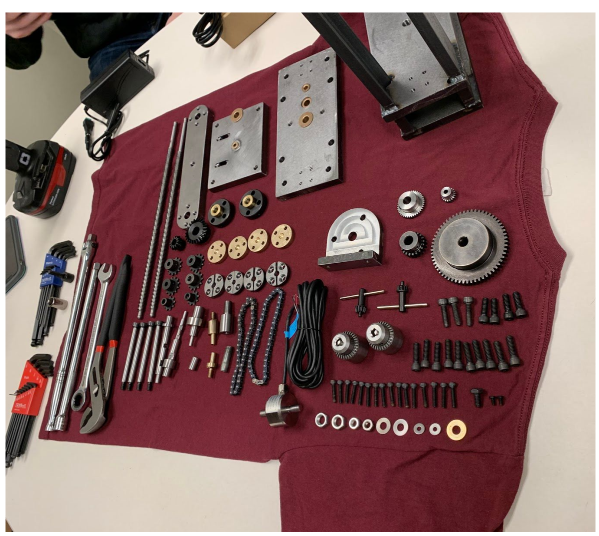


Figure 9: Layout of Components Before Assembly

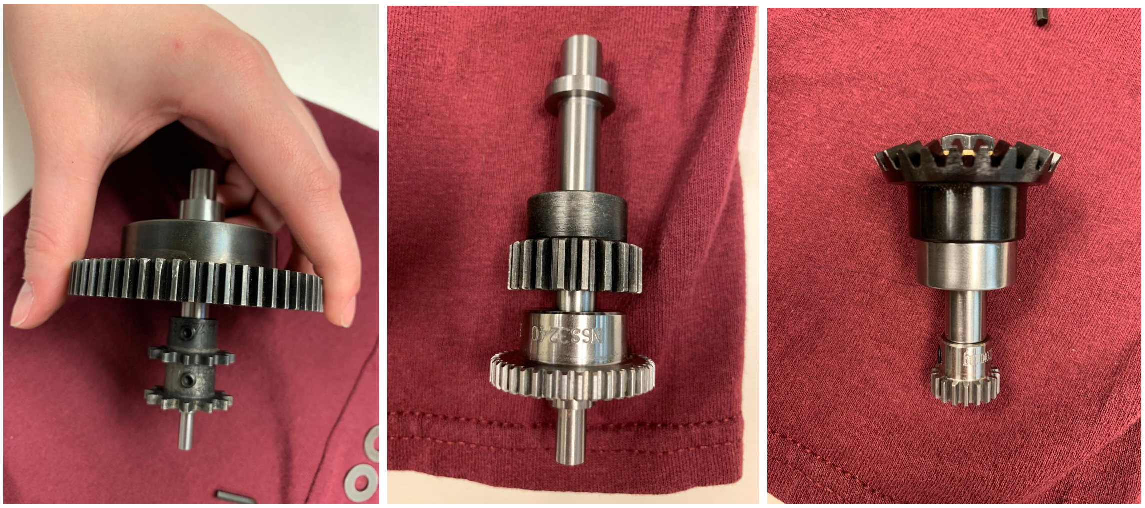


Figure 10: Gearing Assemblies

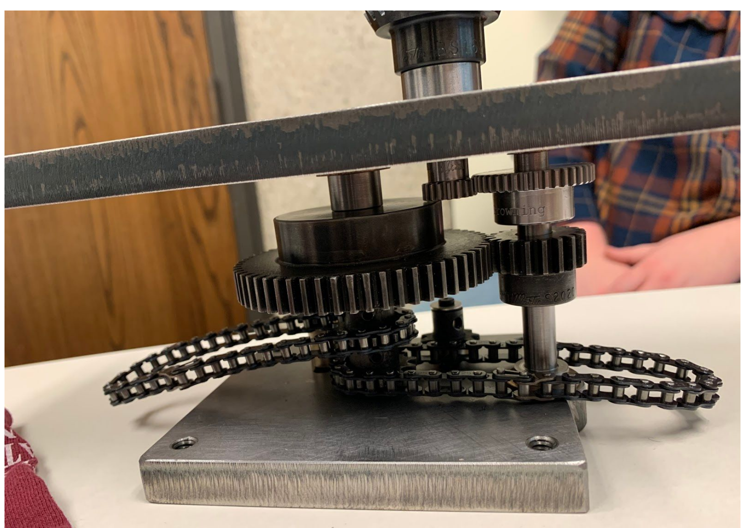


Figure 11: Full Gearbox Assembly with Top Mounting Plate

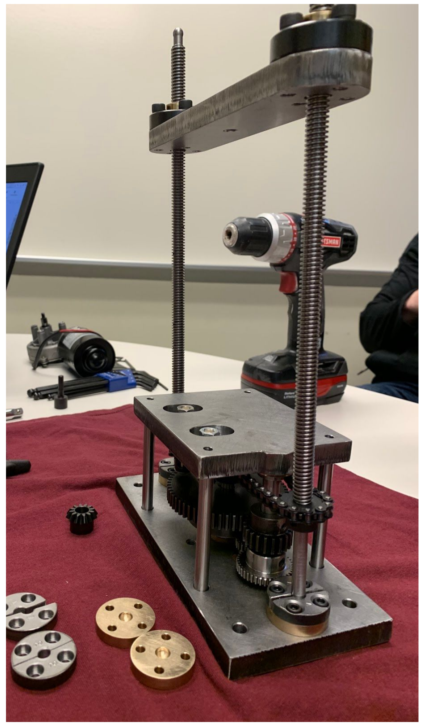


Figure 12: Gearbox Assembly with Lead Screws and Crosshead Incorporated

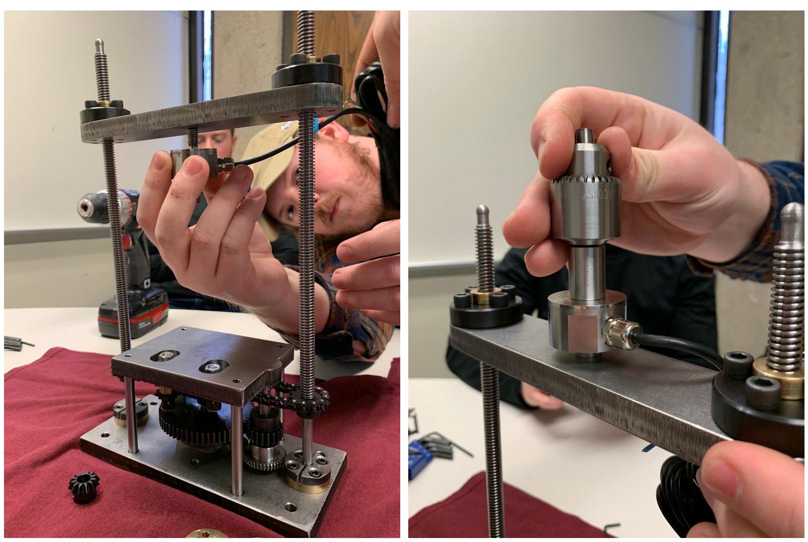


Figure 13: Attaching Load Cell and Drill Chucks

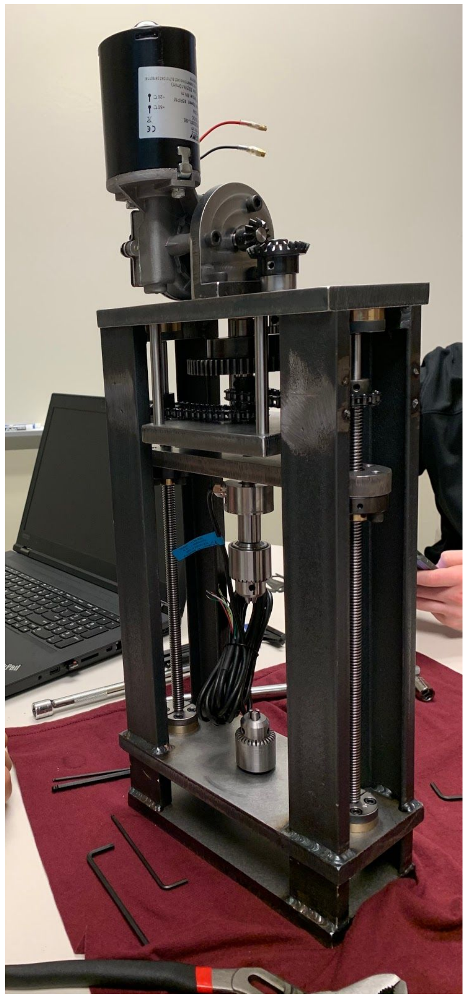


Figure 14: Full Assembly

3.5 Motor Selection

The motor was selected using the force requirement defined by sample material strength and research of typical tensile testing functions. The torque requirement was calculated using this force requirement in tandem with the torque equations for the lead screws. It was also assumed, for calculation purposes, that only one lead screw would be generating the torque, so an inherent safety factor of two is built into the calculations. The general equation for raising torque T_R on a screw and the torque resulting from the collar T_C are as follows:

$$T_R = \frac{F d_m}{2}\left(\frac{l + \pi f d_m sec(\alpha)}{\pi d_m - f l sec(\alpha)}\right) \tag{4}$$

$$T_c = \frac{F f_c d_c}{2} \tag{5}$$

Which can be combined to define the total torque,

$$T = \frac{F}{2}\left[d_m\left(\frac{l+\pi f d_m sec(\alpha)}{\pi d_m - f l sec(\alpha)}\right) + f_c d_c\right] \tag{6}$$

Where the following information is known concerning the lead screw system as related to the dimensions and geometry shown in Shigley's Mechanical Engineering Design,

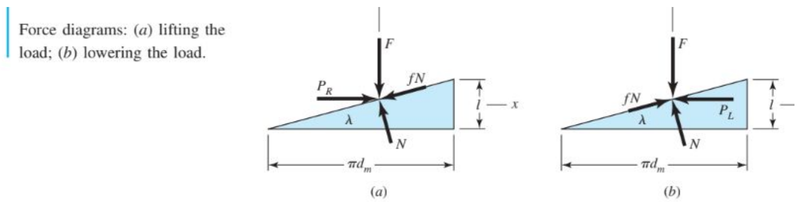


Figure 15: Force Diagram of a Power Screw [Budynas]

$maximum\ force,\ F = 1000\ lbf$
$mean\ screw\ diameter,\ d_m = 0.335\ in$
$mean\ collar\ diameter,\ d_c = 0.543\ in$
$coefficient\ of\ friction,\ f = 0.19$
$coefficient\ of\ collar\ friction,\ f_c = 0.08$
$lead,\ l = 0.079\ in$
$thread\ angle,\ 2\alpha = 30^\circ,\ \alpha = 15^\circ$

Solving for torque then gives,

$$T = \frac{1000\ lbf}{2}\left\{0.335\ in\left[\frac{0.079\ in + \pi(0.19)(0.335\ in)sec(15^\circ)}{\pi(0.335\ in) - (0.19)(0.079\ in)sec(15^\circ)}\right] + (0.08)(0.543\ in)\right\}$$

$$T = 67.92\ lbf \cdot in\left[\frac{1\ ft}{12\ in}\right] = 5.66\ lbf \cdot ft$$

After this torque was found a motor was selected with a torque value close to that of what was required, but also having a relatively low rpm. The garage door motor was selected according to the torque and rpm requirements as well as its low cost. With travel distance per turn from the lead screw dimensions and the desired testing times, the desired speed of the motor and hence the gear ratio were determined. The crosshead needed to move quick enough to avoid a lengthy test, but not too quickly such that the necking region was difficult to examine.

$M10x2$ *lead screw pitch*, $p = 2\ mm$
target vertical travel speed, $u = 5\ \frac{min}{inch} = 0.2\ \frac{in}{min}$

$$target\ rpm,\ v = 0.2\ \frac{in}{min}\left[\frac{25.4\ mm}{1\ in}\right]\left[\frac{1\ rev}{2\ mm}\right] = 2.54\ rpm$$

The torque provided by the motor was $T_m = 4.43\ lbf \cdot ft$ with a speed of $\omega_1 = 35\ rpm$, so a gear ratio of 1:16 was used to decrease the speed and gears were sourced from McMaster-Carr. The gearbox also aided in increasing the torque, as shown in the following calculations.

Number of teeth of chosen gears :

$N_1 = 12$ $N_3 = 18$ $N_5 = 20$
$N_2 = 24$ $N_4 = 40$ $N_6 = 60$

Calculations:

$$\frac{\omega_1}{\omega_6} = \frac{\omega_1}{\omega_2} \times \frac{\omega_2}{\omega_3} \times \frac{\omega_3}{\omega_4} \times \frac{\omega_4}{\omega_5} \times \frac{\omega_5}{\omega_6}$$
$$\frac{\omega_1}{\omega_6} = \frac{\omega_1}{\omega_2} \times 1 \times \frac{\omega_3}{\omega_4} \times 1 \times \frac{\omega_5}{\omega_6}$$
$$\frac{\omega_1}{\omega_6} = \frac{T_6}{T_1} = \frac{N_2}{N_1} \times 1 \times \frac{N_4}{N_3} \times 1 \times \frac{N_6}{N_5} = \frac{(24)(40)(60)}{(12)(18)(20)} = \frac{57600}{4320} = \frac{40}{3}$$

$$\omega_6 = \frac{\omega_1}{(40/3)} = 2.652\ rpm$$
$$T_6 = T_1\left(\frac{\omega_1}{\omega_6}\right) = 4.43\ lbf \cdot ft\left(\frac{35\ rpm}{2.652\ rpm}\right) = 58.5\ lbf \cdot ft$$

3.6 Lay-out and Connection Drawings

There are two main connections that required interfaces with the purpose of reducing wear as much as possible. The first of these is the interface between the lead screw and the framework of the assembly. A 954 bronze cup was machined to mount to the top and middle plates to keep the ball ends of the lead screws in place while reducing wear, as shown in the sketch below.

