Drawing and Twisting of Graphene Fibers

Final Design Report

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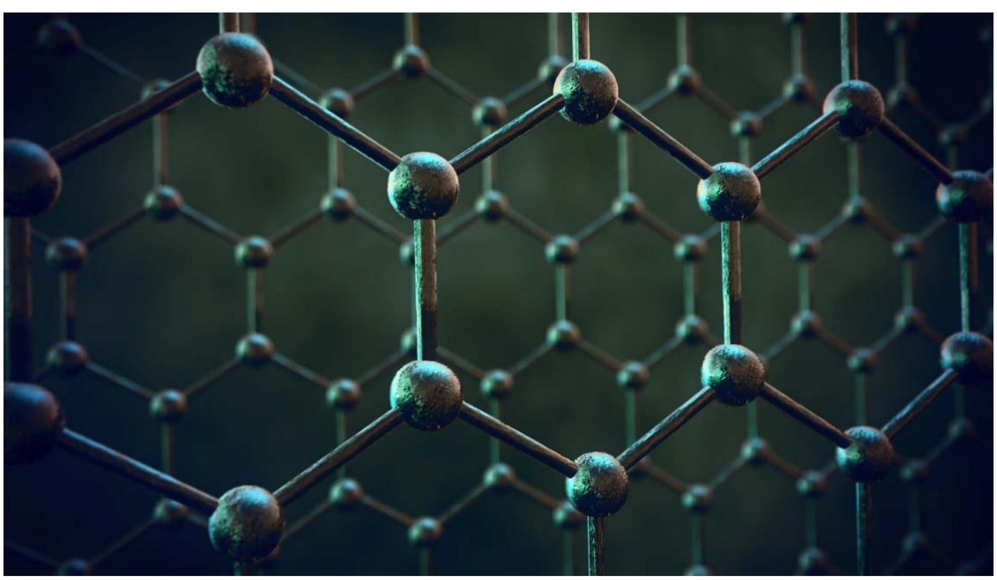

Statement of Disclaimer

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BJT – Bipolar Junction Transistor

CAD – Computer Aided Design

CDR – Critical Design Review

CF – Carbon fibers

CNT – Carbon Nanotubes

DVP – Design Verification Plan

DXF – Drawing Exchange Format

FDA – Food and Drug Administration

FDR – Final Design Review

GF – Graphene fibers

GO – Graphene Oxide

LC – Liquid Crystal

MPa – Megapascals

OD/ID – Outer Diameter/Inner Diameter

PDR – Preliminary Design Review

PTFE – Polytetrafluoroethylene

PVA – polyvinyl alcohol

PVC – Polyvinyl Chloride

PWM – Pulse Width Modulation

QFD – Quality Function Deployment

RPM – Revolutions Per Minute

SEM – Scanning Electron Microscope

VAC/VDC – Volts Alternating Current/Volts Direct Current

Executive Summary

The aim of this project was to develop a more automated process for drawing and twisting of graphene fibers than was currently in place. This was implemented by having two chemical baths with variable speed rollers at either end, and intermediate roller to spool fiber between stages, and a twisting cylinder with integral spool to twist the fiber as it is collected. The goal was to have this first iteration deliver a working prototype, however due to manufacturing delays and timing constraints, that will be missed. A second follow-on project would be able to continue the work presented here and fulfil the stated aims of the project.

The bulk of the structure is fabricated from PVC pieces waterjet cut from a large sheet. This allowed for quick manufacture of most pieces in the design. From there, some secondary machining was done to add mounting and fastening locations. PVC pieces were attached to one another primarily through the use of #8-32 screws with washers and a brass threaded insert. Due to PVC being a soft material, tapping threads into it directly was avoided. The baths were sealed mostly with an automotive gasket compound to permanently seal one half, while one wall was sealed with a silicon gasket laser cut from a sheet. This makes the bath wall removable for maintenance. Two baths were made to allow multiple stages of drawing or one coagulation stage immediately followed by a drawing stage.

From the drawing, the fiber advances to the auxiliary roller. The range of speeds required to get desired properties at all stages did not permit the fiber to go from coagulation to drawing to twisting in one process, therefore following the drawing bath, it is wound on to the auxiliary roller. After the drawing process is finished, the fiber can be pulled from the auxiliary roller into the twisting mechanism, running at a lower speed so as to give the requisite number of turns per length of fiber to yield the optimal fiber twist angle.

The twisting mechanism is a PVC cylinder supported on horizontal rods and driven by a motor mounted beneath the cylinder and connected via a plastic belt. The cylinder, motor, and support rods are encased in a box with one face open to allow the fiber into the cylinder. Inside the cylinder is a spinning rod mounted across the diameter that collects the fiber as it is twisted. The aim of the project called for a quick-release mechanism so that the rod can be removed quickly for storage of the fiber or other testing steps.

All of the motion is powered by small 5V DC motors that go through a 20:1 worm gear reduction. This increases the torque while decreasing the speed from roughly 10,000 RPM to more useful ranges. The motors are powered through a NPN power transistor with the logic being controlled by an Arduino Nano that takes in an analog voltage and converts it to a PWM waveform to control the motor duty cycle.

In total, the project came in under budget, using 84.01% of the $1500 allocated for the project. A third of this cost came from the need to expedite the waterjet cutting by going to a third-party outside of the campus community. Had on campus resources been successfully utilized, the total cost would have been closer to the $925.38 estimate first presented.

Introduction

In the materials field, graphene has vast potential to become a widely-used material for its superior properties, but right now is limited mostly to laboratory research. One current way to apply graphene is by forming graphene platelets into long fibers which can then be woven together. Dr. Shanju Zhang is currently heading a research group in the Cal Poly Chemistry Department to study graphene fiber and its applications. Their current process for fiber production is largely manual and lacks process control. This project presents a solution by creating an automated method to draw and subsequently twist graphene fibers in a continuous method. Over the course of the 2016-2017 academic year, the team designed and manufactured a prototype of a device to be implemented by Dr. Zhang and his research group.

Background

Graphene is a new material that has been receiving a large amount of research attention since it was first isolated in 2004 [1]. It has remarkably high theoretical properties that make it ideal for a wide range of applications. It is an allotrope of carbon defined by a 2-D planar orientation just one atom thick and oriented in a densely packed benzene-ring structure as shown in Figure 1. Carbon has four electrons in its valence shell. The electron orbitals form planar bonds with three neighboring carbon atoms at 120 degree intervals. The remaining electron

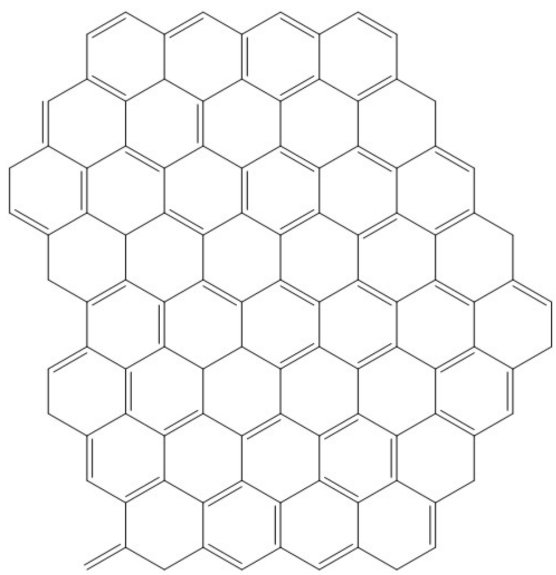

Figure 1 - Graphene chemical structure [2]

forms a bond with one neighboring atom, creating a double bond. This bond configuration forms a thermodynamically stable 2-D arrangement of carbon [3], therefore graphene sheets form the basic constituent of any graphite compound. Thus, it was from graphite that graphene was first isolated using mechanical exfoliation. The strong covalent carbon bonds are what gives graphene its exceptional material properties, specifically a high tensile strength, S_t (130 GPa), Young's modulus, E (1100 GPa), electrical conductivity, σ (10^8 S/m), and ampacity, I_R (10^{12}-10^{13} A/m^2) [4]. These ideal properties have made graphene a very popular material for research, however no current production method is currently capable of achieving those values, with the closest values

being on the order of S_t = 1 GPa, E = 300 GPa, σ = 10^6 S/m, and I_R = 1010 A/m^2 [4]. Current research is focusing on material quality as well as faster production methods.

One of the primary limitations on graphene usage is the lack of large-scale production methods. Unless production methods can produce graphene on a scale large enough to be usable in some technical application, it is more or less irrelevant how strong the material is. Using the technique known as Hummers method developed by Hummers and Offeman in 1958 [5], an aqueous solution of graphene oxide (GO), a single layer of graphite oxide crystals, can be synthesized from solid pieces of graphite. Hummers method is a chemical exfoliation process that produces a highly viscous solution that graphene fibers can then be pulled from and it is easy enough to be done in laboratory batches on the order of 50 mL. Therefore, Hummers method is a typical precursor to most graphene fiber production methods. This stage is a highly important step towards the control of the final graphene fiber. Depending on the care taken during the exfoliation process, the GO solution can range from being nearly homogenous with no large graphene chunks, to having a very high density of chunks large enough to be seen with the naked eye. These chunks pose a risk to the fiber production method because they can clog the equipment, leading to downtime and low fiber quality, as observed in the Cal Poly Chemistry Department research lab. This GO solution is then diluted to be used in the fiber spinning process.

The current process used by the Chemistry Department

All information about the current process used by Dr. Zhang and his research group was obtained through interviews with Dr. Zhang and Mackenzie Kirkpatrick, the graduate student who primarily oversees the process. In addition to interviews, our team was able to observe the fiber creation process first-hand in the chemistry lab.

The process starts with a bottle of filtered graphene-oxide made by the Chemistry department. The bottle is placed into an ultrasonic bath for approximately 10 minutes to break up any particulates which may have formed. During this time, the graphene production equipment is set up. The equipment is as follows: a syringe and syringe pump for controlling the flowrate of the graphene-oxide solution; a 75 micron diameter microfluidic channel for sizing the graphene fiber; a coagulation bath about 8 inches in length which contains a calcium chloride and isopropanol solution; and thin tubing to direct the graphene oxide solution to the proper components during the process.

Setup involves attaching one end of a 100 micron tube to the syringe and the other end to the opening of the microfluidic channel. The other tube is inserted into the far end of the channel and attached to the coagulation bath via tape. The tubes and channel are often clogged when they are first set up, so deionized water is run through the system to dissolve and flush out any particulates. Once the system is free of clogs and the water is flowing properly, graphene fiber production begins. The syringe is disconnected and filled with graphene oxide solution. Then it is placed back onto the syringe pump and reconnected to the tubing. The pump needs to run for about a minute to clear the tubes and channel of bubbles. If there are no blockages to the flow, then graphene fibers are pushed from the tube-channel assembly into the coagulation bath.

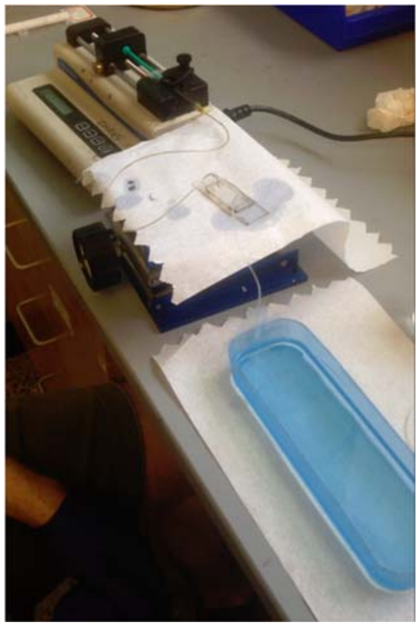

Figure 2 – The initial setup for the graphene extrusion process.

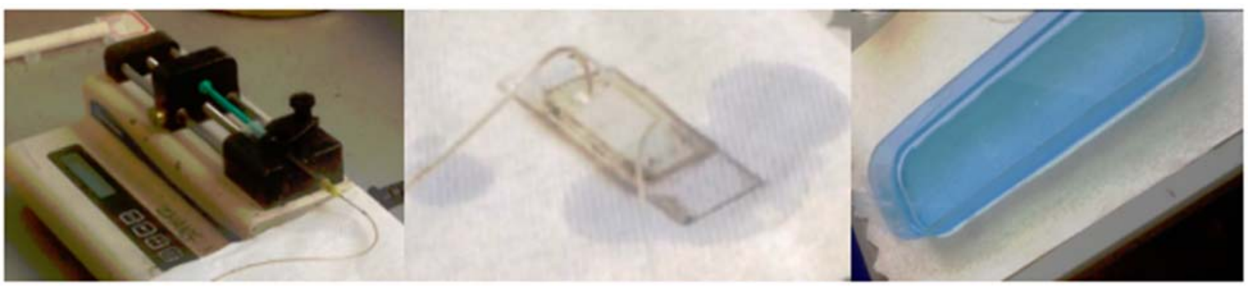

Figure 3 – Individual components. Starting from the left: syringe and syringe pump, microfluidic channel, coagulation bath.

This is where the drawing process occurs. The person making the fibers hooks the end of the graphene fiber as it exits the tube and slowly draws it by hand to the end of the coagulation bath. When the fiber reaches a length of about 6 inches (almost as long as the bath) it is broken off at the tube and placed to one side of the coagulation bath. According to the student who demonstrated this process, a typical syringe of graphene oxide makes 15-20 fibers at 6 inches per fiber.

When an adequate amount of fibers has been drawn, the syringe pump is turned off. Then, one end of a 6 in. fiber is hooked onto an electric drill and the other end is wrapped around the hook that was used to draw the fiber. After being lifted out of the coagulation solution, the fiber is spun for about a minute at a speed of approximately 115 rpm. While being spun, it is occasionally dipped back into the coagulation solution to prevent it from drying prematurely. After spinning, the fibers are placed under a lamp until they dry. Then they are glued across paper slides so that their strength can be tested.

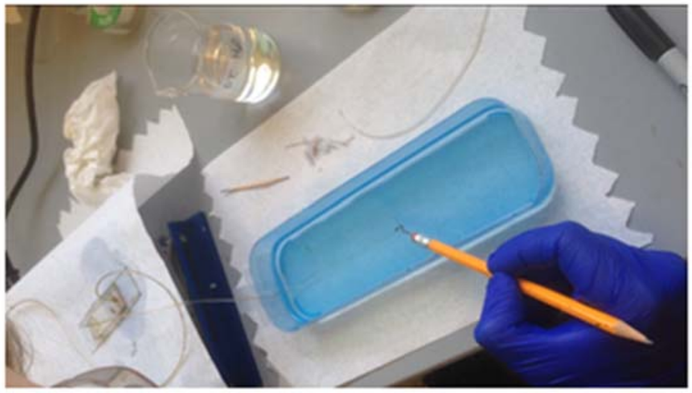

Figure 4 – The end of the fiber is hooked and slowly dragged along the coagulation bath.

There are a few problems with the current process. To begin, drawing the fibers by hand is both inconsistent and inefficient. The speed at which the fiber is pulled through the coagulation bath affects how well the graphene layers align themselves. If the graphene is pulled too slowly, the alignment is poor overall and the fiber may develop imperfections such as kinks. If the fiber is pulled too quickly then alignment may improve, however it has a greater tendency to break or develop thin sections thus reducing its overall strength.

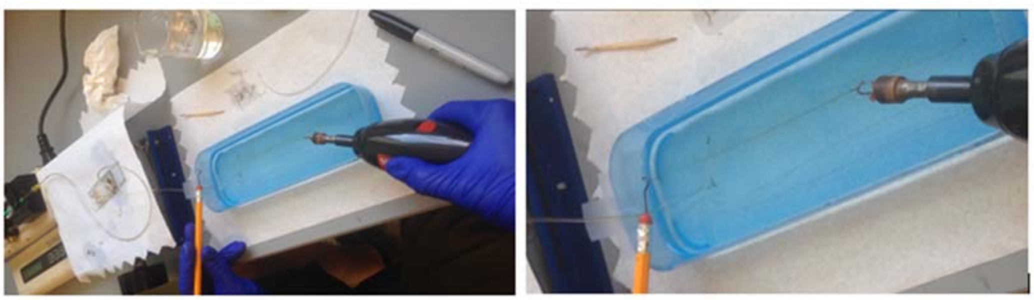

Figure 5 – Current spinning process for graphene fibers.

The current hand-drawing process perpetuates these problems since it is very difficult for a person to maintain the same drawing speed throughout the coagulation bath. Both kinks and thin sections develop in every fiber which wastes material and gives increasingly varied results when they are strength tested. Second, there are many issues that occur with the connections between syringe, microfluidic channel, and tubing. Even after removing all clogs and ensuring proper flow during setup, the tubes constantly fall out of place which stops the process and results in wasted material. Other minor problems that occur are the breaking of fibers while transporting from the coagulation bath to the drying area and overspinning, which causes the fibers to coil on themselves.

Alternative Methods

With the recent rise of graphene as a source of microfiber production, there has been a wave of interest and energy towards creating an effective means of graphene fiber (GF) production on a continuous and industrial scale. Various methods have arisen, each with the goal of adequately producing fibers with desirable mechanical/functional properties. The fabrication

of graphene fibers should rely on a “bottom up” assembly concept, fashioning individual building blocks into an ordered state with atomic precision. This process is ultimately carried out by regularly aligning graphene sheets continuously in a uniaxial direction [4]. Due to the unmeltable nature of graphene, production methods such as the melt spinning, where the material is extruded in a melted state then cooled [6], used for polymeric fibers such as nylon are unable to process graphene into neat fibers. Since 2-D graphene also lacks entanglement the throwing method employed in ancient spinning of cotton threads, as well as dry-spinning, which is the fiber material dissolved into a solvent that is then allowed to evaporate, leaving the fiber behind [6], used to make carbon nanotube (CNT) fibers, are also excluded. Thus, the production of GF must utilize the process of solution assembly, similar to the wet-spinning of polymeric fibers such as Kevlar and CNT fibers [7], where the fiber is dissolved into a solvent then extruded into a coagulation solution that causes the material to precipitate into a solid fiber [6].

In order to fabricate GF in a continuous manner, as well as attain sufficiently desirable quality, there are several prerequisites that must first be met.

(a) *Solution-Processable:* A scalable synthesis of solution-processable graphene is ideal in the fabrication of high quality GF fibers. In order to circumvent the poor dispersibility of pristine graphene in common solvents, chemical functionalization is proposed to introduce functional groups onto graphene [7]. The functionalized graphene is therefore rendered with good dispersibility and resultant processability by fluid assembly.
(b) *Regular Alignment:* GF are composed of well aligned graphene sheets along the fiber axis. This calls for the continuous regular alignment of dispersive graphene during fabrication. This task can be separated into two stages: pre-alignment during the fluid state and the sequential phase transformation to regular alignment in the solid state [7]. Optimal alignment is necessary in the generation of solid GF.
(c) *Re-engineering of bonds:* The re-engineering of the bonding among graphene building blocks is necessary to optimize GF performances. Relatively weak van der Waals interactions between graphene sheets are a weak point that confines the enhancement of the performance of assembled graphene materials [7]. The reinforcing of these bonds is therefore critical to push GF to a high level comparable to carbon fibers (CF) and CNT fibers.

These requirements break down the separate functions of our project. The fiber production method needs to synthesize the fibers in an appropriate manner, the drawing stage needs to ensure the regular graphene alignment, and the twisting method helps create interplay between graphene sheets that add to the overall fiber strength. For the fiber synthesis stage, there are many methods to produce graphene fibers from GO, however only a few predominant ones which occurred in the majority of published academic papers. They include wet spinning, electrospinning, and microfluidic spinning. Each process is discussed in more detail in the following sections.

Wet Spinning

To fabricate GF from graphite, the graphene liquid crystal (LC) wet-spinning has been established in recent years and is becoming a reliable method in obtaining continuous GFs as monofilaments. The process begins with graphite crystals exfoliated to individual graphene

sheets, usually by chemical modification [7]. The modified graphene sheets then form liquid crystals in solvents in a pre-aligned orientation. GO has generally become one of the most readily available chemical precursors to graphene. In principle, the remaining 2-D topology of GO along with its excellent dispersibility renders the spontaneous formation of LCs [7]. After graphene LCs are formed, the wet-spinning assembly is employed to make continuous fibers. This begins with the extrusion of LCs into coagulation baths with uniaxial flow. There is then a phase transition by coagulation with solvents exchange, followed with solidification by evaporating solvent. The process is then ended with either a chemical or thermal reduction generally via hydriodic acid to obtain a highly compact structure. The process of wet-spinning as well as the structural evolution of the graphene fibers through the process can be seen in Fig 6 and Fig 7, respectively.

Coagulation baths were chosen depending on solvents of the GO LC solution (referred to as "dope"). For instance, an ethanol/water mixture, with Ca^{2+} ions, is suitable for aqueous dopes [7]. The stretching operation is deemed necessary to achieve high alignment of GO sheets as well as to help the formation of compact structures. Alternative methods, besides wet-spinning, have

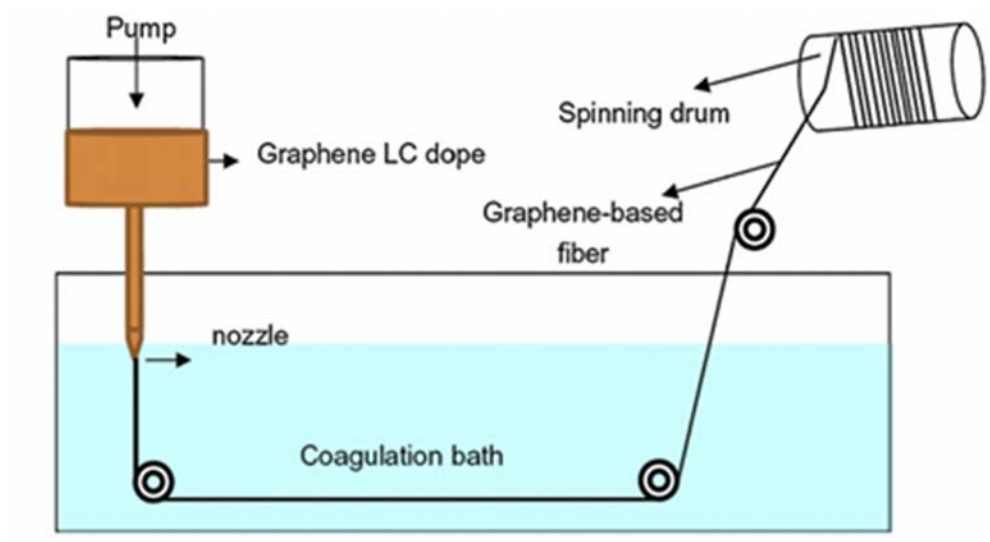

Figure 6 – Graphene-LC Wet-Spinning [17]

also emerged for the fabrication of GF but they tend to have a similar principle to wet-spinning, including the use of a relatively high concentration of GO feed dispersions and continuous flow to ensure the continuous alignment of graphene sheets along the fiber axis [7].

Electrospinning

A common method to fabricate nanoparticle fibers is the use of electrospinning, as shown in Figure 8. A precursor gel of nanoparticles is loaded into a syringe equipped with a capillary metal needle. A high-voltage charge is then applied between the metal orifice and grounded collector to generate a thin charged jet. Ultra-fine gel fibers are produced in the form of nonwoven mats by accelerating toward the collector. The fibers are then heated in argon at an elevated temperature (~3000 °C) to remove organic components and allow nucleation and growth of nanoparticles [2]. Usually this process is employed in the large-scale fabrication of nanofibers of metal oxide particles such as ZnO, TiO_2, SnO_2, etc. [8]

Graphene oxide has recently been employed in the fabrication of composite nanofibers via the electrospinning method. In this work, polyvinyl alcohol (PVA) nanofibers are doped with various amounts of GO in order to increase the mechanical properties of the resultant nanofibers. GO-doping has been found to decrease the decomposition temperature and elongation at break of PVA nanofibers as well as increase the degree of crystallinity and tensile strength [8]. The challenge with electrospinning lies in its inability to mass-produce continuous aligned fibers because as-spun fibers are randomly deposited on the collector.

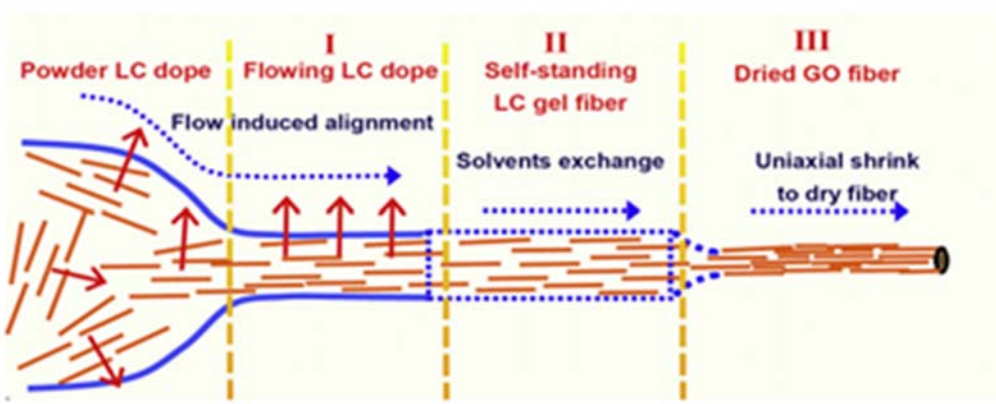

Figure 7 – Structural Evolution of Spinning Process [7]

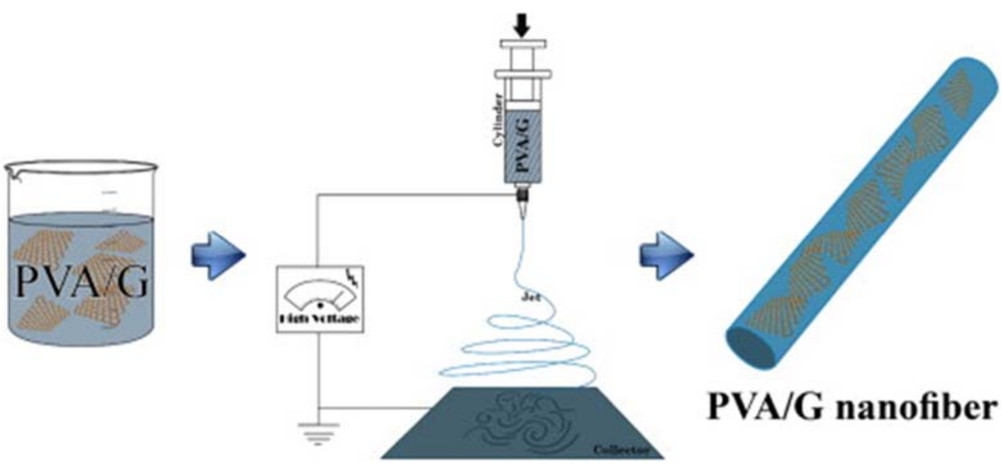

Figure 8 – Electrospinning Process [8]

<u>Microfluidic Spinning</u>

Microfluidic spinning is a recent area of interest in the fabrication of nanofibers due to its simplicity and reliability. Its great potential can be observed by its one-step, continuous process for the scalable forming of well-defined microfibers. The system consists of two inlets and one outlet microchannels. The fiber precursor solution and the coagulant solution are the core and sheath fluids, respectively [9]. The shear force in the core channel induces alignment of the fiber precursor. Since all fluids in the channel are laminar, the core and sheath streams form coaxial flow without mixing. The oriented core stream condenses with the coagulant solution in the sheath phase at the intersection of the two fluids, this where photo-polymerization/ ion cross linking occurs [9]. As the coagulant diffuses into the core liquid a gel-like fiber begins to form.

The fiber is further elongated due to the difference in flow rates between the sheath phase core phase, thus generating well-aligned microstructures. Ideally, complete gelation is reached before exiting the channel in order to retain well-aligned microstructures. Laminar flow is an important advantage in this method due to its precise control and manipulation of small quantities of fluids for tunability of fibers [9]. The resulting fibers are readily controlled at a nanoscale level in terms of size, shape, composition, alignment, and microstructure. It is believed that laminar flow and LC gelation enables microfluidic spinning to fabricate well-defined nanoparticle fibers. The anisotropic coupling between the flow-induced viscous interactions and the surface-induced elastic interactions maintain uniform alignment within the nanoparticle fibers with few structural defects upon gelation.