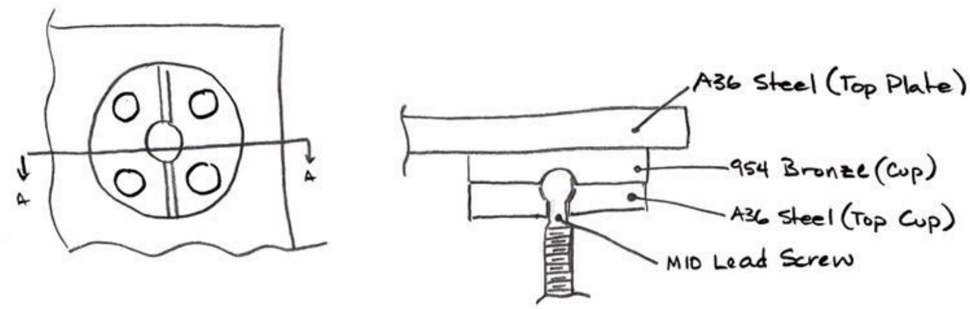


Figure 16: Bronze and Steel Cup to Lead Screw Interface

The second type of interface was between the gear shafts and the gear housing plates. Standard sized 660 bronze bushings sourced from McMaster-Carr were the chosen material.

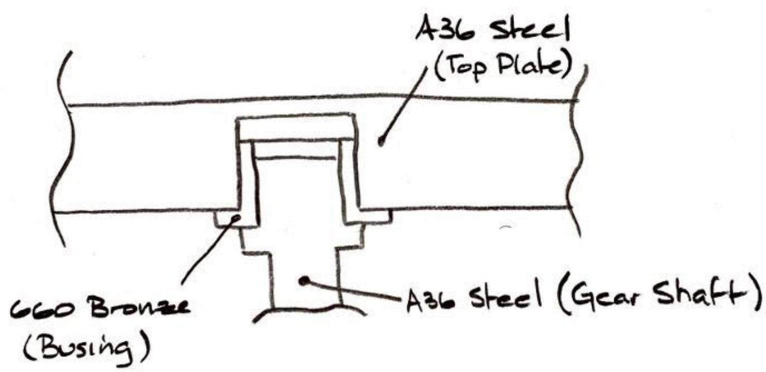


Figure 17: Bronze Bushing to Gear Shafts Interface

Chapter 4: Detailed Design

4.1 Stresses and Loadings

During testing, stress and strain are not only applied to the sample, but can also affect the frame and other components. When designing the frame, forces were evaluated to ensure no buckling or failure would occur. As previously mentioned, all stationary and load bearing components were A36 structural steel. This low carbon steel is easily machined,welded and formed. The yield strength of A36 steel is approximately 36,000 pounds per square inch and the ultimate tensile strength ranges from 58,000 to 79,800 psi. Calculations below analyze the potential strength of the frame compared to the forces experienced by the system by calculating the critical buckling forces P_{cr} under which the supports would fail.

$C-Channel\ Dimensions:\ 1\frac{1}{2}x\frac{1}{2}x\frac{1}{8},\ L = 13\ in$
$Fixed-Fixed\ End\ Condition:\ L' = 0.5L = 6.5\ in$
$Modulus\ of\ steel,\ E_{steel} = 2.9 \times 10^6 psi$
$Moments\ of\ Inertia:\ I_{xx} = 0.08\ in^4,\ I_{yy} = 0.005\ in^4$

$$P_{cr} = \frac{\pi^2 EI}{L^2} = \frac{\pi^2 (2.9\times10^6\ psi)(0.005\ in^4)}{(6.5\ in)^2} = 3387.2\ lbf \quad (7)$$

As mentioned previously, the maximum force expected is $F = 1000\ lbf$, so defining a factor of safety as the ratio of maximum force capability to the max force experienced,

$$SF = \frac{3387.2\ lbf}{1000\ lbf} = 3.40 \quad (8)$$

The factor of safety on a single c-channel support is approximately 3.4, giving a very large window of error, practically guaranteeing that the frame will never buckle under the forces exerted on it, under any circumstance.

4.2 Dimensioning

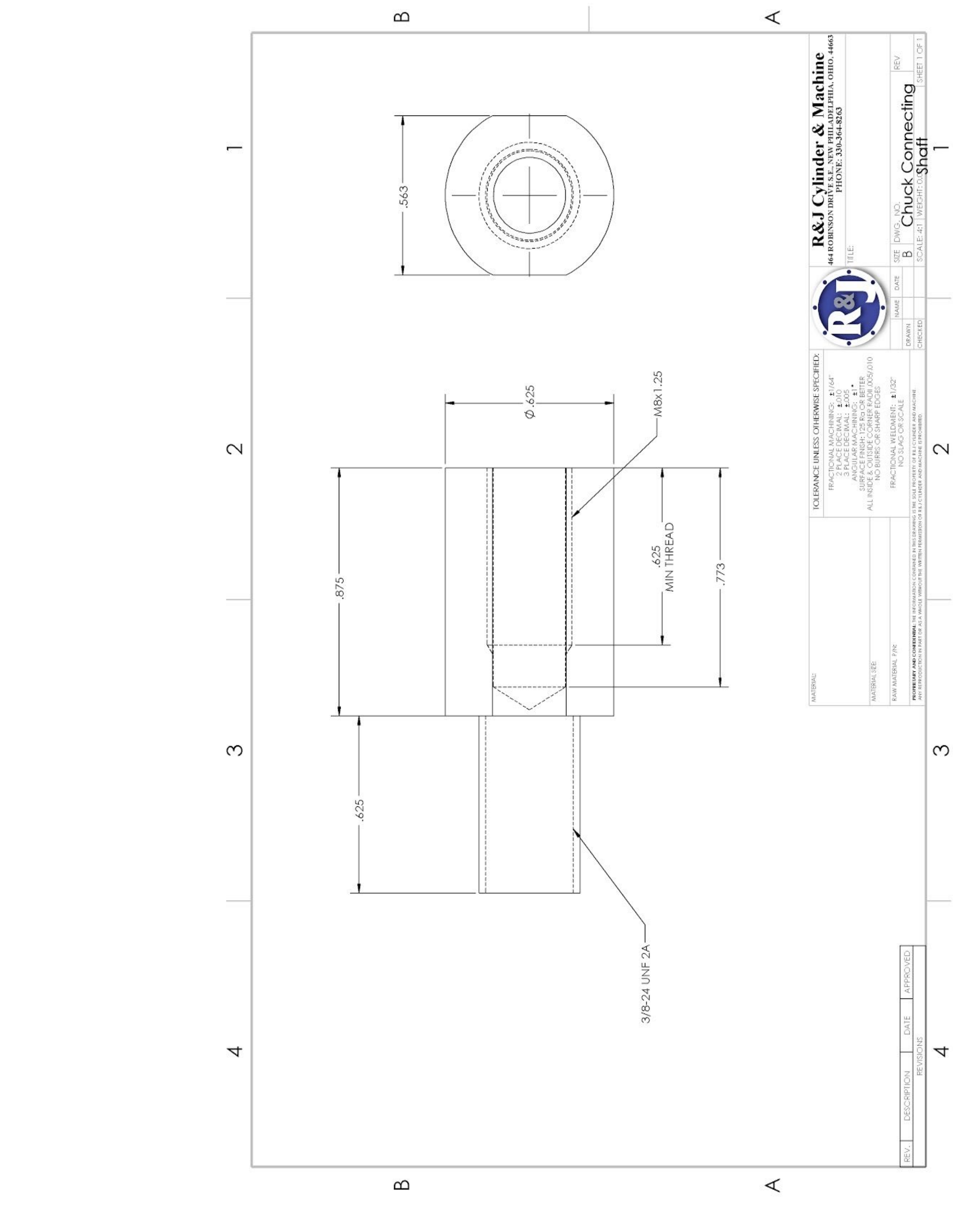
Considering, again, the main purpose of this machine-- to be a demonstrative experience for students and be operator-friendly. The equipment will more than likely be carried around campus, transported from offices to classrooms, to labs, with the possibility of not having an easy way to transport it outside of simply carrying it. The base was kept at 8.5x3.75", the height became 16" with the motor included, and the weight is slightly above 30 pounds. Keeping the machine relatively small makes it easy to place on a desk or table in front of a classroom, store it without creating clutter, and carry it without strain. The specific dimensioning and details of the design can be seen in Section 4.4.

4.3 Standard Components

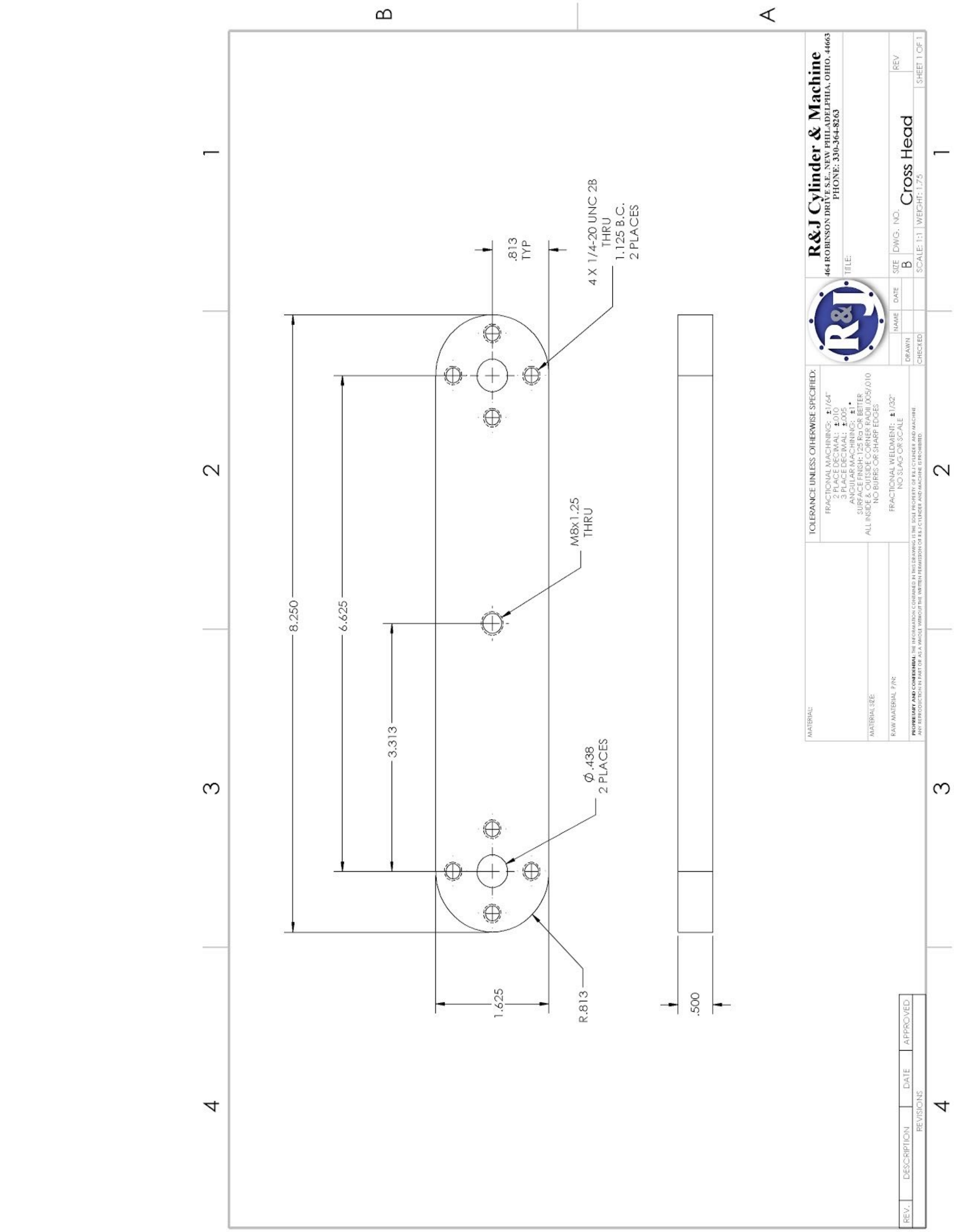
Components such as fasteners, bushings, gears, sprockets and chains along with less standard parts such as the load cell, drill chucks, etc. were sourced and purchased. Details of manufacturers and prices are found in the bill of materials in Section 4.5 as well as the cost sheets in Section 4.6.