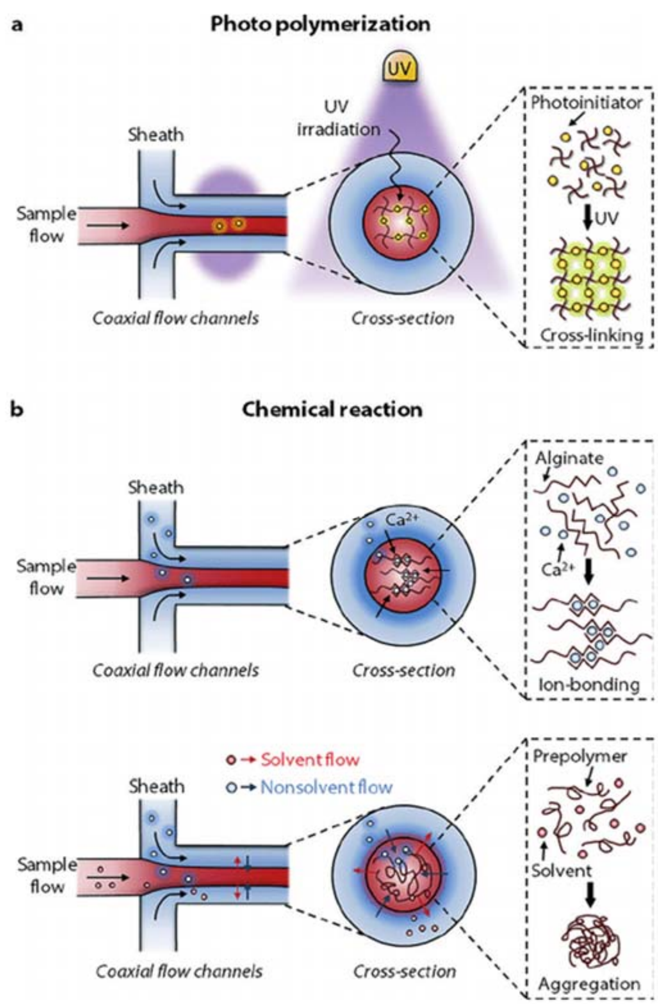

Figure 9 – Microfluidic Spinning [9]

Patents

There are numerous patents regarding the use of graphene in many varied applications like micro sensors, flexible electronics, and fibrous materials. There are also many patents regarding graphene production methods. We found one patent titled “Method for Preparing Graphene Oxide Films and Fibers” [10] is related to our project. It covers a method of

developing a graphene film from graphene oxide slurry, and then spinning said film into graphene fibers. It also heat treats the fibers to improve electrical conductivity. Since our project does not create a graphene film, and does not deal with the electrical conductance of graphene there is no issue with this patent.

Drawing and Twisting

Once the fiber is produced, it is still relatively weak. Researchers have found that by longitudinally stretching the fiber ("drawing"), and by twisting about the longitudinal axis, the fiber exhibits much higher mechanical properties [4] [10]. This is the primary goal of this project, as the current method of drawing and twisting (covered later) does not produce consistent results. Most graphene production methods involve some way of drawing the fibers down to a desired diameter. Maintaining a small, consistent diameter forces the graphene platelets in the fiber to align with each other, giving a high tensile strength. By applying a slight pull onto the fibers while they are being produced, we can increase the tensile strength and decrease the tensile strength standard deviation by employing process control.

Research specifically concerning graphene fiber twisting has found that twisted fibers often display a much higher tensile strength than non-twisted fibers [12]. It is hypothesized that the overlapping of the graphene platelets causes them to transfer the tensile load in a shear mechanism as opposed to tensile failure. Dr. Zhang has indicated that a twist angle of approximately 20-30 degrees offers the best tensile strength. For these reasons, the drawing and twisting mechanisms are the central topic of our project.

Textile Methods

In the composites industry, many processes are carried over from the textile industry, as the manipulation and development of cloth and other textiles is very similar to the process of manufacturing of composites. Similarly, there are many aspects of textile production that could inspire solutions to this project. Particularly, fiber spinning from plant and animal materials is a technology that has been a staple of human civilization. The earliest spinning wheel appeared around 500 to 1000 C.E. in India [13]. One particularly useful item is the "bobbin-and-flyer" mechanism at the end of the spinning wheel. Even as spinning technology has evolved from a spinning wheel to more automated processes, the bobbin-and-flyer has remained a fundamental component of fiber spinning machinery. This mechanism (Fig. 10) is used to collect the fiber after it is spun and imparts longitudinal twist. The bobbin and flyer both rotate in the same direction, with the flyer rotating slightly faster. The overall rotation imparts the longitudinal twist while the relative motion between the two causes the fiber to wrap around the bobbin. The magnitudes of the two rotations can be changed to adjust both the twist rate and the wrap rate. Given that one of the more high-risk specifications the team needs to meet is to twist the graphene fibers after drawing them, this might be one of the easier and more reliable methods to implement.

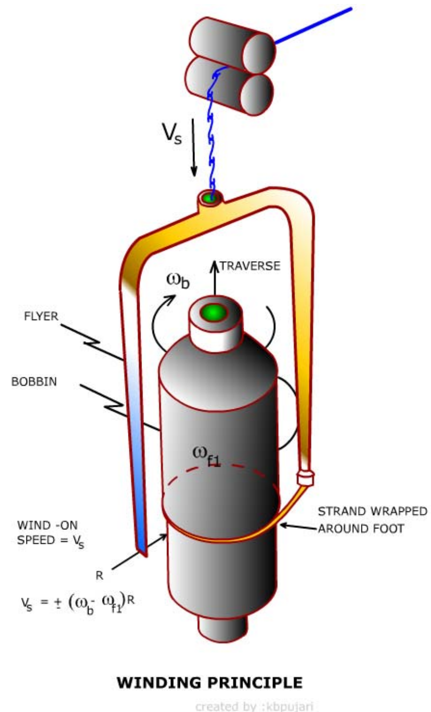

Figure 11 – Bobbin and flyer mechanism [14]

Figure 10 – Sir Richard Arkwright's water frame [15]

In his 1769 patent, British industrialist Sir Richard Arkwright patented a cotton mill that made use of a bobbin and flyer mechanism to take up several strands of yarn in order to make cotton spinning viable on a larger scale [16]. His machine also made use of successive pairs of rollers, each moving slightly faster than the last, to stretch the cotton out. Doing this produced a longer, thinner fiber that had a high tensile strength. This is a similar approach we have seen in graphene research and may consider using in our design.

In industrial production of steel cables or fiber ropes, multiple strands are twisted together [17] [18]. The mechanism used for this is less concerned with individual strand twisting, and as such, most of that machinery is not very applicable to our design. We are primarily

focused on twisting monofilament fiber, so we have different kinematic concerns and machinery designed for making rope would be overly complicated while not being entirely effective for our purpose.

Objectives

Drawing and twisting graphene fibers improves their mechanical performance, however current manual methods produce fibers limited to short lengths. Based upon what we learned from talking with Dr. Zhang and his research group as well as observing their current production method, we have established that Dr. Zhang needs a continuous, consistent process for drawing and twisting graphene fibers that has an adjustable output. We established a set of requirements and through the Quality Function Deployment (QFD) process developed a list of specifications, shown in Table 1. Our QFD matrix is attached in Appendix B. QFD is a large matrix with interactions between the users, their needs, current methods, how well the methods satisfy the customer needs, and how the resulting specifications are related to each other. The QFD process allows us to compare the different user requirements and evaluate their relative importance. By combining this with benchmarking of existing methods, we turn the user requirements into a set of measurable engineering specifications.

Table 1 – Engineering specifications

Specification	**Description**	**Target**	**Tolerance**	**Risk**	**Compliance**
1	Output Fiber Length	15 in	Min	M	T
2	Machine Weight	500 lb	Max	L	A, T, I
3	Cost	$1,200	Max	L	A
4	Machine Dimensions	10 ft^2	Max	L	A, T, I
5	Throughput	30 mL/hr	Min	M	T
6	Fiber Tensile Strength	200 MPa	Min	H	T
7	Fiber Tensile Strength Standard Deviation	50 MPa	Max	H	T
8	Fiber Twist Angle	25 degrees	±5 degrees	H	A, T
9	Setup Time	20 min setup	Max	L	T, I
10	Protective Equipment	Goggles and gloves	Max	L	S
11	Output Control	Yes	Min	M	I

The main objective of this project is to make the drawing and twisting process continuous. For the fiber length, specification 1, the current method produces fibers with a maximum length of about 6 inches. Therefore, we defined “continuous” to be at least 15 inches

in length for a single fiber. Such an improvement would significantly increase large-scale prospects of graphene fiber production.

For the machine itself, we are limited in space, weight, and cost. The machine will be supported by a table, therefore the machine weight, specification 2, cannot exceed the table's load rating. We conservatively estimate this to be around 500 pounds, however our final design should be far below that. The 500-pound figure is an extreme target we cannot exceed.

For the overall project cost, specification 3, we have access to as much funding as we deem necessary, however there is an upper limit on what will be acceptable. Based upon estimations of what other machines cost to build and the resources required to manufacture the components, our total cost should be under $1200.

Similar to weight, for machine size, specification 4, we cannot exceed the table dimensions, but given the scale of the equipment that should not be an issue. We estimate that approximately 10 square feet is the upper limit of how much table area our machine can use.

One of the main shortcomings we noted in the current lab process is that the setup often leaks and clogs, taking time away from the fiber production process and impairing fiber quality. We want our machine to improve on this to allow for production of the most continuous and consistent fibers possible. We will be measuring this by looking at the total throughput of the machine, specification 5, measured in mL of diluted GO turned into fibers per hour. More graphene fiber will be produced if tubes, clogs, etc. do not have to be cleared. Based upon the feed rate of the syringe pump and the dependence of feed rate on fiber quality, we want to hit at least 30 mL of diluted GO per hour.

Since the drawing and twisting processes are intended to increase fiber strength, we will be using the resulting tensile strength, specification 6, to evaluate how well our drawing process is working. Based upon current capabilities of the hand method and other methods in literature, we want to have the fiber tensile strength be at least 200 MPa with a standard deviation, specification 7, of no more than 50 MPa. The current hand method produces large variations in fiber quality, and our aim with an automated process is to drastically reduce that variability.

Since the relative strength of the fiber can be directly inferred from the amount of twisting, we will use a scanning electron microscope (SEM) to measure the twist angle of the fiber, specification 8. As mentioned in our background section, the ideal twist angle is in the range of 20-30 degrees, so our target is around 25 degrees, plus or minus 5 degrees.

Because we are aiming for a reliable method, we want a process that will be easily set up and maintained. To evaluate this, we want our process to be set up and running in no more than 20 minutes, specification 9. That is, if a part needs to be changed or fixed, the machine should be producing fibers 20 minutes or less after the repair is completed. A faster set up time will make the machine more useful to the lab group with students who may not have extended periods of time to wait for the machine to be running again. We want the machine to be as useful as possible, which also means we want it to be durable. By having a machine that is easily maintained, the machine will be durable and usable by research students for several years.

Similar to set up time, we want to design the machine such that extraordinary safety procedures are not necessary, specification 10. Already, by nature of dealing with various chemicals, the current process requires the use of nitrile gloves and splash goggles. We do not want our process to require any more extensive equipment, so that it can easily be integrated into the current lab.

Because this machine is to be used in a research environment and we want it to be useful to that end, the machine parameters should be adjustable (i.e. vary the feed rate, draw speed, twist angle, etc.) so that the output can be investigated for what process parameters affect the overall quality of the fiber. This is detailed in specification 11, output control.

Many of these specifications (weight, size, cost) should not be an issue as they are based upon the limit of usable space and do not entirely reflect what our actual expectations for the final design to be. We conservatively estimate that we should be far below these requirements. These specifications are marked with either a low (L) or medium (M) risk rating. For the requirements such as tensile strength, twist angle, and fiber length, we anticipate that those will pose much greater technical challenges and may be harder to achieve. That said, they are mostly based off the existing process capabilities which we aim to match or improve while adding continuous production. Such specifications are marked with a high (H) risk rating. It is also highly likely that in making a more controlled, repeatable process, that the overall fiber strength will see a decrease in variability.

The specifications table also lists the ways we will measure the final design to evaluate how it satisfies the requirements. Testing (T) indicates that we will physically test our machine to see if it can produce the desired output or not. Specifications where this is the primary evaluation method are difficult to analyze by other means (ending fiber length, tensile strength, etc.). Analysis (A) shows that we will be performing calculations during the design process to ensure that our result satisfies the specification. The machine weight can be evaluated during the solid modeling phase by imputing accurate material properties, and the overall project cost will be estimated, so we will have good ideas as to what those will be and how they reflect the specifications before we begin the manufacturing phase. Inspection (I) means that we will directly measure these specifications once the prototype is complete to ensure that they satisfy the requirements and to verify the accuracy of our solid models. Similitude (S) indicates that we will evaluate this compared to similar devices. For safety equipment, this means that we will compare our design to the current hand method to see if additional pieces of protective equipment are necessary. Most specifications will be verified in multiple ways to ensure the design meets the specifications both during the design process and once the final prototype is completed.

Design Development

The fiber extrusion portion of the prototype will be facilitated by Dr. Zhang's research group. The scope of our project begins when the fiber leaves the microfluidic channel into the coagulation bath. Therefore, we did not focus on concepts for the microfluidic alignment of the

GO prior to coagulation. We focused instead on the functions of fiber drawing and twisting. In our conversations with Dr. Zhang and, we learned that the fiber must be drawn first then twisted in two separate processes, not combined or the other way around. This is because the drawing process relies on placing the fiber in a solution bath that swells the fiber and allows the platelets to realign. Once the fiber is twisted onto itself, it would be difficult for the fibers to absorb the solution and swell, thereby limiting the effectiveness of the drawing process. Because the fiber has to go from one function to the other, we considered them as separate and independent for idea generation stage. That is, none of the concepts for one function would be mutually exclusive with any concept for the other. This allowed us the greatest freedom for idea generation.

The idea generation process began with team brainstorming where all team members threw out any ideas they had without judgement or qualification. This led to about 40 total ideas for both functions. From here, our first selection stage was a simple feasibility test to see which ones were worth pursuing and evaluating further. The concepts reported in the next two sections are the results of this test.

Drawing

For the drawing function, our ideas were: (1) to use rollers with different angular velocities in a bath, (2) one large roller partially submersed in a bath, similar to a grinding stone, (3) drawing the fiber over a conic form, (4) transverse fluid flow in between two rollers, (5) a transversely moving roller, (6) a spinning "jump rope" type method, (7) axial fluid flow in a tube, (8) or three transversely moving rollers. These concepts are shown in figures 12a-d and 13a-d, respectively.