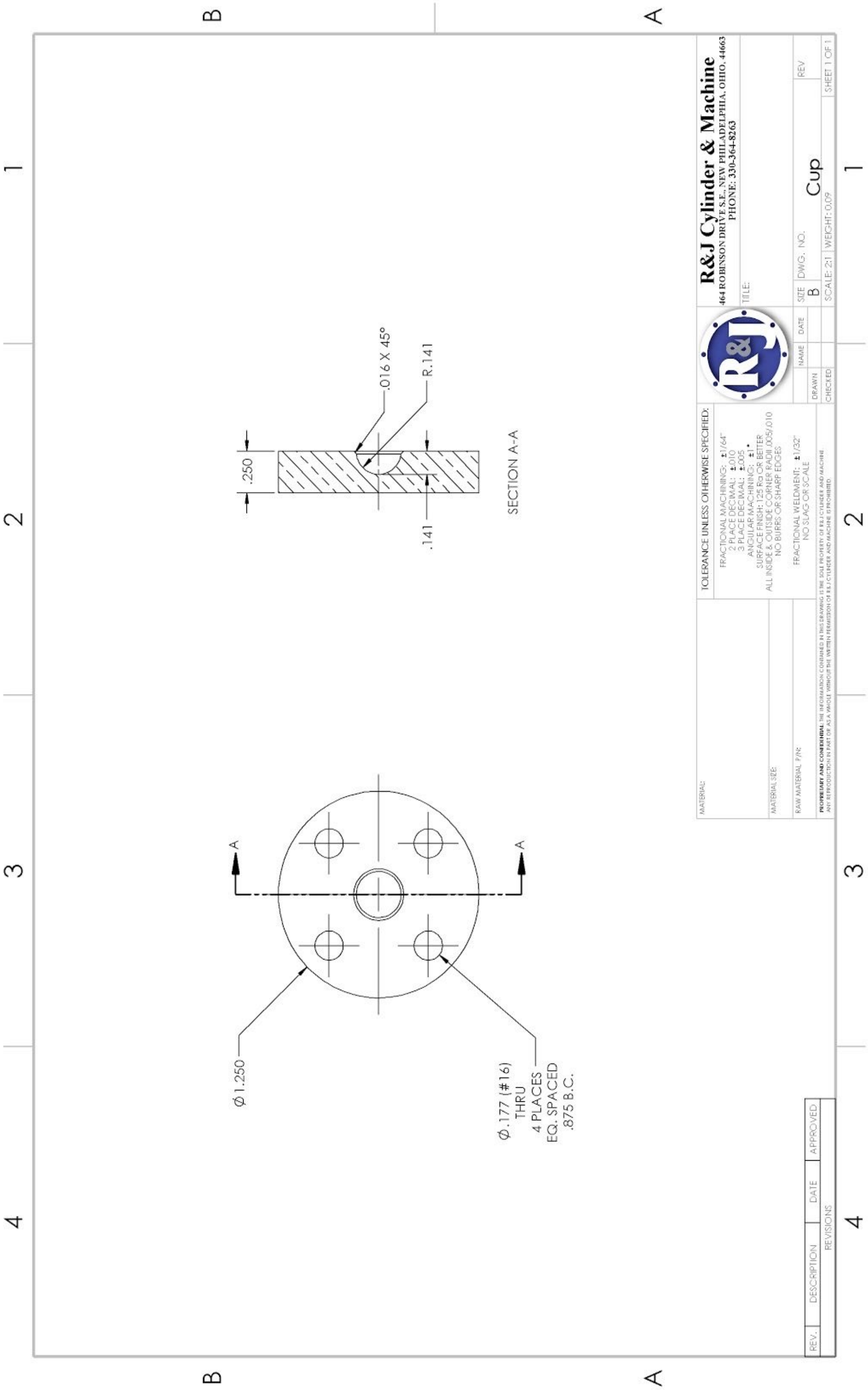
4.4 Part Drawings

The following fifteen pages are detailed drawings of each part of the assembly as follows: chuck connecting shaft 1, crosshead, cup, gear housing plate, gear shaft 1 through 4, idler shaft 1 and 2, lead screw, middle plate, motor mount, mounting block, top cup, and top plate.

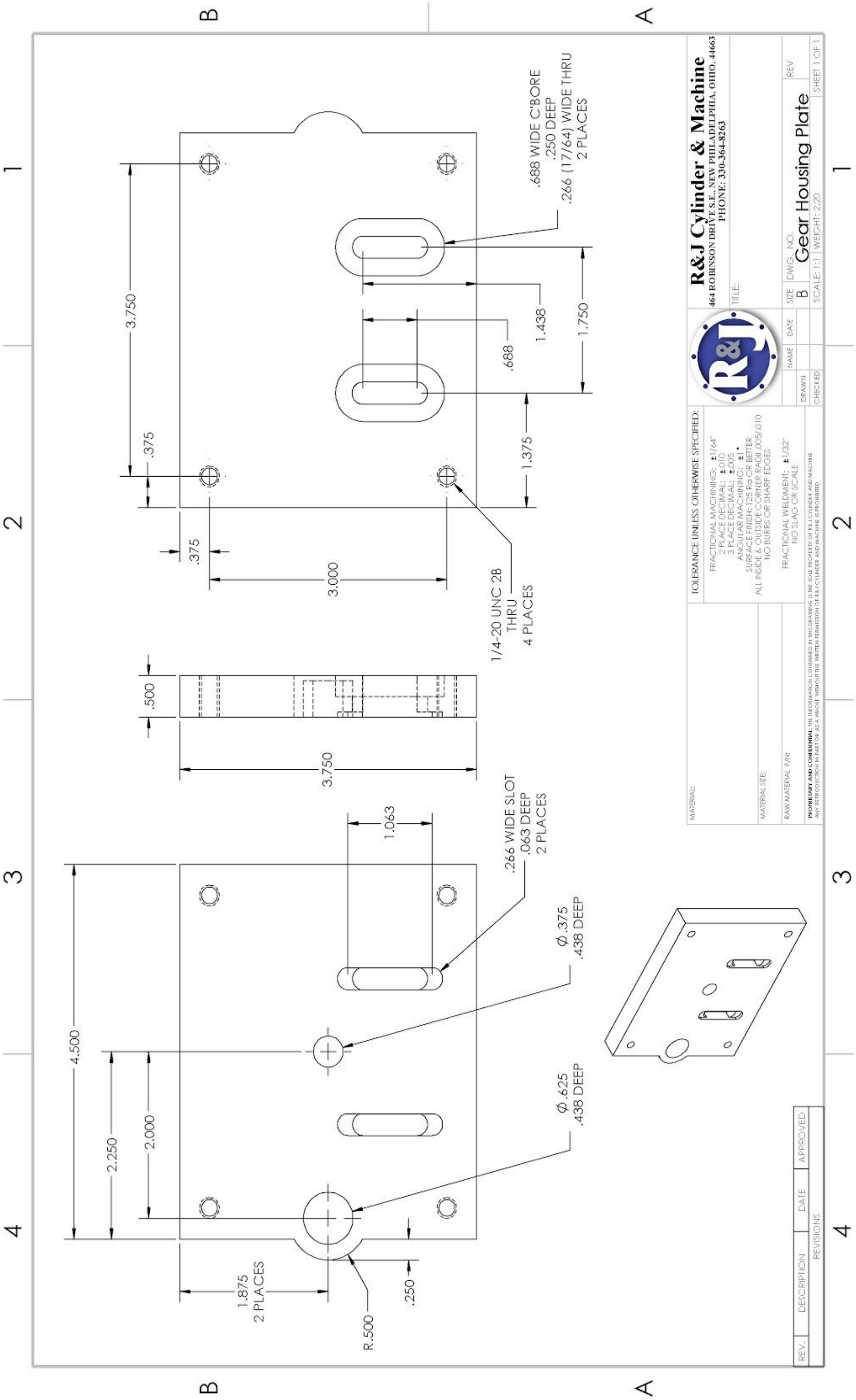


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Chuck Connecting Shaft
SIZE B
DWG. NO.
REV
SCALE: 4:1
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
.563
Ø.625
M8x1.25
.875
.625
MIN THREAD
.773
.625
3/8-24 UNF 2A

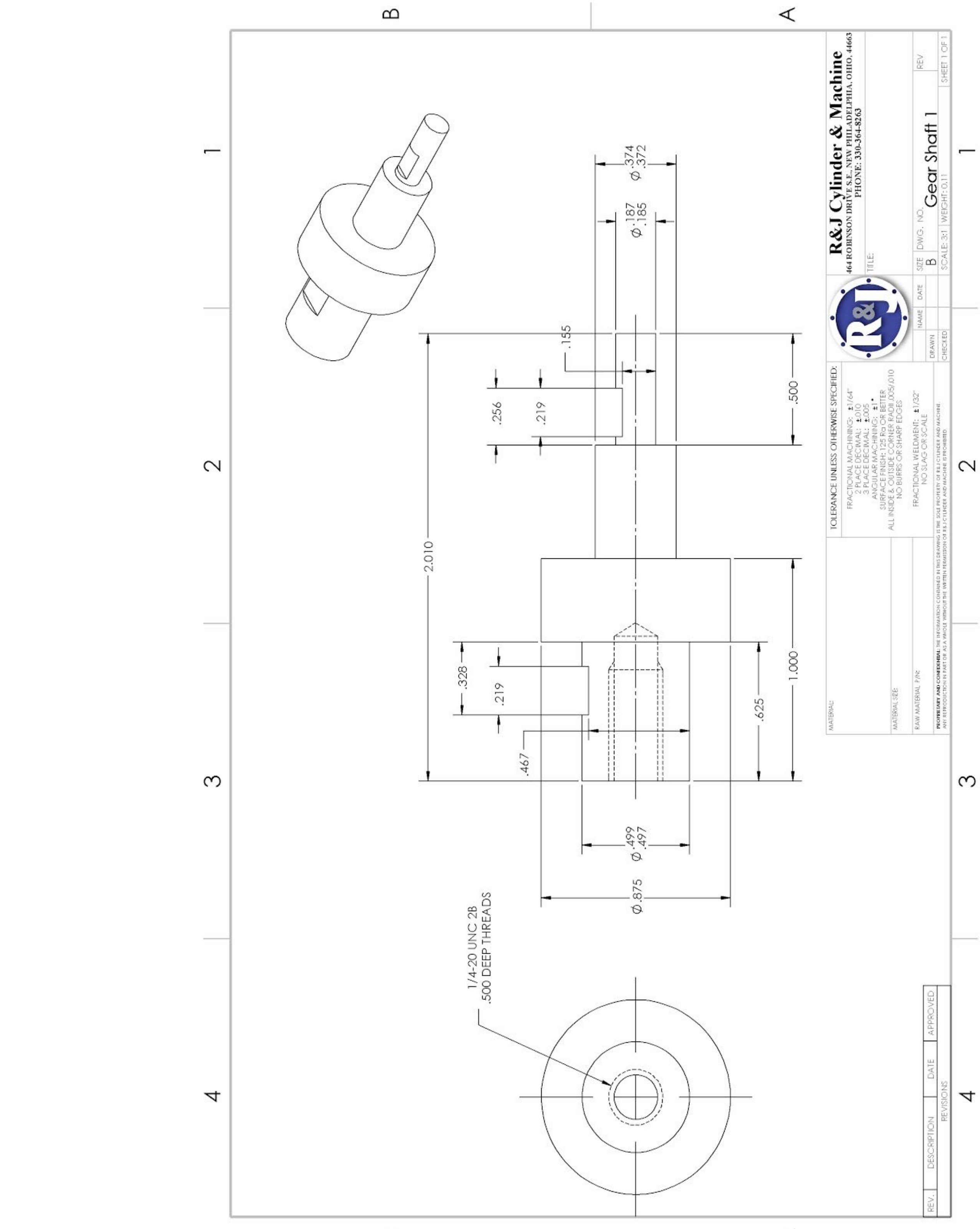

8.250
6.625
3.313
.813
TYP
4 X 1/4-20 UNC 2B
THRU
1.125 B.C.
2 PLACES
M8x1.25
THRU
Ø.438
2 PLACES
1.625
R.813
.500
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 RA OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
DRAWN
CHECKED
NAME
DATE
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
SIZE
B
DWG. NO.
Cross Head
REV
SCALE: 1:1
WEIGHT: 1.75
SHEET 1 OF 1

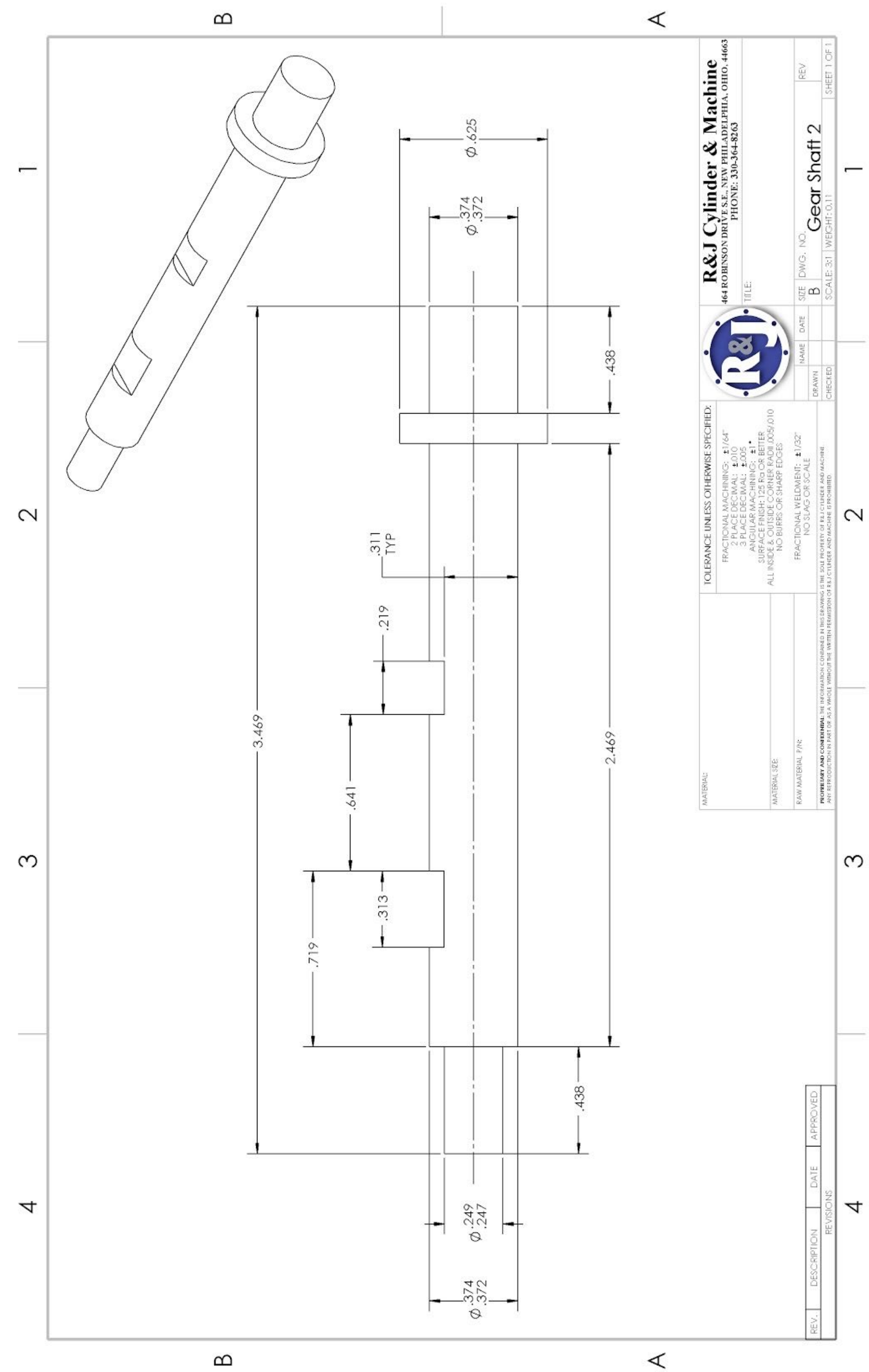


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Cup
SIZE B
DWG. NO.
REV
SCALE: 2:1
WEIGHT: 0.09
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
SECTION A-A
.250
.141
.016 X 45°
R.141
Ø1.250
Ø.177 (#16)
THRU
4 PLACES
EQ. SPACED
.875 B.C.
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS

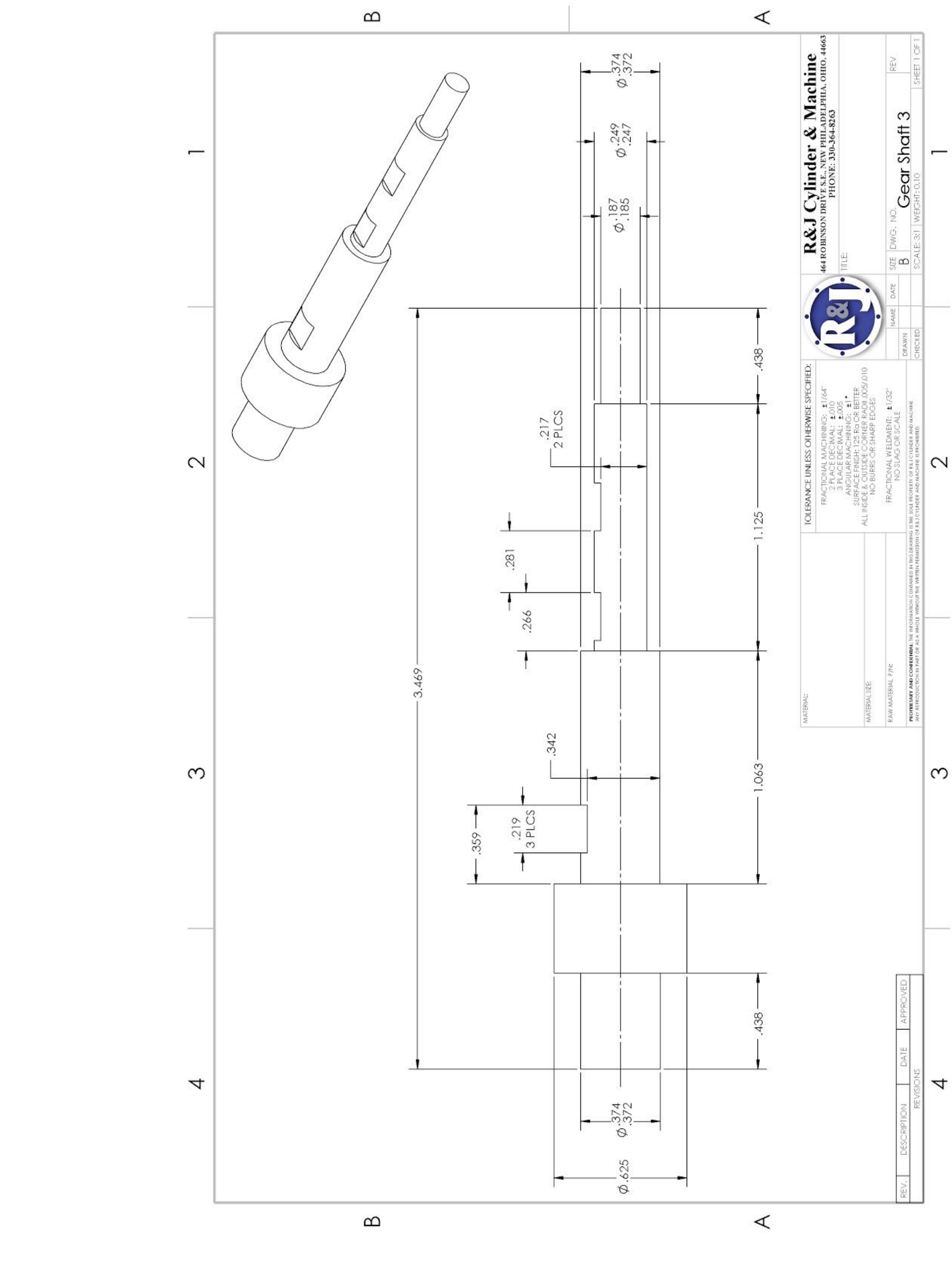


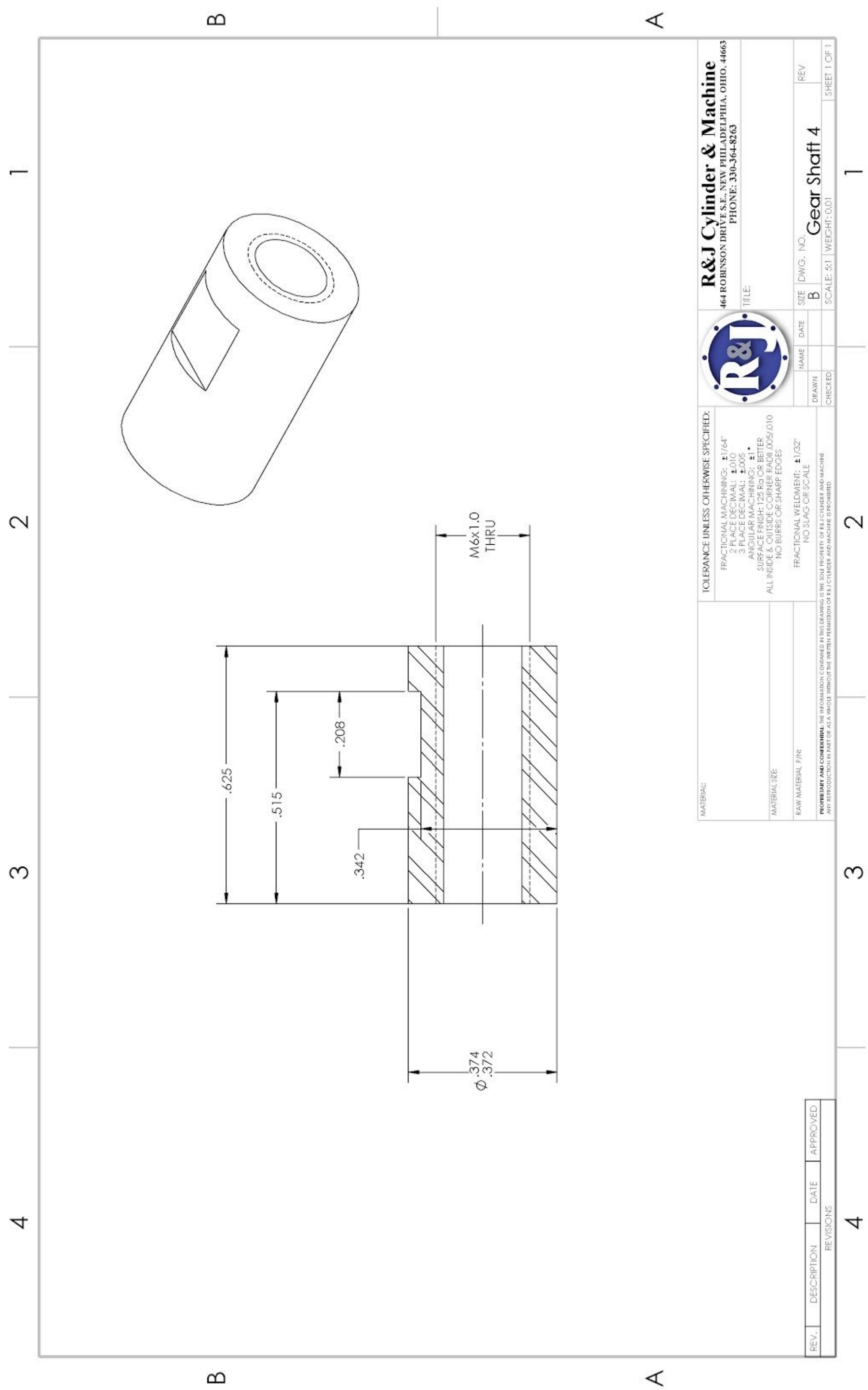
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
SIZE B
DWG. NO.
Gear Housing Plate
REV
SCALE: 1:1
WEIGHT: 2.20
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
.688 WIDE C'BORE
.250 DEEP
.266 (17/64) WIDE THRU
2 PLACES
3.750
.375
1.438
1.750
.688
1.375
.375
3.000
1/4-20 UNC 2B
THRU
4 PLACES
.500
3.750
1.063
.266 WIDE SLOT
.063 DEEP
2 PLACES
Ø.375
.438 DEEP
Ø.625
.438 DEEP
4.500
2.250
2.000
1.875
2 PLACES
.250
R.500


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Gear Shaft 1
SIZE B
DWG. NO.
REV
SCALE: 3:1
WEIGHT: 0.11
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
1/4-20 UNC 2B
.500 DEEP THREADS
Ø.875
Ø.499
.497
Ø.374
.372
Ø.187
.185
2.010
1.000
.625
.500
.467
.328
.219
.256
.219
.155
A
B
1
2
3
4

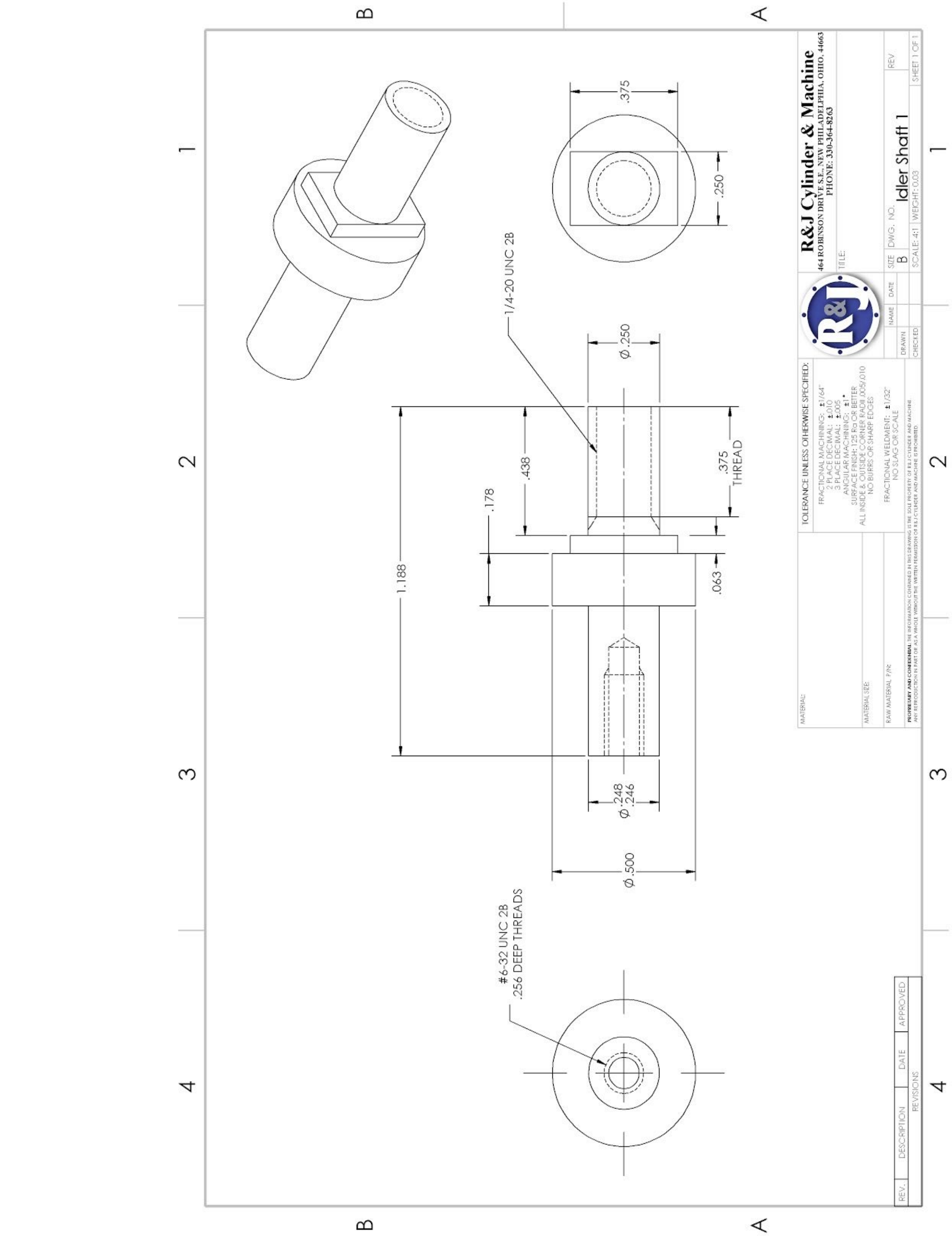


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TITLE:
NAME
DATE
DRAWN
CHECKED
SIZE
B
DWG. NO.
Gear Shaft 2
REV
SCALE: 3:1
WEIGHT: 0.11
SHEET 1 OF 1
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
Ø.625
Ø.374 .372
.438
3.469
2.469
.311 TYP
.219
.641
.313
.719
Ø.249 .247