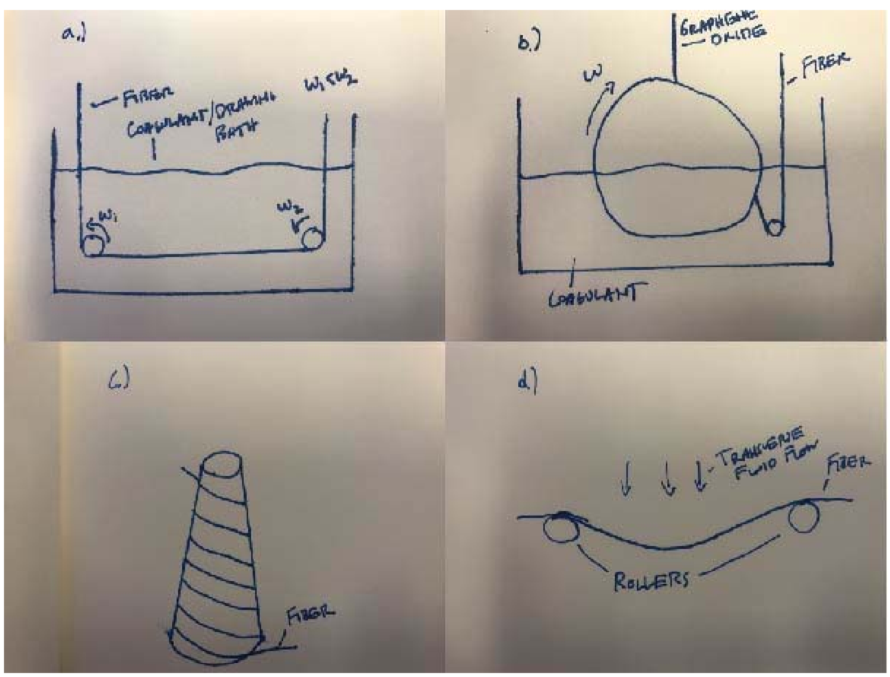

Figure 12 – Drawing concept sketches

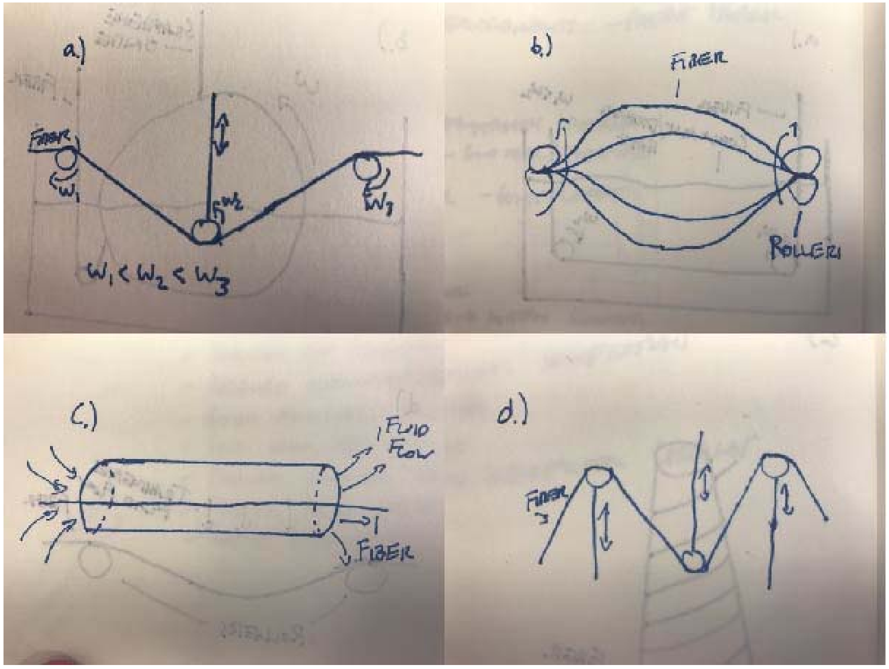

Figure 13 – Additional drawing concept sketches

Decision Matrix: Drawing Processes													
Criteria	Score Modifier	Rollers: Varied Speeds		Grinding Wheel		Conic		Fluid Crossflow		Microfluidic		Actuating Roller	
	[Out of 1]	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Performance	0.8	5	4.0	1	0.8	2	1.6	3	2.4	5	4.0	3	2.4
Continuous	0.7	5	3.5	3	2.1	3	2.1	5	3.5	4	2.8	5	3.5
Feasibility	0.6	5	3.0	4	2.4	1	0.6	3	1.8	5	3.0	3	1.8
Reliability	0.5	4	2.0	4	2.0	1	0.5	3	1.5	4	2.0	2	1.0
Servicability	0.5	5	2.5	5	2.5	4	2.0	2	1.0	4	2.0	3	1.5
Consistency	0.5	4	2.0	1	0.5	1	0.5	2	1.0	5	2.5	2	1.0
Automated	0.5	4	2.0	4	2.0	2	1.0	4	2.0	4	2.0	4	2.0
Adjustable Output	0.3	5	1.5	2	0.6	2	0.6	3	0.9	4	1.2	4	1.2
Lightweight (lbs)	0.2	4	0.8	3	0.6	3	0.6	2	0.4	5	1.0	4	0.8
Cost	0.2	4	0.8	3	0.6	2	0.4	2	0.4	3	0.6	3	0.6
Safety	0.2	4	0.8	4	0.8	4	0.8	3	0.6	5	1.0	3	0.6
Size	0.1	3	0.3	3	0.3	4	0.4	2	0.2	5	0.5	3	0.3
Durability	0.1	4	0.4	4	0.4	4	0.4	3	0.3	4	0.4	3	0.3
Weighted Totals			23.6		15.6		11.5		16		23		17

Figure 14 – Drawing Weighted Decision Matrix

We decided to evaluate our concepts for drawing more in depth in a weighted decision matrix as shown in Fig.14. The criteria weightings reflected which requirements were most important and were adapted from our QFD matrix and input from Dr. Zhang. We also added a couple of requirements to help decide which concepts were best. The main criteria that we added was their performance, which is how well the concept would perform its specific task. For twisting, performance took the place of the twist angle requirement and for drawing performance took the place of the fiber strength. We also added an "Automated" evaluation, which is a measure of how much user interaction the concept requires to begin fiber production. The Pugh matrix for the drawing concept is show in Appendix C.

Twisting

After we evaluated our twisting concepts for basic feasibility, our concepts were (1) twisting via a microfluidic channel, (2) a bobbin-and-flyer mechanism as discussed in our background section, (3) a rotating bobbin attached to an L-shaped arm that is also rotating, (4) a rotating disk that has an off-center hole that the fiber is threaded through, and (5) a pair of rollers that are rotating about the fiber. These concepts are shown in figure 15a-e, respectively.

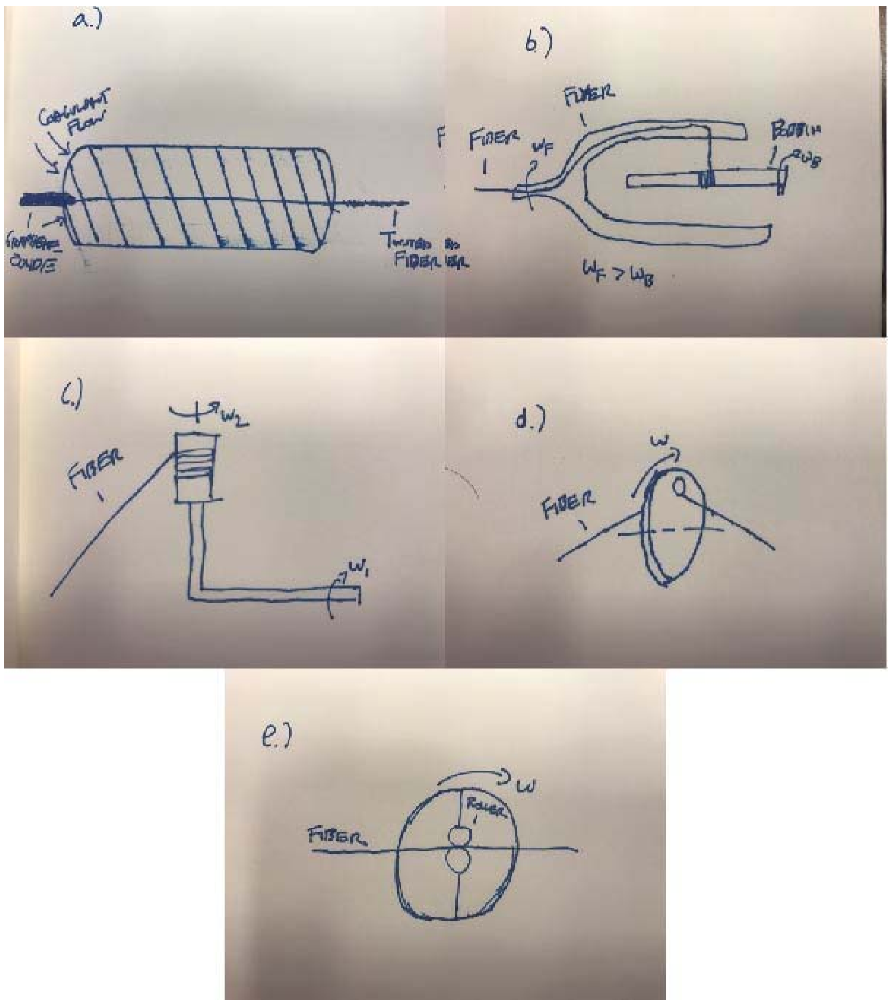

Figure 15 – Twisting concept sketches

From the results of the twisting Pugh matrix in Appendix D, we combined the bobbin-and-flyer and L-arm spool concepts to form a new concept. It is a gear differential concept with the spool on the axis of the pinion gears. The rotation of one ring gear while the other is held fixed causes the bobbin to

Decision Matrix: Twisting Processes													
Criteria	Score Modifier	Differential		Bobbin and Flyer		L-arm spool		Off-Center Hole		Double Rollers		Microfluidic	
	[Out of 1]	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Performance	0.8	5	4	4	3.2	4	3.2	3	2.4	2	1.6	3	2.4
Continuous	0.7	4	2.8	4	2.8	4	2.8	4	2.8	3	2.1	4	2.8
Feasibility	0.6	5	3	3	1.8	4	2.4	5	3	2	1.2	1	0.6
Reliability	0.5	5	2.5	2	1	4	2	3	1.5	1	0.5	2	1
Servicability	0.5	4	2	4	2	5	2.5	5	2.5	5	2.5	3	1.5
Consistency	0.5	5	2.5	4	2	4	2	4	2	3	1.5	4	2
Automated	0.5	4	2	2	1	4	2	3	1.5	2	1	5	2.5
Adjustable Output	0.3	3	0.9	5	1.5	3	0.9	5	1.5	5	1.5	1	0.3
Lightweight (lbs)	0.2	1	0.2	2	0.4	2	0.4	4	0.8	3	0.6	3	0.6
Cost	0.2	2	0.4	3	0.6	4	0.8	5	1	3	0.6	2	0.4
Safety	0.2	4	0.8	3	0.6	3	0.6	5	1	4	0.8	3	0.6
Size	0.1	2	0.2	3	0.3	3	0.3	4	0.4	2	0.2	3	0.3
Durability	0.1	5	0.5	3	0.3	4	0.4	4	0.4	2	0.2	4	0.4
Weighted Totals			21.8		17.5		20.3		20.8		14.3		15.4

Figure 16 – Twisting Weighted Decision Matrix

rotate about its own longitudinal axis as well as precess about the fiber axis. The rotation causes fiber take-up and the precession causes the fiber to twist. A sketch of this concept is shown in Fig 17. We added this concept to the weighted decision matrix shown in Fig 16. Because there were only a handful, all the concepts from the Pugh matrix in Appendix D were also included in the weighted decision matrix, which was evaluated using the same parameters as the drawing weighted decision matrix.

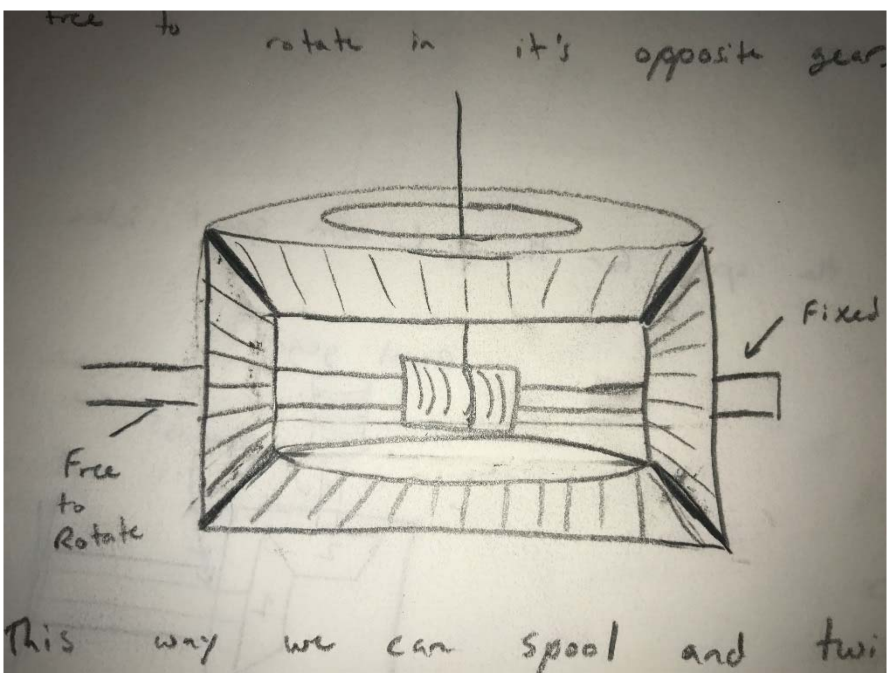

Figure 17 – Differential concept sketch

Selected Concept

From the results of our two weighted decision matrices, we will be using the two different speed rollers for drawing and the differential concept for twisting. The roller concept is two rollers submerged in a bath of methanol. The later roller is driven slightly faster than the first roller, and friction forces cause the fiber to stretch. This process is shown in figure 18. As briefly

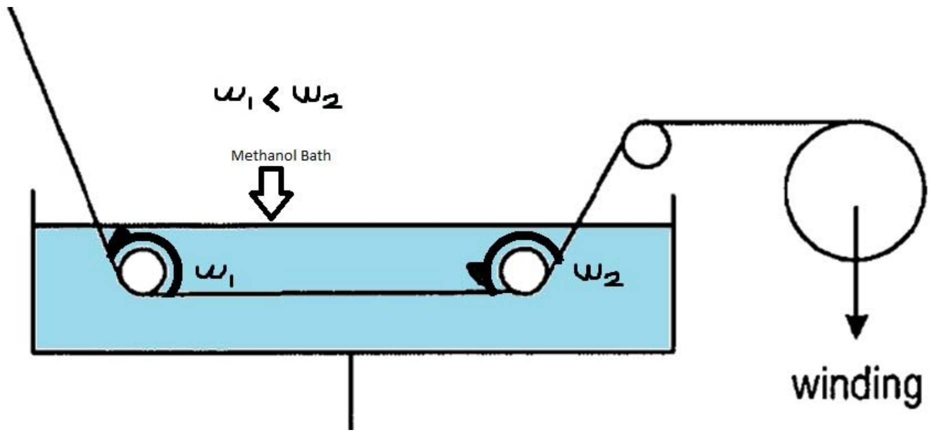

Figure 18 – Drawing bath diagram

mentioned earlier, the methanol bath causes the fibers to swell which helps promote platelet realignment on a microscale level. The primary challenge with this is the amount of tension we apply to the fiber. According to Dr. Zhang, the fiber has an approximate tensile strength of 200 MPa and a final diameter of around 35 µm. We conservatively estimate that the extruded diameter of the fiber is close to 50 µm and the strength is around 100 MPa. This means that the highest tension we can apply to our fiber is only 0.196 N, which is equivalent to the weight of approximately 8 pennies (one penny has a mass of 2.5 grams [19]). This tension limit will be the most challenging technical aspect of the drawing method, as any amount of friction between the rollers can cause the fiber to break. The simplicity of the system means that it can be repeated in stages as many times as necessary to get the final draw ratio, defined as the ratio of final to initial cross-sectional area.

The differential concept for twisting as briefly described above is shown in Fig 19. We chose the differential concept over the others primarily due to concerns of friction. We saw that redirecting the fiber over different rollers and spooling at large angles would cause a large degree of tension in the fiber. The differential eliminates that concern because it twists the fiber in a linear fashion without changing its direction. Therefore, it removes much of the tension inherent in the other concepts. The differential twists and spools the fiber simultaneously. From there the spool can be removed to store the fiber for later testing and replaced with an empty one to continue fiber production.

With the differential concept, the twist rate is defined by the gear ratio between the pinions and ring gears. This leads to the drawback that the twist rate is not adjustable. We will accommodate for this by calculating what the gear ratios should be to give us the desired ending twist angle and by testing with different gear ratios to validate our calculations. We could also design interchangeable parts to give some level of variability for research purposes. While this is

not optimal, this design is the best in terms of feasibility and loads applied to the fiber, thus it is our chosen design.

The entire system concept will consist of three parts. First the graphene oxide will flow

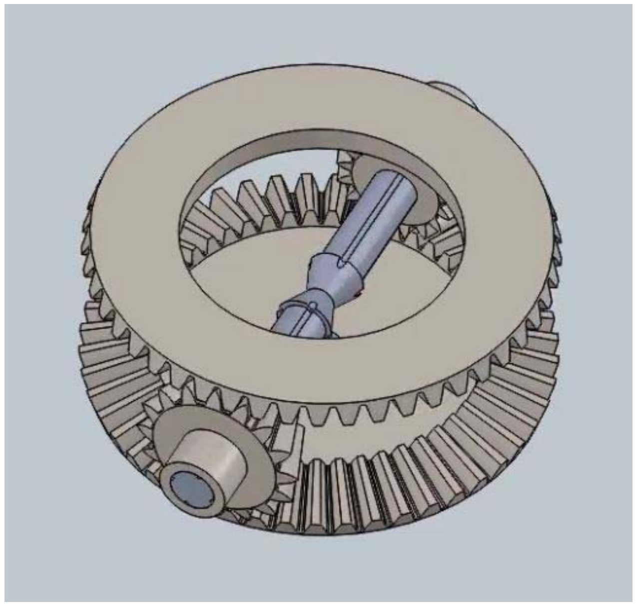

Figure 19 – Differential solid model

from the microfluidic channel into a coagulation bath, as discussed in our background section. This is where the fiber will form from the gel solution and it will spend about a minute coagulating. From here, rollers will pull it out of the bath and into a bath of methanol where it will be drawn to the desired diameter via rollers at different speeds. This bath may be one or several stages, each drawing the fiber successively more. After the final bath, it will be pulled into the spool on the differential where it will be twisted and wound. The separate stages allow us flexibility in placement and system length.

Other than the fiber tension issue previously discussed, it should be easy for this combined concept to yield a continuous fiber process. It should also be compact and relatively light, far beneath the size and weight limits. It may push the cost limit because of different motors and gears needed to drive everything, however our original target of $1,200 is still reasonable. Since there are limited areas where the fiber could break and we are minimizing the loads applied to it, both throughput and set-up time should be met. Based on the results Dr. Zhang’s research group has had so far, we also expect that the goals for fiber strength and standard deviation should be met as well. Fiber twist angle will be difficult because the twist rate is fixed as stated above and the gears required may have a large size difference to yield the twist rate we need. This also hampers output control as we mentioned previously. We completed a preliminary analysis of hazards in our design and identified ways to reduce the risks these pose to the user, which can be seen in our Design Safety Hazard Checklist in Appendix E. Safety should not be an issue and the current safety equipment used in the lab should more than suffice for our machine as well.

Management Plan

With the completion of this report by the 18th of November, we are perfectly on track as per our Gantt chart in Appendix F. The most prominent outstanding deliverables remaining are the Critical Design Review (CDR), Project Update Report, Hardware Safety Demo, and Final Design Report. The CDR will be built largely upon this report and filled in with detailed design analysis. This will include part drawings for all system components which we will be manufacturing ourselves and specifications supporting selections for any off-the-shelf components. Our CDR deadline is February 7th, 2017. Our Project Update Report will cover progress on our project manufacturing through the end of March. It is primarily intended to update Dr. Zhang on the status of the project and will be ready for him by March 16th, 2017. The final Design Report will be built upon CDR and cover the entirety of the project. It will include all of our results from manufacturing and testing to report on the design process as a whole. This report will be done by the Senior Design Expo on June 2nd.

Our analysis for the full detailed design will predominately be kinematic analysis of the rotating components in order to quantify properties such as the draw ratio and the final twist angle. Since the maximum tension the fiber can support is less than one Newton, we are not highly concerned with component stresses, however we will be doing some basic analysis to make sure that assumption is valid.

We have a method of calculating the twist angle of the fiber based upon twist rate, however we have not been able to validate it against current lab results as of yet. Our initial plan is to construct a prototype differential assembly with a gear ratio close to what we expect to need, then conduct tests with either actual fibers or some monofilament analog followed by SEM imaging analysis to validate our calculations. This should give us a good idea of how accurate we are on the twist angle calculations and how much our differential needs to change. We will be prototyping the gear box using 3D printing for quick iteration time. The gears will be either 3D printed or from a commercial source if the variety is large enough with a low enough cost. The final gear sizes will be commercially sourced, as will the final differential housing. Material for the gears will be selected based on cost. Since the gears will be dealing with relatively small loads, durability is not as much of a concern in material selection.

System-level testing will consist of fiber production tests to determine the actual output of the prototype. We will measure the throughput of the machine and fiber properties such as strength, diameter, and twist angle to assess how well the design meets the stated requirements. Time permitting, we will iterate some aspects of the design for increased performance and conduct additional testing. All test results will be included in our final design report.

Final Design Description

The following figures display the finalized CAD designs for each major component. First comes the Drawing/Coagulation Bath. The extruded fiber travels over the first roller and under the next two. By increasing the speed of each consecutive roller the fiber stretches. The bath can be filled with a variety of chemicals due to its chemically resistant materials.

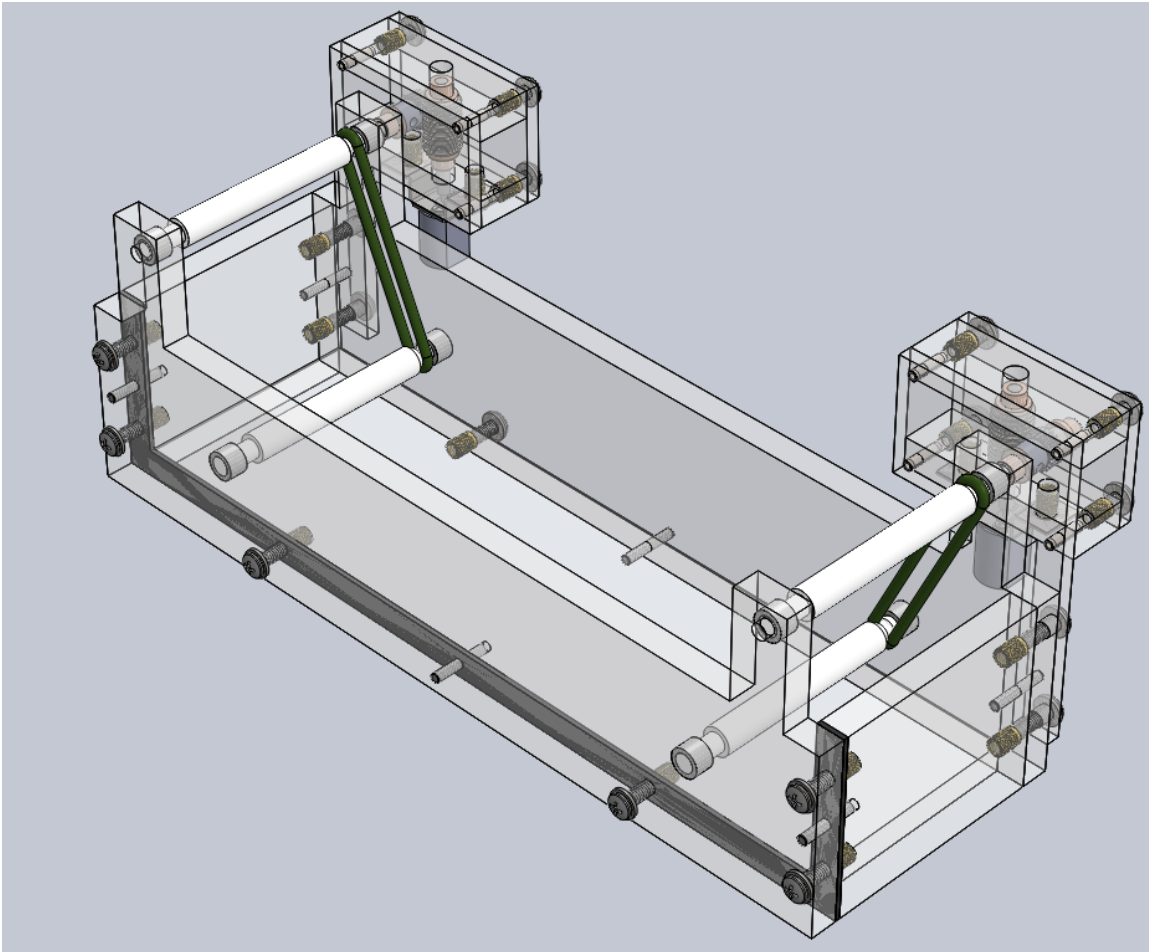

Figure 20 – CAD Model of the finalized Drawing/Coagulation Bath

Due to a slight change in the scope of our project, the Auxiliary Roller was designed. Since the twisting speed could not keep up with fiber extrusion speed it became necessary to create a break in the process. The fiber spools around the Auxiliary Roller either after coagulation or after the drawing process. The CAD for the Auxiliary Roller can be seen in figure 21 below.

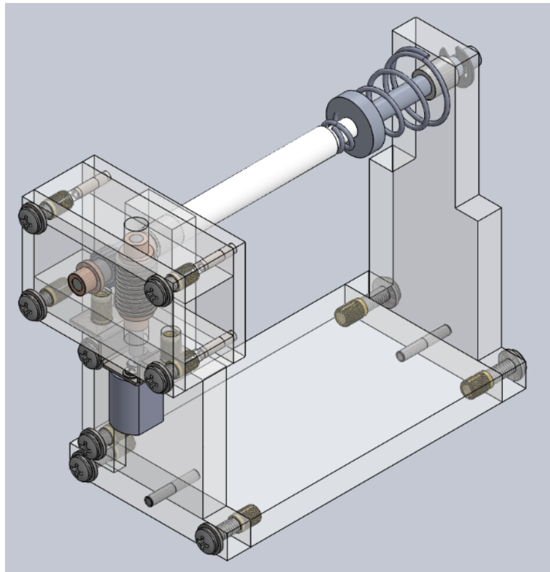

Figure 21 – CAD model of the finalized Auxiliary Roller

The final part of our design is the Electric Differential. In this part, an internal and external motor work in tandem to twist and spool the fiber.

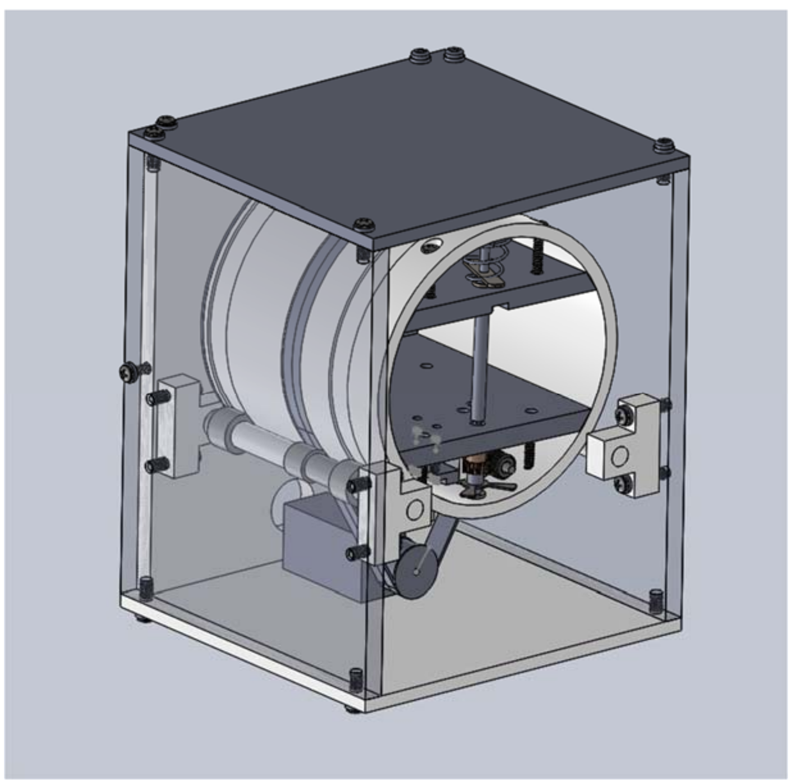

Figure 22 – CAD model of the final Electronic Differential

Bath

The bath subassembly manifests the coagulation and drawing portions of our design. The final prototype will have two bath assemblies, so that one can be used for coagulation and the other can be used for drawing. This can also be rearranged in the future based upon the user's requirement at that time. The baths are identical in design and function so that either may be used for either stage of the fiber production process. The bath is shown in figure 23 as both an isometric assembled view (a) and an exploded view (b), showing the major subassemblies of the

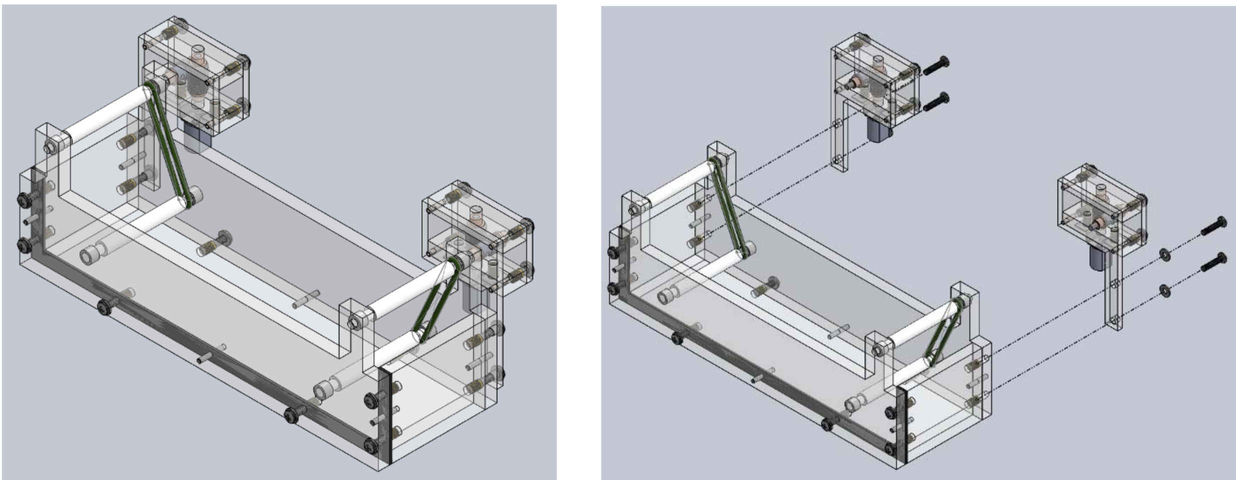

Figure 23 – (a) Bath assembly and (b) exploded bath assembly

bath body and the gearboxes as well as assembly-level fastening components. The bath body encloses the chemical compound (working fluid) currently being used in the system as well as the rollers that pull the fiber through the bath. The rollers are powered as pairs in either the first half or second half of the bath. By adjusting the relative speed between the front and back roller sets, the graphene fiber can be drawn to a smaller diameter. The gearboxes house the DC motor and gear reduction stage the steps down the shaft speed and increases the applied torque. This allows us to use a greater range of the motor's speed range. The gearboxes bolt onto the bath body via bolts on the edge that connect the side to the end frame panels. This connection is highlighted by the box in figure 23 (b). The precise roller speeds will be controlled via pulse width modulation (PWM) control of the DC motors' duty cycle. More detail on the motor control will be presented in the Electronic section below. Further design analysis will be presented separately for the bath body and the gearboxes.