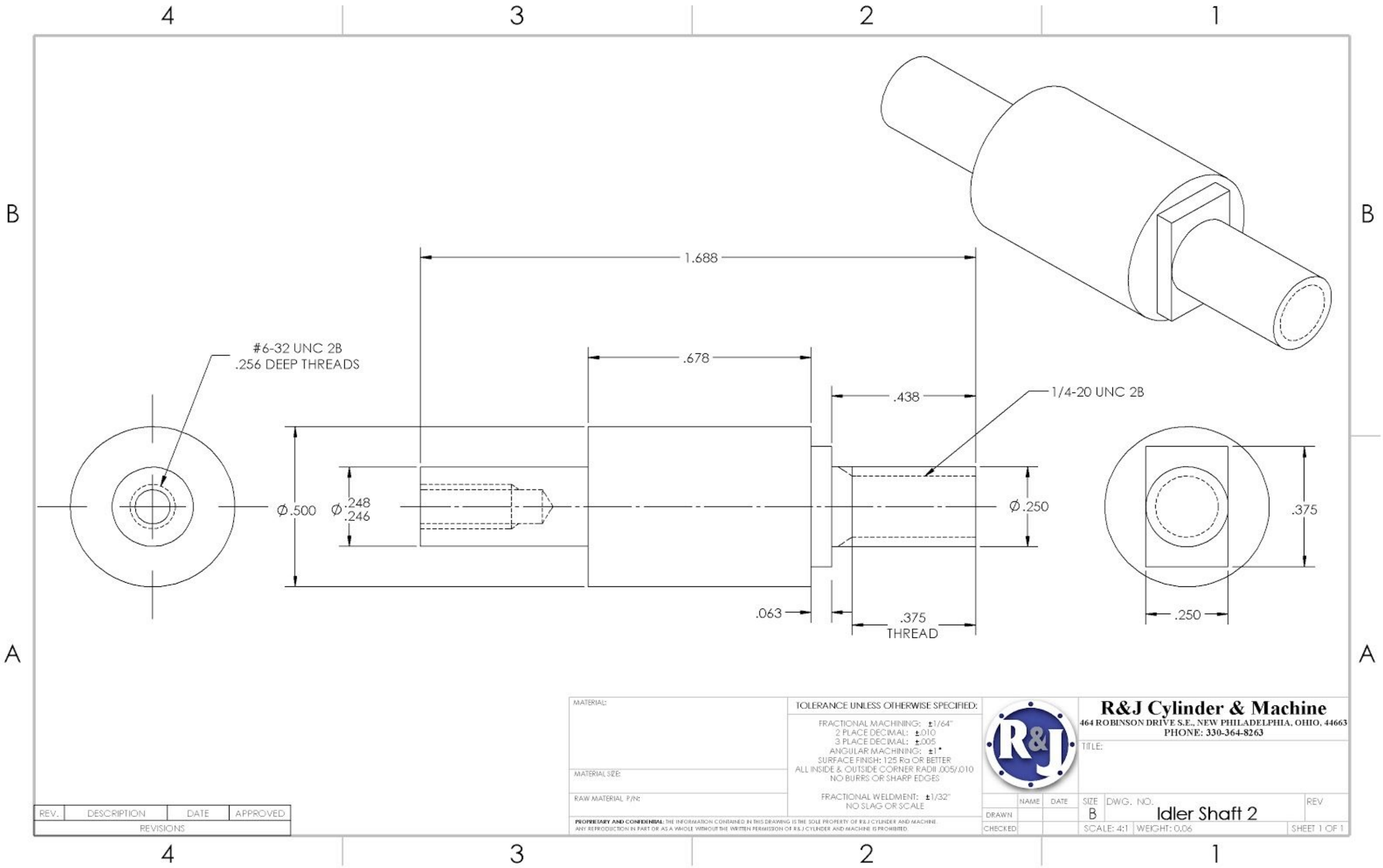

R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TITLE:
Gear Shaft 3
SIZE B
DWG. NO.
REV
SCALE: 3:1
WEIGHT: 0.10
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
3.469
.438
1.125
1.063
.438
.217
2 PLCS
.281
.266
.342
.359
.219
3 PLCS
Ø.374
Ø.372
Ø.249
Ø.247
Ø.187
Ø.185
Ø.625
1
2
3
4
A
B



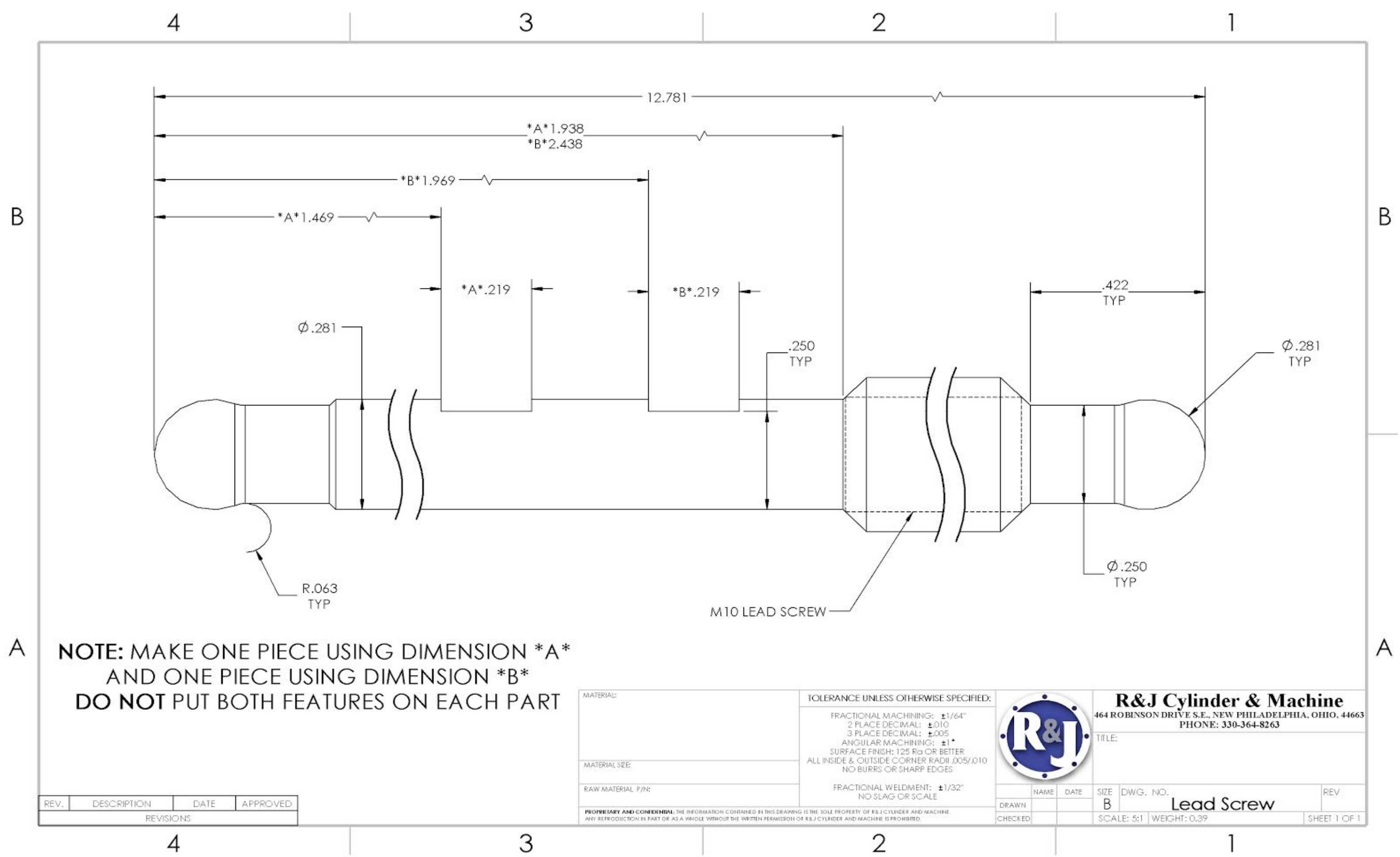
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Gear Shaft 4
SIZE B
DWG. NO.
REV
SCALE: 5:1
WEIGHT: 0.01
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
.625
.515
.208
.342
M6x1.0
THRU
Ø .374
.372
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS



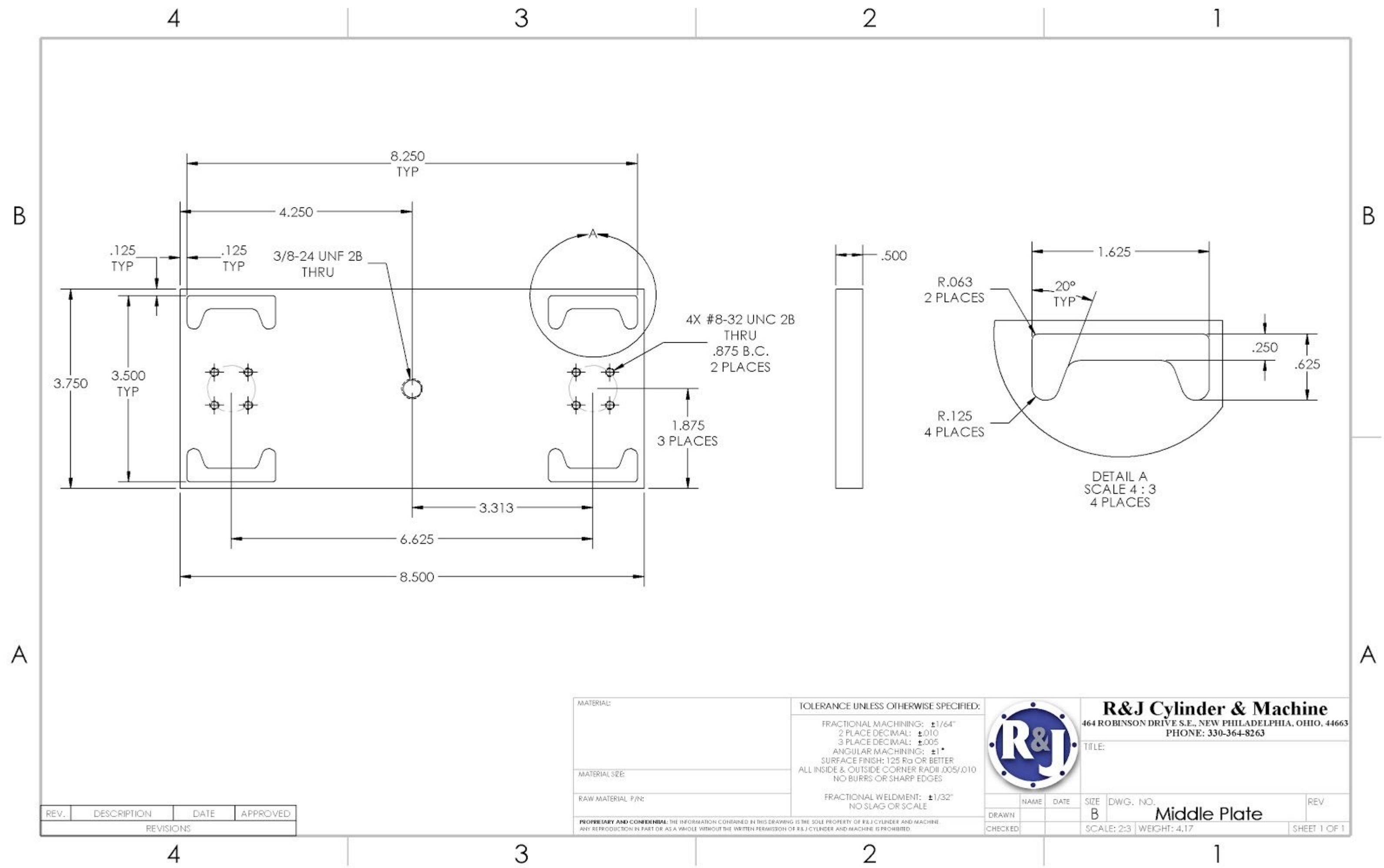
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
Idler Shaft 1
1/4-20 UNC 2B
#6-32 UNC 2B
.256 DEEP THREADS
.375 THREAD
TOLERANCE UNLESS OTHERWISE SPECIFIED:
SIZE B
SCALE: 4:1
WEIGHT: 0.03
SHEET 1 OF 1
REVISIONS