Bath Body

The main function the bath body has to achieve is to hold the working fluid without leaks. A critical aspect of this is that it must not negatively react with the chemical solution placed in the bath, which varies not just within the graphene fiber process, but will vary should the research group want to use the prototype to work on a different polymer compound. Therefore, material section was largely driven by which materials were the most chemically stable and would not corrode or otherwise degrade when in contact with a variety of chemical solutions. This same design criterion was applied to all other materials which will or may come

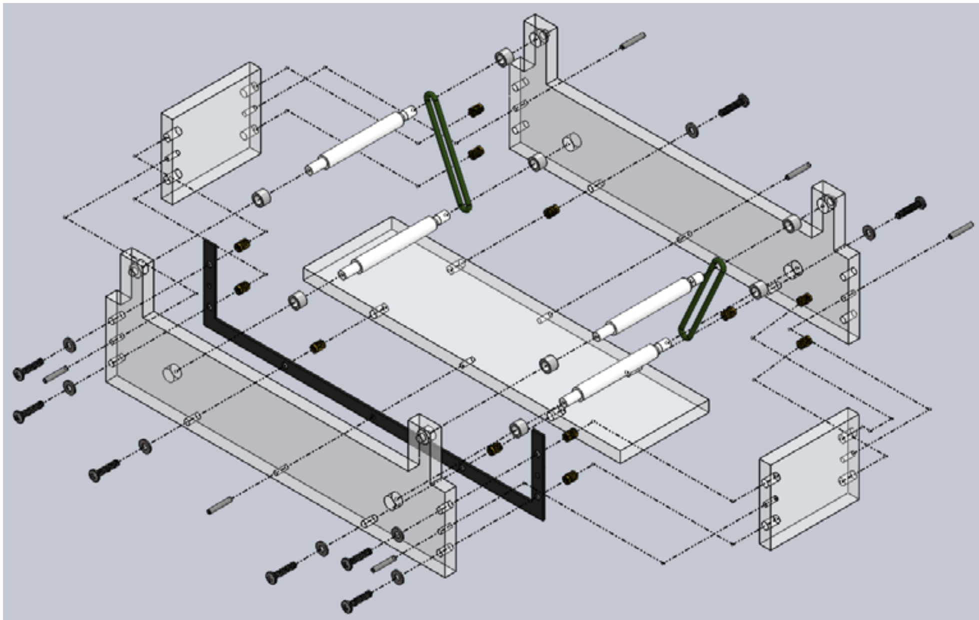

Figure 24 – Exploded bath subassembly

in contact with the working fluid. Secondary material section criteria were that the material needed to be machined easily and low cost, while a tertiary criterion was that it be lightweight. Comparing a few different polymers and common metals, we selected Type 1 Polyvinyl Chloride (PVC) as the base material for our bath and the majority of our overall design. Type 1 PVC is a lightweight and strong polymer. Its polymeric structure leads to it being easier to machine than aluminum or steel alloys. Type 1 PVC is also widely available and is used in many common applications, making it a very economical material. Full cost analysis will be presented in the budget section of this report.

Figure 24 shows an exploded view of the bath, which is made up of the body, rollers, belts, bearings, fasteners, and a silicone gasket. The bath body is comprised of five major pieces: the base, two side walls, and two end caps. These are all made out of PVC sheet and shown in figure 25. The walls must contain mounting surfaces for the rollers, however drilling through holes below the fluid level would increase the propensity to leak. Therefore, it was decided that the bearings the rollers mount to would be placed in blind holes in the surface and the wall thickness must be sufficient to accommodate the blind hole and retain adequate material thickness. The bearings needed to be mechanically simple and chemically resistant. Greased ball bearings would either have to be sealed, increasing their complexity, or their lubricant might interfere with the chemical environment of the bath. Our loading case on these rollers is less than a 0.4N fiber load and under a rotary speed of 550 RPM. Since the loads applied to the rollers are small, ball bearings are not worth the mechanical and chemical complexity the involve. From there, it was decided that a simple sleeve bearing would offer ample lubricity while remaining mechanically simple. Researching sleeve bearing materials, a FDA-approved fluoropolymer called Rulon 641 emerged as one of the best options as far as having both low friction and high chemical resistance. A stock size of 1/4” ID x 3/8” OD x 1/4” length was selected as fitting the scale of the design and is shown in figure 26. These bearings will be stable for a range of anticipated working fluids and will significantly cut down on the friction between the rollers and

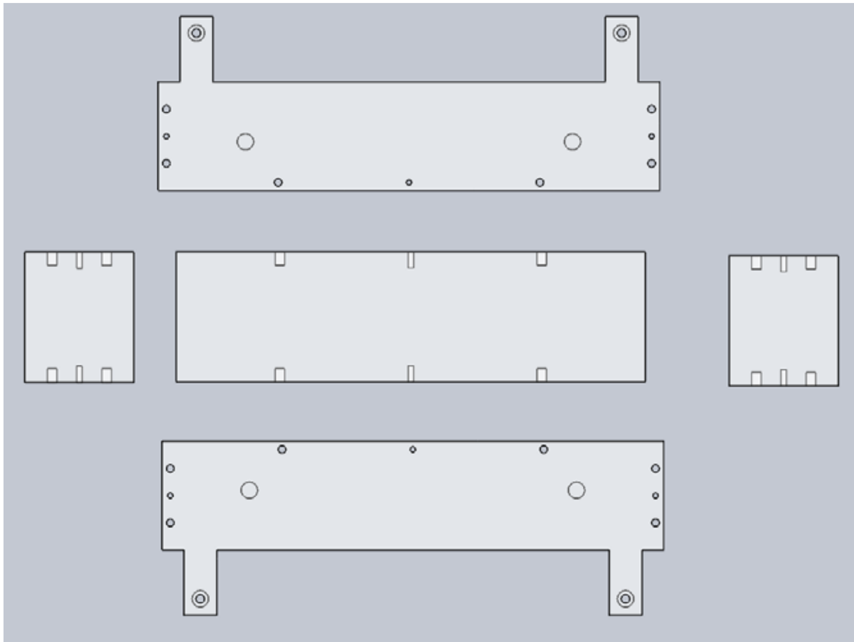

Figure 25 – Bath frame components

the bath walls. For the bearing depth of 1/4", a 3/8" wall thickness of PVC was chosen. This also gives enough thickness insert fasteners into for bath assembly.

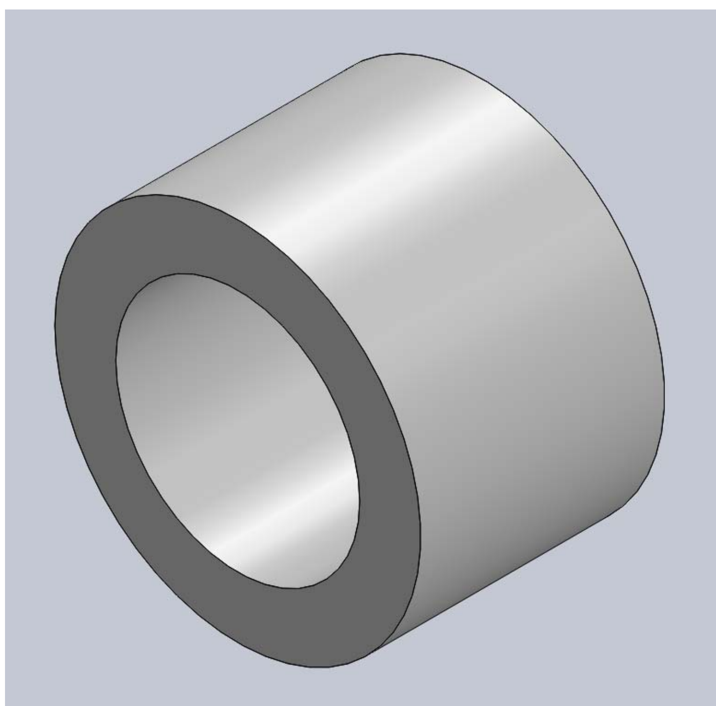

Figure 26 – Rulon 641 Bearing

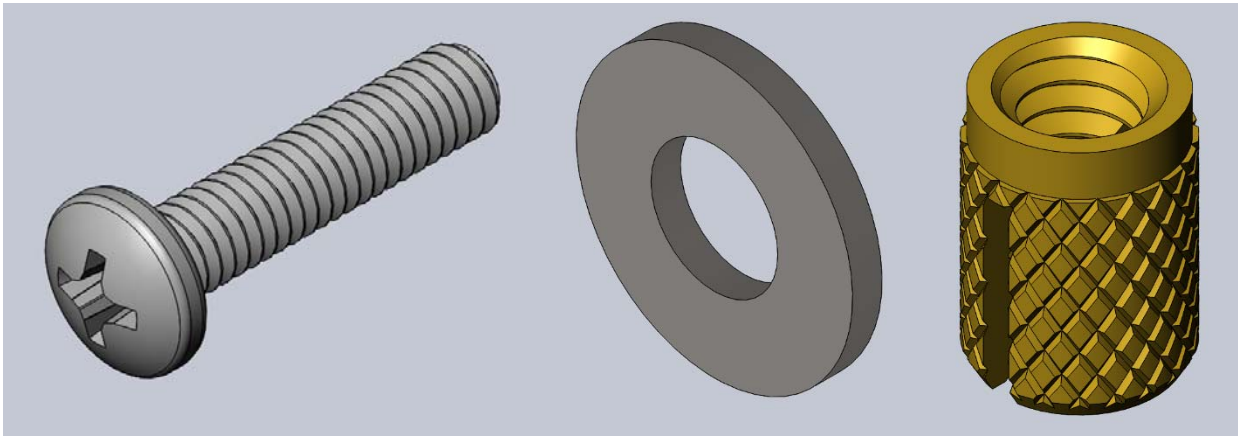

Figure 27 – Three-piece fastening method

One downside of selecting PVC as the body material is the low material strength. This means that tapping threaded holes directly into the material would result in weak threads which could fail over time, leading to leaks. Therefore, we selected a three-piece fastening method as shown in figure 27. Each fastener consists of a Phillips head screw, flat washer, and a brass threaded insert. The treaded insert is pressed into the oversized screw hole in the mating piece, then when the screw is inserted, the knurled flanges press out into the surrounding plastic, giving a strong screw location. The specific size for this design was #8-32 because the OD of the insert (0.2187") was a reasonable size while still leaving sufficient wall thickness around the insert. This fastening method is used through all aspects of the final design and uses screws from 1/4" to 1" long in 1/4" increments. We sought to minimize the number of different screw lengths to cut down on hardware costs, as the minimum package size for each screw length is 100 pieces. All screws used in this method are the same thread size, so only one threaded insert size is needed. Additionally, by using Philips head screws, only a screwdriver is needed to maintain the device.

For part longevity, it is important that our roller bearings be aligned with each other, which depends on how the sides are mounted to the bottom and side frame components. In order to help align these pieces, each junction will be located with a 1/8" diameter stainless steel dowel pin. The tight diameter tolerance of this pin will help locate the plates relative to each other and reduce our assembly tolerance stack-up.

One function of the bath that will determine its success or failure is how well it contains the working fluid. A leak would not only be messy, but could be expensive in terms of unrecoverable and reusable chemicals, and dangerous as spills create slippery floor surfaces. Particularly in a chemistry lab, spilled chemicals could come in contact with and react with other chemicals in the surrounding area. Therefore, it is paramount that the bath seals adequately and reliable. On the other side, the interior of the bath needs to be accessible for cleaning and possible part removal should a failure occur in one of the rollers or bearings. This was solved by having most of the bath frame permanently sealed together with a gasket compound, but having one side panel, the one that the motors do not mount to, removable and sealed with a silicone

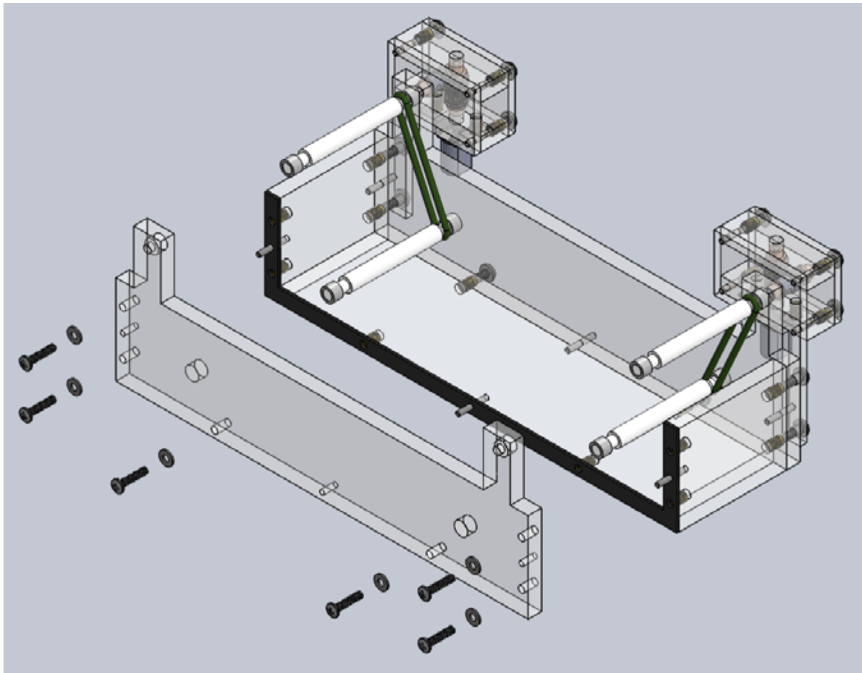

Figure 28 – Bath assembly with side removed

gasket. Should the bath need to be take apart, this one side could be removed with ease and the seal can be reformed on reassembly. An exploded view of this process is shown in figure [28].