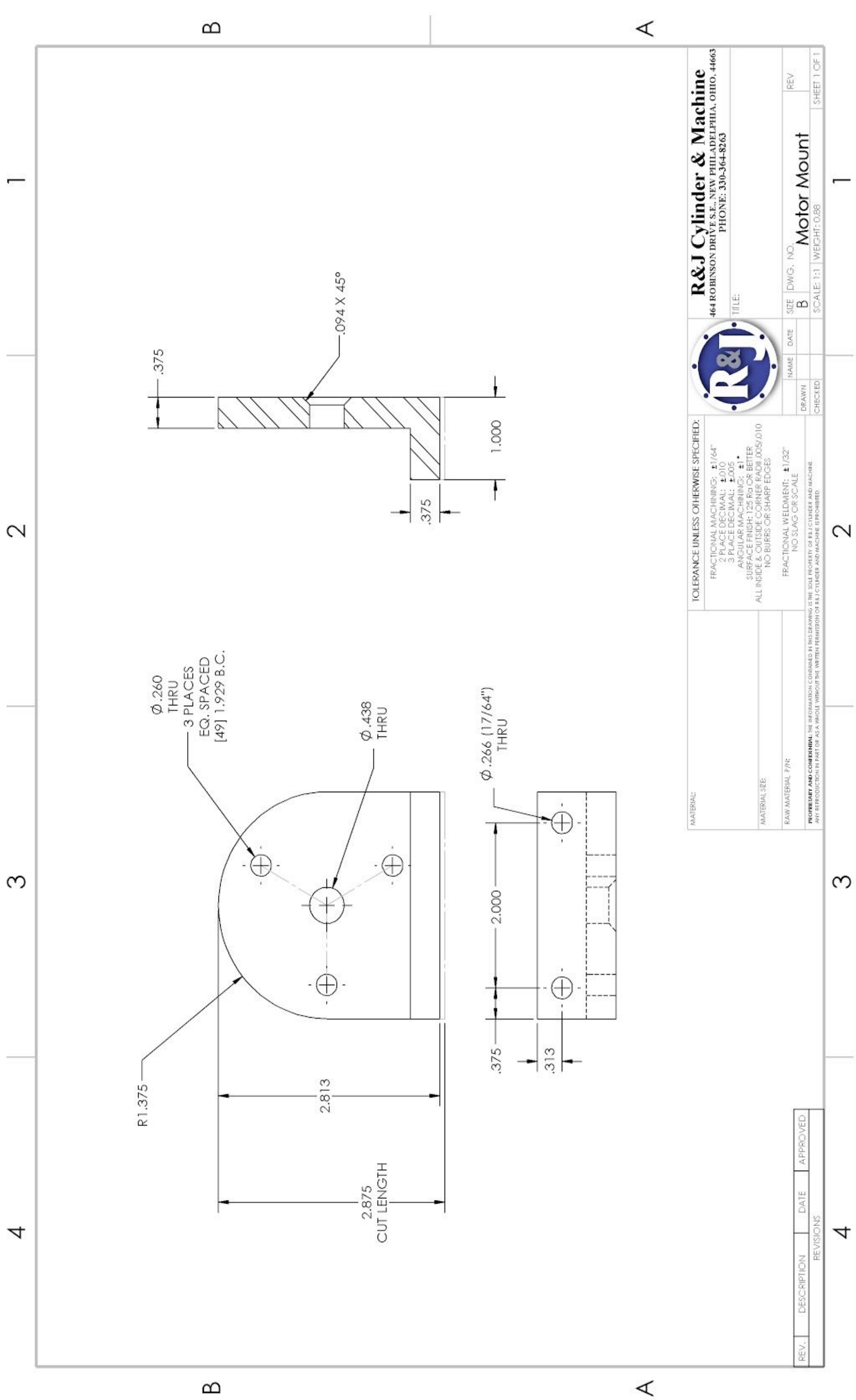


#6-32 UNC 2B
.256 DEEP THREADS
1.688
.678
.438
1/4-20 UNC 2B
Ø.500
Ø.248
.246
Ø.250
.375
.063
.375
THREAD
.250
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
NAME
DATE
DRAWN
CHECKED
SIZE
B
DWG. NO.
Idler Shaft 2
REV
SCALE: 4:1
WEIGHT: 0.06
SHEET 1 OF 1
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS

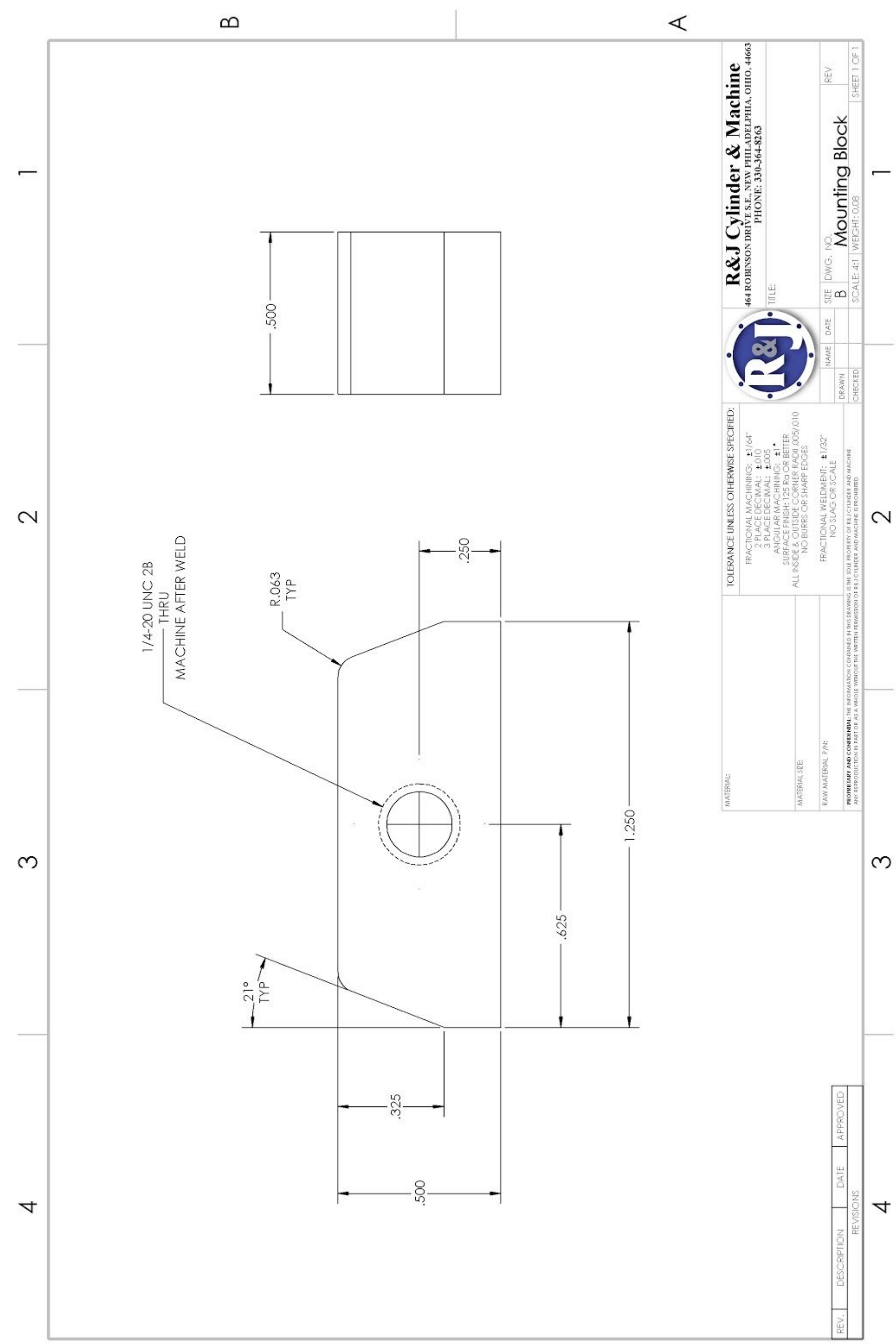


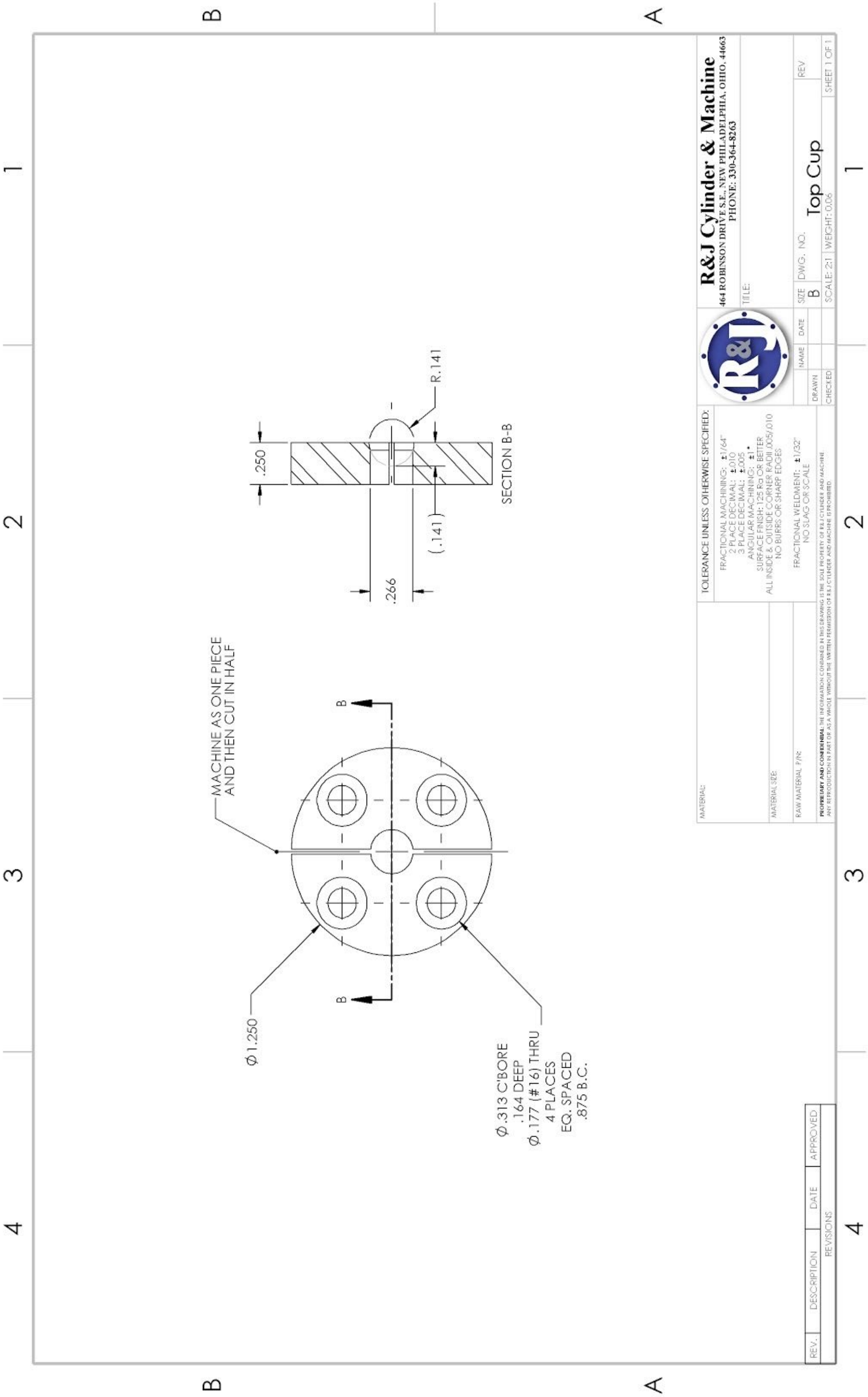
12.781
*A*1.938
*B*2.438
*B*1.969
*A*1.469
A.219
B.219
.422
TYP
Ø.281
.250
TYP
Ø.281
TYP
R.063
TYP
M10 LEAD SCREW
Ø.250
TYP
NOTE: MAKE ONE PIECE USING DIMENSION *A*
AND ONE PIECE USING DIMENSION *B*
DO NOT PUT BOTH FEATURES ON EACH PART
REV. DESCRIPTION DATE APPROVED
REVISIONS
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
NAME DATE
DRAWN
CHECKED
SIZE B
DWG. NO.
Lead Screw
REV
SCALE: 5:1 WEIGHT: 0.39
SHEET 1 OF 1


4
3
2
1
B
A
8.250
TYP
4.250
.125
TYP
.125
TYP
3/8-24 UNF 2B
THRU
A
4X #8-32 UNC 2B
THRU
.875 B.C.
2 PLACES
3.750
3.500
TYP
1.875
3 PLACES
3.313
6.625
8.500
.500
1.625
R.063
2 PLACES
20°
TYP
.250
.625
R.125
4 PLACES
DETAIL A
SCALE 4 : 3
4 PLACES
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
PROPRIETARY AND CONFIDENTIAL: THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF R&J CYLINDER AND MACHINE ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF R&J CYLINDER AND MACHINE IS PROHIBITED.
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
NAME
DATE
DRAWN
CHECKED
SIZE
B
DWG. NO.
Middle Plate
REV
SCALE: 2:3
WEIGHT: 4.17
SHEET 1 OF 1
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS

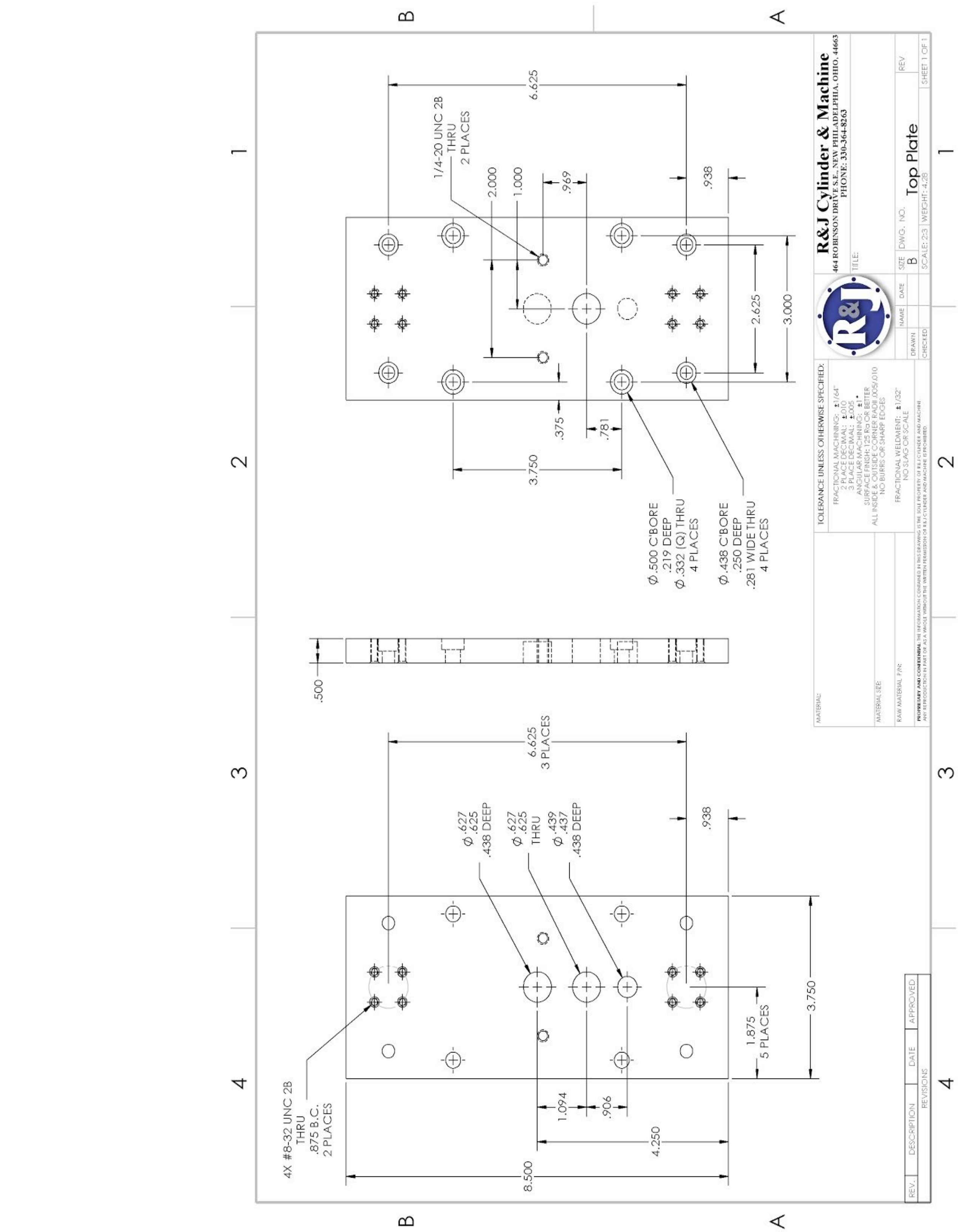


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Motor Mount
SIZE B
DWG. NO.
REV
SCALE: 1:1
WEIGHT: 0.88
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
Ø.260
THRU
3 PLACES
EQ. SPACED
[49] 1.929 B.C.
Ø.438
THRU
Ø.266 (17/64")
THRU
R1.375
2.813
2.875
CUT LENGTH
.375
.313
2.000
.375
.094 X 45°
1.000
.375

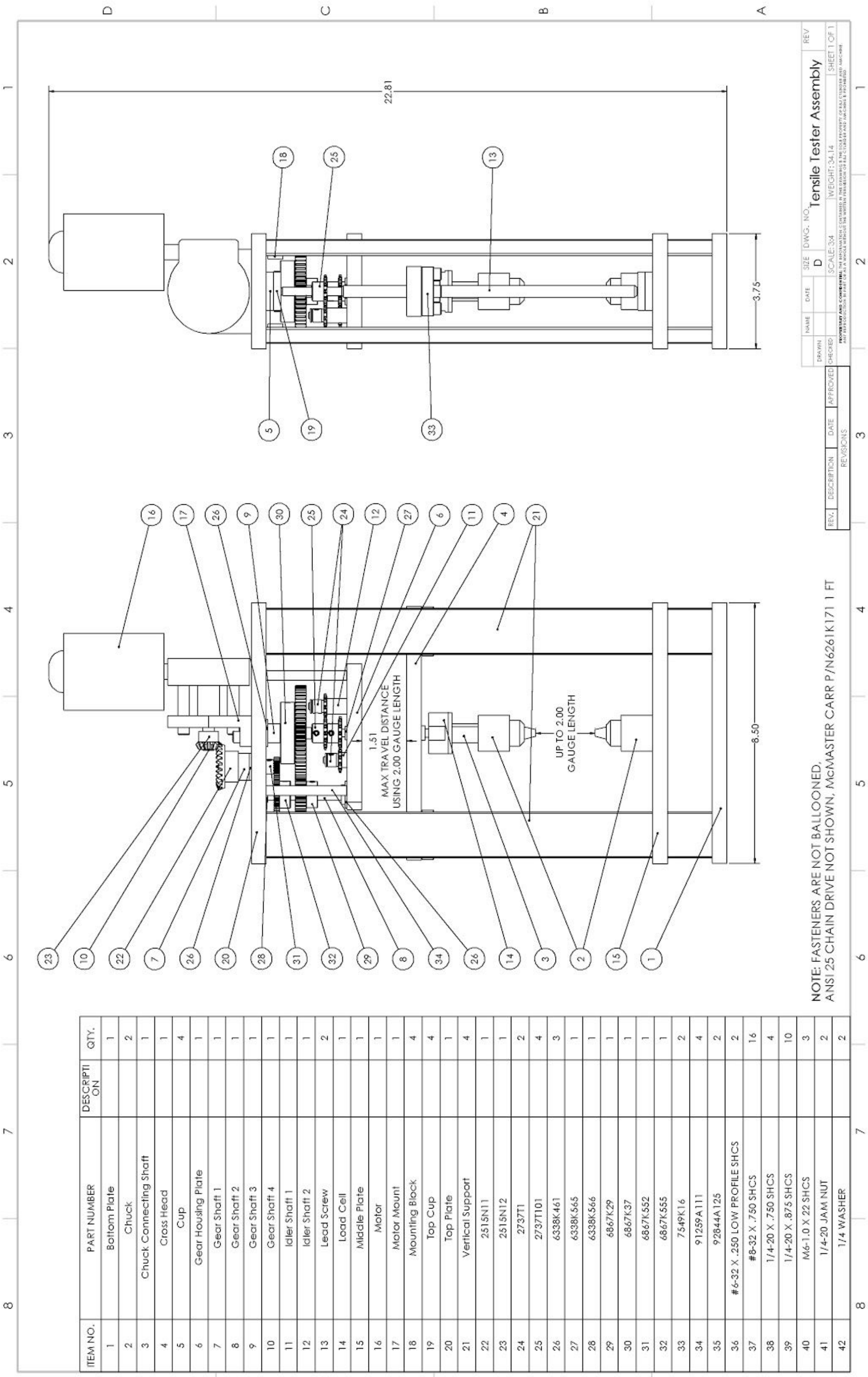

R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Mounting Block
SIZE
B
DWG. NO.
REV
SCALE: 4:1
WEIGHT: 0.08
SHEET 1 OF 1
DRAWN
CHECKED
NAME
DATE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
1/4-20 UNC 2B
THRU
MACHINE AFTER WELD
R.063
TYP
21°
TYP
.250
.500
.325
.500
.625
1.250
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
1
2
3
4
A
B



B
A
1
2
3
4
MACHINE AS ONE PIECE AND THEN CUT IN HALF
Ø1.250
Ø.313 C'BORE
.164 DEEP
Ø.177 (#16) THRU
4 PLACES
EQ. SPACED
.875 B.C.
B
.250
R.141
(.141)
.266
SECTION B-B
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
ANGULAR MACHINING: ±1°
SURFACE FINISH: 125 Ra OR BETTER
ALL INSIDE & OUTSIDE CORNER RADII .005/.010
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
PROPRIETARY AND CONFIDENTIAL: THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF R&J CYLINDER AND MACHINE. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF R&J CYLINDER AND MACHINE IS PROHIBITED.
NAME
DATE
DRAWN
CHECKED
R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
SIZE
B
DWG. NO.
Top Cup
REV
SCALE: 2:1
WEIGHT: 0.06
SHEET 1 OF 1


R&J Cylinder & Machine
464 ROBINSON DRIVE S.E., NEW PHILADELPHIA, OHIO, 44663
PHONE: 330-364-8263
TITLE:
Top Plate
SIZE B
DWG. NO.
REV
SCALE: 2:3
WEIGHT: 4.28
SHEET 1 OF 1
TOLERANCE UNLESS OTHERWISE SPECIFIED:
FRACTIONAL MACHINING: ±1/64"
2 PLACE DECIMAL: ±.010
3 PLACE DECIMAL: ±.005
NO BURRS OR SHARP EDGES
FRACTIONAL WELDMENT: ±1/32"
NO SLAG OR SCALE
MATERIAL:
MATERIAL SIZE:
RAW MATERIAL P/N:
DRAWN
CHECKED
NAME
DATE
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
1/4-20 UNC 2B THRU 2 PLACES
Ø.500 C'BORE .219 DEEP Ø.332 (Q) THRU 4 PLACES
Ø.438 C'BORE .250 DEEP .281 WIDE THRU 4 PLACES
4X #8-32 UNC 2B THRU .875 B.C. 2 PLACES
Ø.627 .625 .438 DEEP
Ø.627 .625 THRU
Ø.439 .437 .438 DEEP
6.625
6.625 3 PLACES
2.000
1.000
.969
.938
2.625
3.000
3.750
.375
.781
.500
1.875 5 PLACES
1.094
.906
4.250
8.500
A
B
1
2
3
4

4.5 Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bottom Plate		1
2	Chuck		2
3	Chuck Connecting Shaft		1
4	Cross Head		1
5	Cup		4
6	Gear Housing Plate		1
7	Gear Shaft 1		1
8	Gear Shaft 2		1
9	Gear Shaft 3		1
10	Gear Shaft 4		1
11	Idler Shaft 1		1
12	Idler Shaft 2		1
13	Lead Screw		2
14	Load Cell		1
15	Middle Plate		1
16	Motor		1
17	Motor Mount		1
18	Mounting Block		4
19	Top Cup		4
20	Top Plate		1
21	Vertical Support		4
22	2515N11		1
23	2515N12		1
24	2737T1		2
25	2737T101		4
26	6338K461		3
27	6338K565		1
28	6338K566		1
29	6867K29		1
30	6867K37		1
31	6867K552		1
32	6867K555		1
33	7549K16		2
34	91259A111		4
35	92844A125		2
36	#6-32 X .250 LOW PROFILE SHCS		2
37	#8-32 X .750 SHCS		16
38	1/4-20 X .750 SHCS		4
39	1/4-20 X .875 SHCS		10
40	M6-1.0 X 22 SHCS		3
41	1/4-20 JAM NUT		2
42	1/4 WASHER		2

4.6 Cost Estimates and Purchasing

The following tables lay out the initial cost estimate for the entire project, the actual costs involved, and a comprehensive list of purchases. The financial support from R&J Cylinder and Machine and American Axle Manufacturing made this project possible. Labor and manufacturing was also sourced through R&J. Initially, a $1000 budget was set as a goal, but many of the parts such as load cell, extensometer, grips, and lead screws, were much more expensive than anticipated. As mentioned before, drill chucks were used as an alternative to typical tensile grips as a cheaper alternative. Epsilon worked with our team as well to bring down prices on the extensometer and signal conditioner needed.

Table 5: Project Cost Estimate Including Total Weight Estimate

Phase One						
	Product/ Material	*Cost/Unit*	*QTY.*	*Total Cost*	*Weight/Unit (lbs)*	*Total Weight (lbs)*
1	Motor			$590.00		13.00
	Motor	$50.00	1	$50.00	3.00	3.00
1.2	Gearing	$300.00	-	$300.00	10.00	10.00
1.3	Sprockets	$200.00	-	$200.00	2.00	2.00
1.4	Bearings	$20.00	-	$20.00	1.00	1.00
1.5	Chains/Links	$20.00	-	$20.00	-	-
2	Lift Mechanism			$200.00		2.00
2.1	Lead screws	$25.00	2	$50.00	0.50	1.00
2.2	Nuts	$75.00	2	$150.00	0.50	1.00
3	Frame			$185.00		10.00
3.1	Raw Materials	$60.00	-	$60.00	3.00	3.00
3.2	C-channel steel	$75.00	1	$75.00	7.00	7.00
3.3	Fasteners/accessories	$50.00	1	$50.00	-	-
4	Testing			$3,015.00		2.00
4.1	Wire Grips	$500.00	2	$1,000.00	1.00	2.00
4.2	Limit Switch	$15.00	1	$15.00	-	-
4.3	Extensometer	$2,000.00	1	$2,000.00	-	-
Total Phase 1:			$3,990.00		Weight:	27.00
Phase Two						
5	Load cell			$300.00		1.00
6	Wire			$20.00		-
Total Phase 2:			$320.00		Weight:	1.00
Phase Three						
7	Data acquisition			$112.00		0.00

7.1	Raspberry Pi	$42.00	1	$42.00	-	-
7.2	Breadboard	$10.00	-	$10.00	-	-
7.3	Hats	$40.00	-	$40.00	-	-
7.4	Power supply	$10.00	1	$10.00	-	-
7.5	Resistors	$10.00	-	$10.00	-	-
8	Accessories			$100.00		3.00
8.1	Display/ Controls	$80.00	-	$80.00	2.00	2.00
8.2	3D Printed Parts	$20.00	-	$20.00	1.00	1.00
Total Phase 3:			$212.00		Weight:	3.000
Total Project:			$4,522.00		Weight:	31.000

Table 6: Project Cost Summary

Product/ Material		*Source*	*Cost/Unit*	*QTY.*	*Total Cost*
1	Motor				$465.15
1.1	Motor	Amazon	$43.88	1	$43.88
1.2	Motor Controller	DROK	$15.59	1	$15.59
1.3	Gearing	MMC	$316.90	-	$316.90
1.4	Sprockets	MMC	$63.16	-	$63.16
1.5	Bearings	MMC	$8.10	-	$8.10
1.6	Chains/Links	MMC	$17.52	-	$17.52
2	Lift Mechanism				$194.06
2.1	Lead screws	MMC	$23.67	2	$47.34
2.2	Nuts	MMC	$73.36	2	$146.72
3	Frame				$159.52
3.1	Raw Materials	MMC	$57.92	-	$57.92
3.2	C-channel steel	Sparta Steel	$45.00	-	$45.00
3.3	Fasteners/accessories	Various	$41.60	-	$41.60
3.4	Plexiglass	Amazon	$15.00	-	$15.00
4	Testing				$1,722.31
4.1	Drill Chucks	Home Depot	$62.60	2	$125.20
4.2	Limit Switches	Amazon	$7.99	1	$7.99
4.3	Extensometer	Epsilon	$900.00	1	$900.00
4.4	Signal Conditioner	Epsilon	$689.12	1	$689.12
5	Load Reading				$230.40
5.1	Load cell	eBay	$224.15	1	$224.15
5.2	Amplifier	DIYmall	$6.25	1	$6.25
6	Wire	Home Depot	$7.38	-	$7.38
7	Data acquisition				$134.04

7.1	Raspberry Pi	Amazon	$42.00	1	$42.00
7.2	Breadboard	MCIGICM	$6.99	1	$6.99
7.3	Hats	Various	$24.74	-	$24.74
7.4	Power Supplies	Various	$25.68	-	$25.68
7.5	Tools, etc.	Various	$19.96	-	$19.96
7.6	Other Accessories	Various	$14.67	-	$14.67
8	Labor/ Manufacturing	Various	$4,506.21	-	$4,506.21
Total Project:					$7,419.07

Table 7: List of Products Purchased for Project

Product	Source	Price	Qty.	Ext Price
Garage Motor	DC Gear Motor	$43.88	1	$43.88
Motor Controller	DROK	$15.59	1	$15.59
24 Tooth Metal Bevel Gear 20° Pressure Angle	McMaster-Carr	$56.24	1	$56.24
12 Tooth Metal Bevel Gear 20° Pressure Angle	McMaster-Carr	$33.80	1	$33.80
20 Tooth Metal Gear 14-1/2° Pressure Angle	McMaster-Carr	$52.44	1	$52.44
60 Tooth Metal Gear 14-1/2° Pressure Angle	McMaster-Carr	$84.18	1	$84.18
18 Tooth Metal Gear 14-1/2° Pressure Angle	McMaster-Carr	$28.21	1	$28.21
40 Tooth Metal Gear 14-1/2° Pressure Angle	McMaster-Carr	$62.03	1	$62.03
12 Tooth Roller Chain Sprocket	McMaster-Carr	$10.81	4	$43.24
9 Tooth Roller Chain Sprocket	McMaster-Carr	$9.96	2	$19.92
5/8" X 3/8" x 1/2" Lg Oil-Embedded Flanged Sleeve Bearing	McMaster-Carr	$1.42	3	$4.26
3/8" X 3/16" x 3/8" Lg Oil-Embedded Flanged Sleeve Bearing	McMaster-Carr	$1.22	1	$1.22
7/16" X 1.4" x 1/2" Lg Oil-Embedded Flanged Sleeve Bearing	McMaster-Carr	$2.62	1	$2.62
ANSI 25 Roller Chain 1 ft section	McMaster-Carr	$5.14	2	$10.28
ANSI 25 Roller Chain Add & Connect Link	McMaster-Carr	$2.00	2	$4.00
ANSI 25 Roller Chain Adding Link	McMaster-Carr	$0.62	2	$1.24
ANSI 25 Roller Chain Connecting Link	McMaster-Carr	$1.00	2	$2.00
Lead Screw Precision Acme, M10 x 2mm Thread, 500 mm Long	McMaster-Carr	$23.67	2	$47.34
Precision Acme Flange Nut, M10 x 2mm	McMaster-Carr	$73.36	2	$146.72

Thread for Lead Screw				
5/8" 954 Aluminum Bronze	MMC	$14.64	1	$14.64
1-1/4" 954 Aluminum Bronze	MMC	$43.28	1	$43.28
C-channel (1-1/2 x 1/2 x 1/8)	Sparta Steel	$45.00	1	$45.00
316 Stainless #6 Washer	MMC	$3.04	2	$6.08
1/4-20 Socket Head Shoulder Bolt, 3" Shoulder Length	McMaster-Carr	$6.80	4	$27.20
Steel Hinge without Holes, Non-removable Pin, 1" x 1/2" Door Leaf, 0.047" Leaf Thickness	McMaster-Carr	$2.08	4	$8.32
Plexi-glass	Amazon	$15.00	1	$15.00
1B-3/8 Plain Bearing Medium Duty Drill Chuck	Jacobs/Home Depot	$62.60	2	$125.20
Limit switches	Amazon	$7.99	1	$7.99
Extensometer	Epsilon	$900.00	1	$900.00
Signal Conditioner	Epsilon	$689.12	1	$689.12
Tension and compression load cell 500kg Inline force sensor 5kN force transducer	eBay	$224.15	1	$224.15
Load Cell Amplifier	DIYmall HX711	$6.25	1	$6.25
Copper wire (8 and 12 gauge)	Home Depot	$7.38	-	$7.38
Raspberry Pi 4 Model B 2019 Quad Core 64 Bit WiFi Bluetooth (2GB)	Raspberry Pi	$42.00	1	$42.00
Breadboards	MCIGICM	$6.99	1	$6.99
Motor controller hat	Amazon	$16.75	1	$16.75
Prototype Hat	Maker Spot	$7.99	1	$7.99
Motor power supply	Amazon	$10.99	1	$10.99
Pi Power Supply	Raspberry Pi	$14.69	1	$14.69
Multimeter		$6.99	1	$6.99
Soldering Iron		$4.99	1	$4.99
Soldering Iron		$3.99	2	$7.98
Wiring	SunFounder	$6.68	1	$6.68
Heat Sinks		$7.99	1	$7.99
Mounting Block		$2.02	4	$8.08
Bearing Housing Plate		$8.07	1	$8.07
Middle Plate		$13.05	1	$13.05
Crosshead		$7.89	1	$7.89
Additional Burnout		$36.27	-	$36.27
Outside Machining		$540.00	-	$540.00
Machining Cost		$3,892.85	51.8 hrs	$3,892.85
			Project Total:	$7,419.07

4.7 Preliminary Testing

After assembly of the frame, but before the motor was integrated, the first test of the machine capabilities was through use of a cordless drill used to turn the gearbox and lift the crosshead. The crosshead moved smoothly and evenly and the motor was then installed. The first sample tested was a Ø0.250" copper wire. The chucks were tightened as much as possible, and testing began. With this sample, and a few more to follow, the samples continued to pull out of the chucks before failure, even after an attempt to continuously tighten the chucks during testing. Through this process, a sample did manage to break and an ideal break was achieved showing the expected "cup-cone" characteristics shown in the figures below.

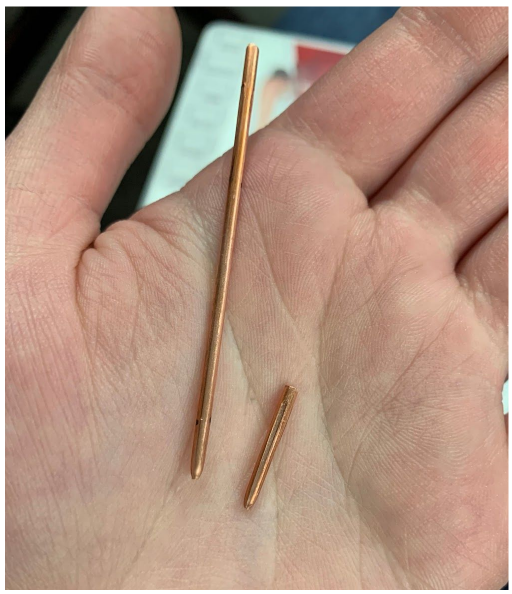


Figure 18: First Break of Copper Wire on Tensile Tester

Figure 19: Cup Cone Fracture of Ductile Materials [Ductility]

The ends of the samples had long gouges in them from the jaws of the drill chucks, but regardless, the majority of samples slipped. Based on research we had done looking at typical tensile grips, the conclusion was made that the drill chucks needed altered. The inside of the chucks were tapped in an attempt to essentially add threads or grooves to provide a better holding capacity.

Figure 20: Wedge Grip with Grooved V-Slot from MTS

After tapping the drill chucks, another copper sample was tested and it slipped at a much slower rate. The concept that adding threads to the inside of the jaws proved to have a larger gripping force. An aluminum sample was then tested due to it being harder. This sample had almost no slip inside the drill chucks and broke consistently in the middle of the gauge length.

Chapter 6: Conclusions

Due to the COVID-19 outbreak causing the total shutdown of campus and increased measures to practice social distancing, the goals set and progress anticipated at the beginning of the project planning phase, was slowed and altered considerably. We hope that in the following years, other senior design groups can work to integrate the load cell, control system, and extensometer. By design, the parts purchased during this phase are capable of providing real time graphs of the stress-strain relationships with the proper coding and control system work.

The data acquisition and controls portion of the machine are near complete. The load cell is in the process of being calibrated, but will need more calibration for loads closer to the full capacity of 1000 lbs., and code will need to be incorporated to take the output from the load cell and transfer the data into a spreadsheet that can be graphed real time on a computer or projector. The extensometer will need to be integrated to the Raspberry Pi through USB connection and code to record this data as well. The motor controller needs to be implemented and the connection will need some troubleshooting. Mechanical limit switches, purchased with the intent of disabling the motor as the crosshead reaches its travel limit, need to be mounted to the frame and connected to the prototype hat that was purchased. With the amount of control systems and coding knowledge needed, an electrical or computer engineer would be useful to add to the team of mechanical engineers. It would also be significant for alternative grips to be found for use with dog bone samples of various materials or other wire samples of a different diameter range. Plexiglass or another transparent material should be used to cover the gearbox and potentially the lead screws to prevent foreign objects impeding the functionality as well as provide a safer system without covering the mechanisms completely. To finalize, the frame should be painted for a professional appearance and a plaque with the sponsoring company logos should be mounted to commemorate and acknowledge their overwhelming support.

The impact of this tabletop tensile tester has the potential to reach thousands of engineering students. As mechanical engineers who have worked through three co-op work rotations, our team deeply understands the importance of hands-on, practical experiences in the furtherance of each engineer's metaphorical toolbox. The more we are exposed to the technical world and the mechanics behind it, the more prepared we will be to join the workforce and serve others. The future is bright for the continuance of this project and for the young engineers impacted by it.

References

Budynas, Richard G., et al. *Shigley's Mechanical Engineering Design*. 10th ed., McGraw-Hill Education, 2020.

"Build a Digital Raspberry Pi Scale (with Weight Sensor HX711)." *Raspberry Pi Tutorials*, tutorials-raspberrypi.com/digital-raspberry-pi-scale-weight-sensor-hx711/.

"Ductility." *Wikipedia*, Wikimedia Foundation, 30 Mar. 2020, en.wikipedia.org/wiki/Ductility.

"Grade Guide: A36 Steel." *Metal Supermarkets - Steel, Aluminum, Stainless, Hot-Rolled, Cold-Rolled, Alloy, Carbon, Galvanized, Brass, Bronze, Copper*, 11 Dec. 2019, www.metalsupermarkets.com/grade-guide-a36-steel/.

"Mechanical Wedge Action Tensile Grips." *Instron*, www.instron.us/products/testing-accessories/grips/mechanical-wedge-action-grips.

"Stress-Strain Curve." *Stress-Strain Curve - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/engineering/stress-strain-curve.

"Tensile Testing." *Wikipedia*, Wikimedia Foundation, 27 Nov. 2019, en.wikipedia.org/wiki/Tensile_testing.

"Tensile Testing." *Wikipedia*, Wikimedia Foundation, 27 Nov. 2019, en.wikipedia.org/wiki/Tensile_testing#Equipment.

Tu, Shengwen, et al. "Stress–Strain Curves of Metallic Materials and Post‐Necking Strain Hardening Characterization: A Review." *Wiley Online Library*, John Wiley & Sons, Ltd, 21 Oct. 2019, onlinelibrary.wiley.com/doi/full/10.1111/ffe.13134.

"What Is Tensile Testing?" *Instron*, www.instron.us/our-company/library/test-types/tensile-test.

"Wire and Cable." *Instron*, www.instron.us/en-us/products/testing-accessories/grips/wire-cable.