Each pair of rollers is connected via a urethane band connecting the two. Slight grooves are cut into one end of the rollers to locate the band longitudinally. Contrary to how it was simplified in the CAD renderings presented earlier, each band will have a figure eight twist in it. This will cause the rollers to rotate in opposite directions, allowing the fiber to go over one roller and under the other. The band was selected for its pliability, simplicity, and chemical resistance. The bands are a one-piece construction and fixed outside diameter, so incorporating them into the assembly is rather easy.

The rollers themselves are made out of polypropylene because it is easy to machine, chemically resistant, and inexpensive. From 1/2” OD stock, each roller can be turned down on a lathe. The top roller in each pair has a 4mm diameter hole drilled into the end nearest the drive band groove to connect to the output shaft of the gearbox.

The majority of fabricated components are planar pieces cut from the PVC sheet stock. Because of the number of pieces that need to be cut, the pieces will be cut out on a waterjet cutter. This allows high production rate and high accuracy compared to machining parts by hand. Some of the parts have holes on other planes that will need to be done by hand on a mill. Additionally, the blind holes and counter bores on the side pieces will need to be drilled manually.

Gear Box:

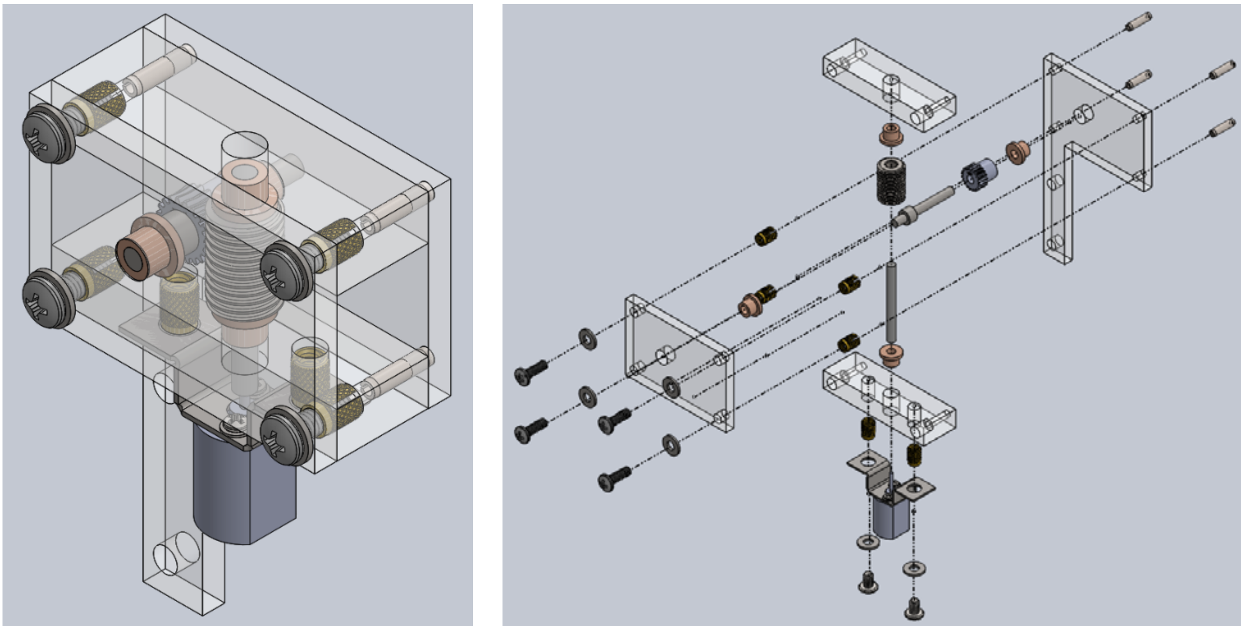

Figure 29 – (a) Gearbox subassembly and (b) exploded gear box

As stated above, the main function of the gearbox is to reduce the speed and increase the torque supplied by the motor then transmit that to the rollers in the bath. It does this by means of a 20:1 worm gear reduction ratio. The goal of the gearbox design was to be compact in the space requirements and allow for easy maintenance. The gearbox was made compact by eliminating thick PVC material where it was unneeded. The goal of easy maintenance was achieved by externally mounting the motor and by having the front face of the gearbox easily removable. Assembled and exploded views of the gearbox are visible in figure 29 (a) and (b). The parts of the gearbox are designed such that even though there is a left and right configuration, both are made from the same pieces, just in a different orientation. This streamlines the manufacturing cycle by having a fewer number of unique pieces to produce.

The top and bottom plates of the gearbox are made from the same 3/8" thick PVC. They will be waterjet cut then manually post-machined on a mill. The front and back plates do not have any hardware mounted through their thickness, so those are just waterjet cut out of 3/16" PVC. This reduction saves 3/8" on the overall gearbox thickness. All four plates are shown in figure 30. The front plate of the gearbox also prevents the user from sticking their hand into the rotating gear train during operation.

The gear pair selected for this is a metric set from KHK Gears, shown in figure 31. They have a 4mm bore and a 20:1 reduction. The worm is made from ground steel while the gear is acetal. The design incorporates a total of six worm gear sets, so price was an important aspect of selection. At $15.77 per set, this was one of the more economical sets for the scale.

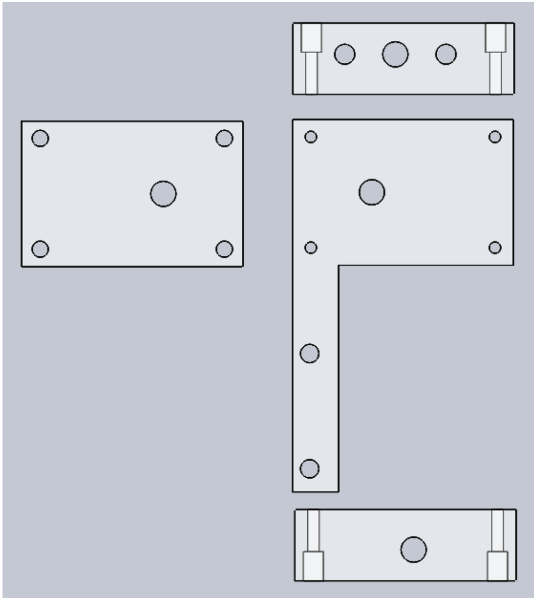

Figure 31 – Gearbox frame panels

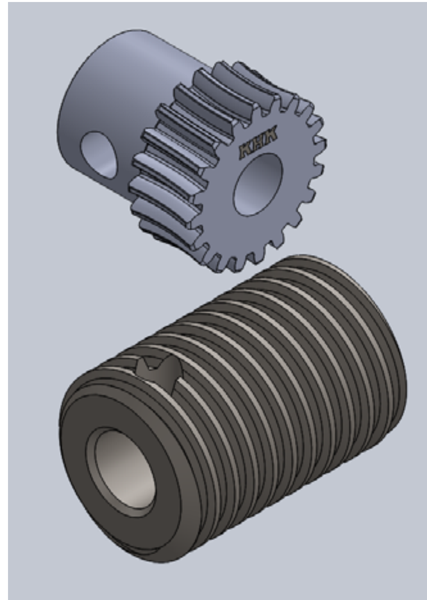

Figure 30 – Worm gear pair

With the use of a worm gear set, the gearbox bearings need to be able to take a thrust load. Because one goal of the gearbox design is to reduce size, a sleeve bearing design was chosen again, this time a flanged bearing made from SAE 841 oil-impregnated bronze. Because the gearbox is separate from the bath, we are not concerned with oil from the bearing coming in contact with the bath chemicals.

Both the worm shaft and the drive shaft, shown in figure 32 (a) and (b), respectively, are turned down from polypropylene stock similar to the bath rollers. The worm shaft attaches to the worm via a set screw, then connects to the motor output shaft with a slight interference fit. The acetal gear is located on the drive shaft by the stepped shoulder, and transmits torque via an interference fit.

The motor is packaged as a separate subassembly, shown exploded in figure 33. This makes it easier to remove should the motor need be changed for any reason. The motor mount is a waterjet cut piece of 304 stainless steel sheet that is then bent to the proper shape. The holes

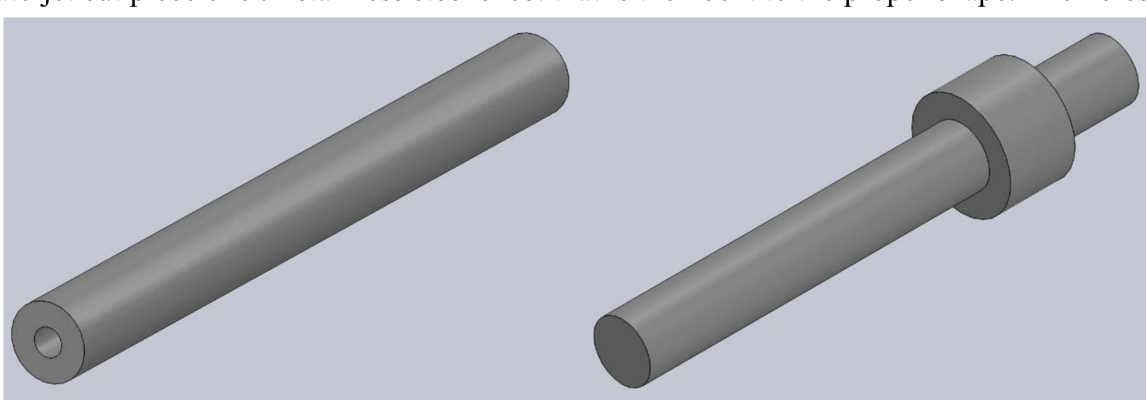

Figure 32 – (a) Worm shaft and (b) drive shaft

use for attaching the mount to the gearbox are deliberately oversized to compensate for any bending misalignment. The motor attaches to the mount with two M2 screws.

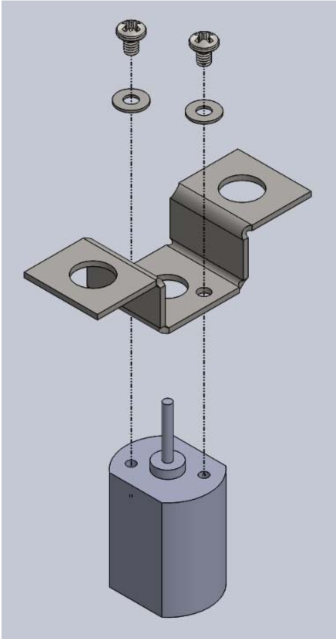

Figure 33 – Exploded motor assembly

The face of the gearbox against the bath is assembled using stainless steel roll pins. This is to eliminate the overall bulk of the system since that side does not require a large normal clamping force or disassembly. The outward face is held together with Phillips head screws, similar to the bath.

Auxiliary Roller

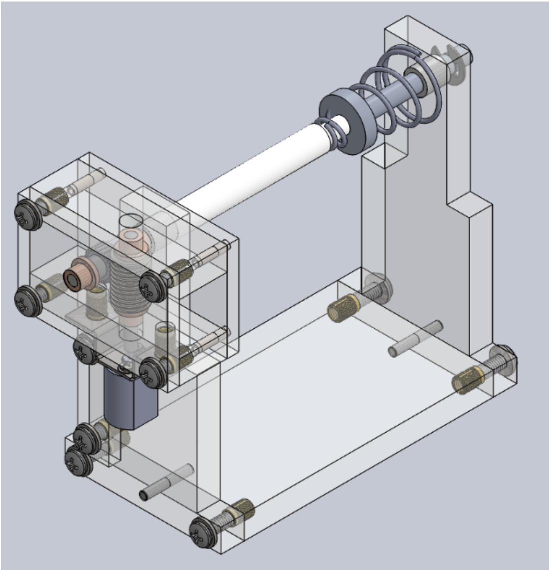

Figure 34 – Auxiliary roller assembly

Using the parameters supplied by the project sponsor of a 40 mL/hr GO flowrate and a 25-degree twist angle, the twisting mechanism at the end of the system would have had to rotate on the order of 10^5 RPM, which was entirely infeasible for the scope and timeline of this project. After discussion with the sponsor, the design shifted to include an additional spooling step in between coagulation and drawing, shown in figure 34. This allows the process to be broken up into two distinct sections, each running at optimal speeds to produce maximum fiber strength. The auxiliary roller assembly utilizes the exact same gear box design as the bath does, and a similar roller design. Something notable about the auxiliary roller is the conical spring on the end of the roller. This is a mechanism that allows the roller to be removed quickly and easily. The shaft on end of the assembly slide back and forth along its axis. At its fully closed position, the shaft engages with the roller and the roller collects the fiber. By pulling back on the spring shaft, the roller can be removed.

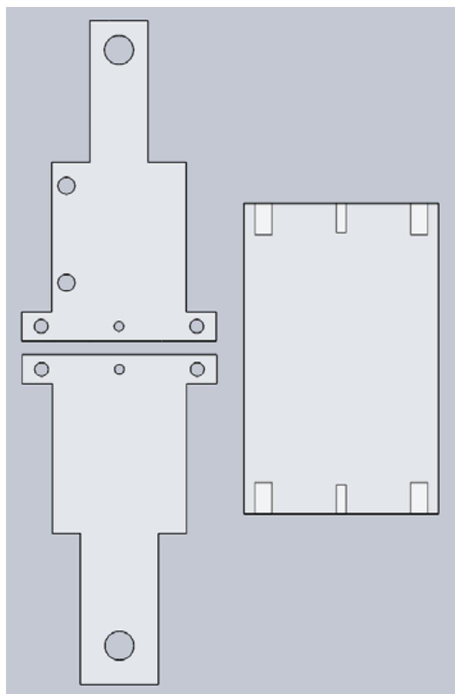

Figure 35 – Auxiliary roller frame

The frame for the auxiliary roller has very similar architecture to the bath. The main components, shown in figure 35, are waterjet cut from 3/8” thick PVC and the bolted together using Phillips head screws and threaded brass inserts. The gearbox bolts onto the side with the vertically aligned through holes. The base plate was made to be wider than necessary to offer a little bit wider base of support since the assembly’s center of gravity is higher due to the height of the gearbox.

The roller, shown in figure 36 is very similar to the rollers made for the bath assembly. The auxiliary roller is turned down from polypropylene stock and has a max OD of 3/8” while designed to fit into a 1/4" bearing.

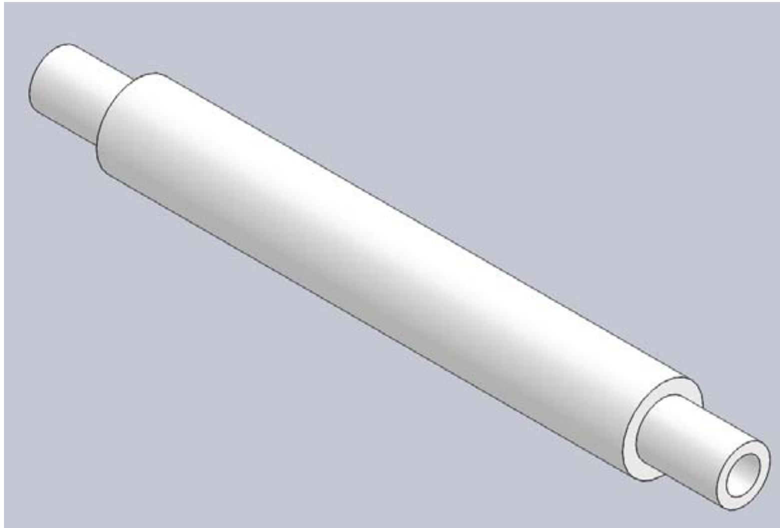

Figure 36 – Auxiliary Roller

The bearing for the auxiliary roller are custom machined from Teflon PTFE. They have a 3/8” OD, a 1/4" ID, and a 3/8” length, slightly longer than the Rulon 641 bearings in the bath. Because Teflon PTFE stock is being ordered for cylinder housing components, it was more economical to utilize leftover material than order additional Rulon 641 bearings.

The spring shaft, shown in figure 37 with additional hardware, is the moveable portion of the auxiliary roller assembly that allows the roller to be removed with relative ease. It will be

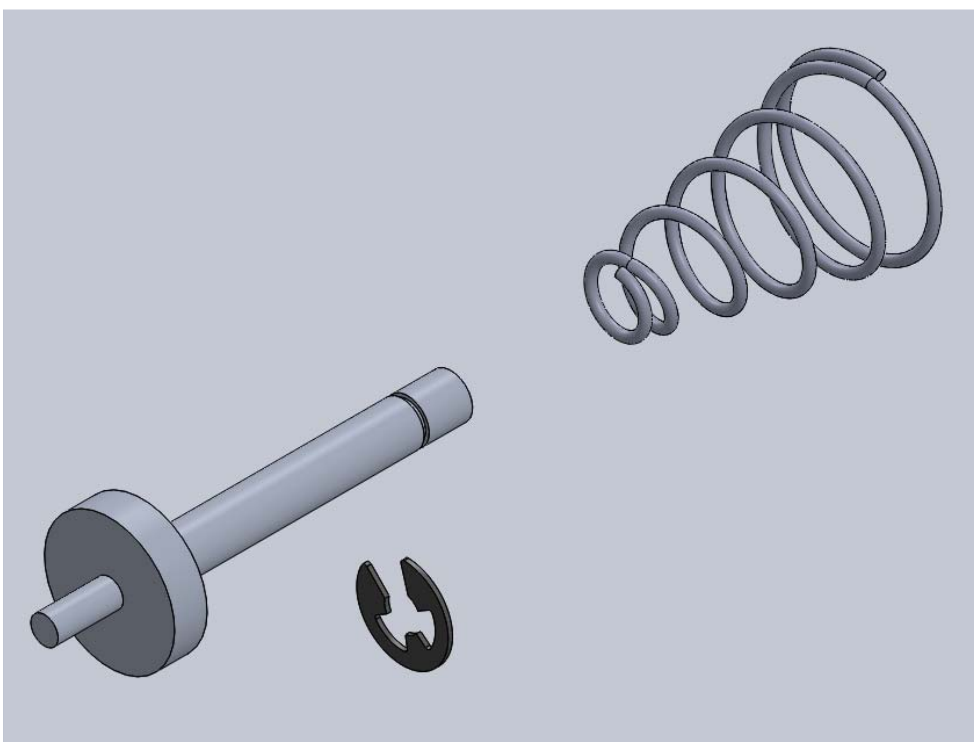

Figure 37 – Spring shaft and hardware

machined down from polypropylene as well, and features a larger disc section that allows the user to pull back on the shaft to remove the roller. When the roller is removed from the assembly, an e-clip installed into a grove at the back of the spring shaft will prevent the spring from pushing the shaft entirely out of the assembly. The spring itself is a conical spring ordered from McMaster-Carr. A conical spring was chosen for the spring's ability to pack almost entirely flat. Given the limited displacement of the shaft, the spring design needed to maximize the useable space. The spring has a constant of 9.18-pound force per inch. Therefore, under the small deflections necessary to release the roller, the force will not be too large.

Differential Redesign:

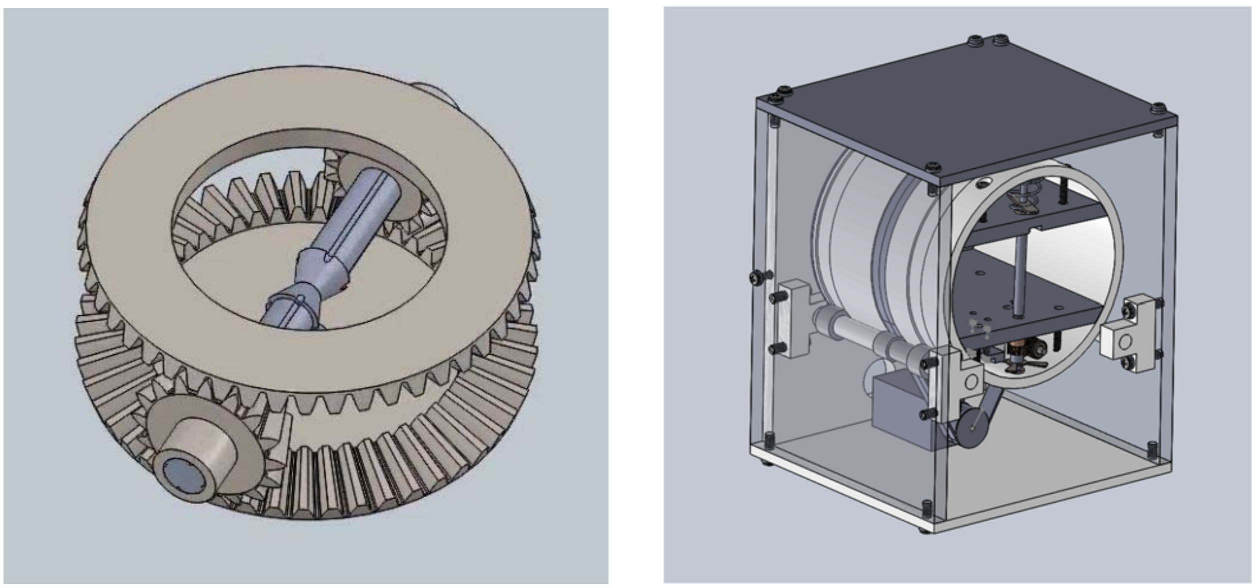

Figure 38 – CAD Assembly of the Differential and Electronic Differential located within its housing.

The Electronic Differential is the newest iteration of the differential idea talked about in our "Selected Concept" section. We liked the idea of a differential (pictured on the right) because it was able to spool and twist the fiber at the same time. Even better than this fact, however, was that it could do it with only one motor. This meant that we only needed one control circuit in order to adjust both the spooling and twisting motion of our fibers. Unfortunately, we ran into a problem with the gear ratios required for spooling and twisting at the correct rate to get our desired twist angle of 25° in the fiber which ultimately resulted in the redesign of the twisting mechanism.

In the "Selected Design" section it was mentioned that we would perform calculations to determine the optimum gear ratio in the differential, these calculations ended up being the reason the differential had to be redesigned, which shall be explained in the following paragraphs. Through research and meetings with our sponsor, it was determined that the desired twist angle of the graphene fibers we produce should be about 25°. The following calculations were then performed in order to determine how many twists per inch we would need to achieve this angle.

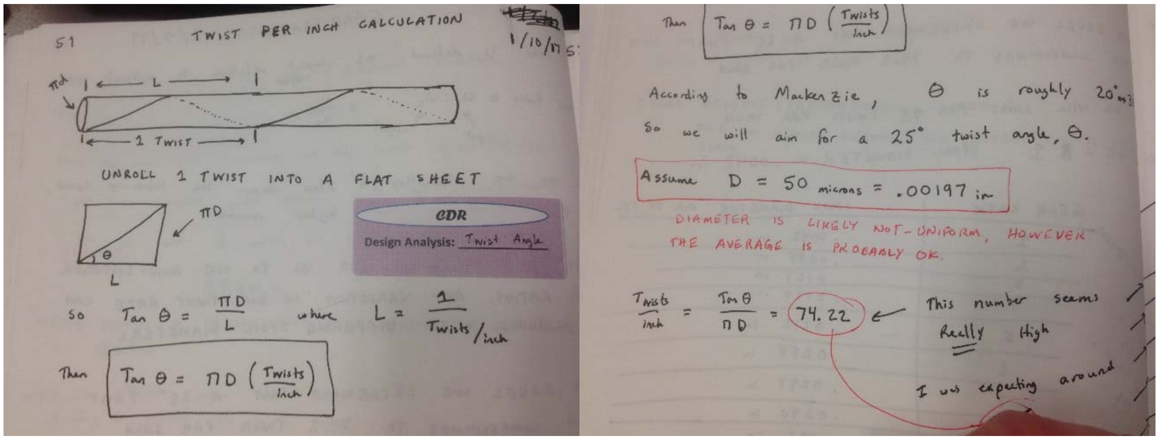

Figure 39 – Hand calculations to determine the number of twists per inch required for a certain fiber twist angle.

It was determined through research that we could geometrically approximate the angle of twist of the fibers. What this resulted in was the following equation to determine the number of twists per inch we would need to achieve a desired fiber twist angle Θ.

$$Tan(\Theta) = \pi D/L$$

We then set L = 1 inch and effectively eliminated that term from the equation. Next, we assumed a diameter, D, of 50 microns or 0.00197 inches since that was the fiber diameter our sponsor requested. What this showed us was that we needed approximately 75 twists per inch in order to get a twist angle of 25°.

Next came developing the equations to size the spool and gear ratio in the differential to achieve 75 twists per inch. The general concept is that every time the spool rotates once about its axis, it takes up its circumference in fiber length. For example, if the spool has a diameter of 1 inch, then it's circumference is πD so 3.14 inches. Therefore, every time a 1-inch diameter spool rotates, it takes up 3.14 inches of fiber. Now if we need 75 twists per inch to get our desired fiber twist angle, this means we need to spin the spool 3.14 x 75 times which comes out to 235.5 revolutions of the differential for 1 single rotation of the spool, a 235.5:1 gear ratio. This number is ridiculously high, so we tried out our calculations with smaller spool sizes. What we found was that a spool diameter of approximately 1/32 of an inch (0.034") gave us a gear ratio of 8:1. A spool with a diameter of 0.100 inches resulted in a 24:1 gear ratio in the differential, and a spool diameter of 0.250 inches gave us a gear ratio of 59:1.

We estimated that a spool diameter of ¼ inches would be acceptable for human use, and attempted to design a 59:1 gear ratio differential. The following is the result of those attempts.

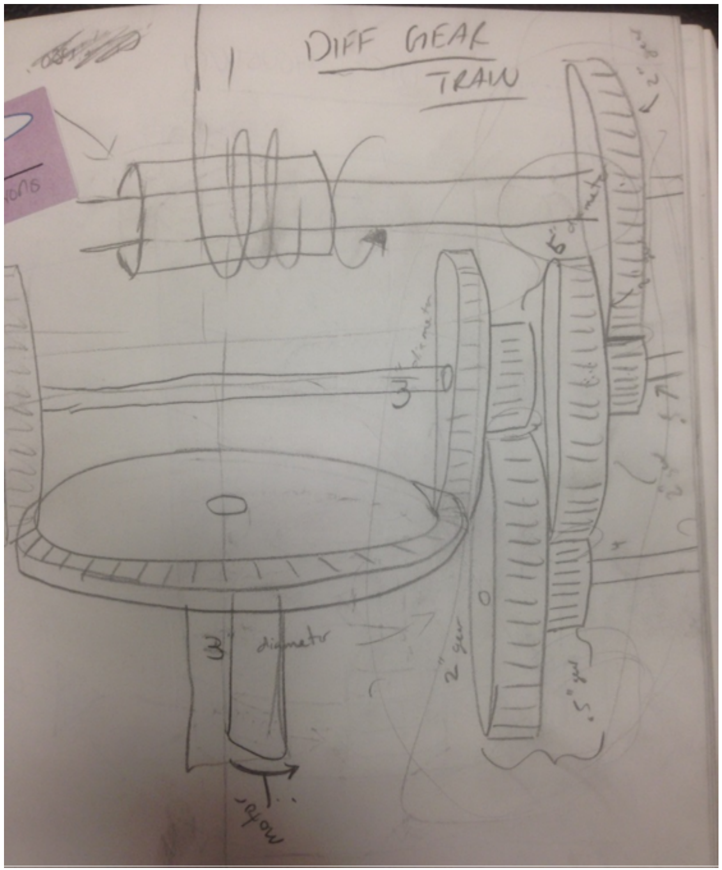

Figure 40 – Attempted 59:1 gear ratio differential

There were, naturally, numerous problems with the design of such a differential. First, the manufacturing of a 59:1 gear box is possible, but not easy. There is a very high degree of precision and accuracy required to locate all of the gears correctly so that the mesh without misalignment. Next, it is a very costly design, since it needs to be very precise and the gears would most likely need to be custom ordered. Lastly, it introduces a huge amount of rotating imbalance into a system spinning at speeds of greater than 200 RPM. For these reasons, the differential was eliminated as a possibility.

Since we couldn’t power the two different directions and speeds of rotation with a single motor, our design evolved to a two motor design where one motor powers the take-up and one motor powers the twisting.

We encountered two interesting design challenges with this new design. First, we had to determine where to locate the motor that powers the take-up since it would likely be spinning with the twisting motion in order to maintain the relative motion of the two systems. Second, we had to figure out how to continuously power a motor that was moving since any wires connected to this motor would quickly be wrapped about the stationary components in the assembly. There ended up being one solution to both challenges: an electrical component called a slip ring. Slip rings are mounted onto rotating parts at the center of rotation and are able to transmit electrical power through the bearings they rotate around. This means that the wires inside the

rotating component have no velocity relative to the rotating component and therefore will not get tangled or twisted.

The Electronic Differential (E-Diff)

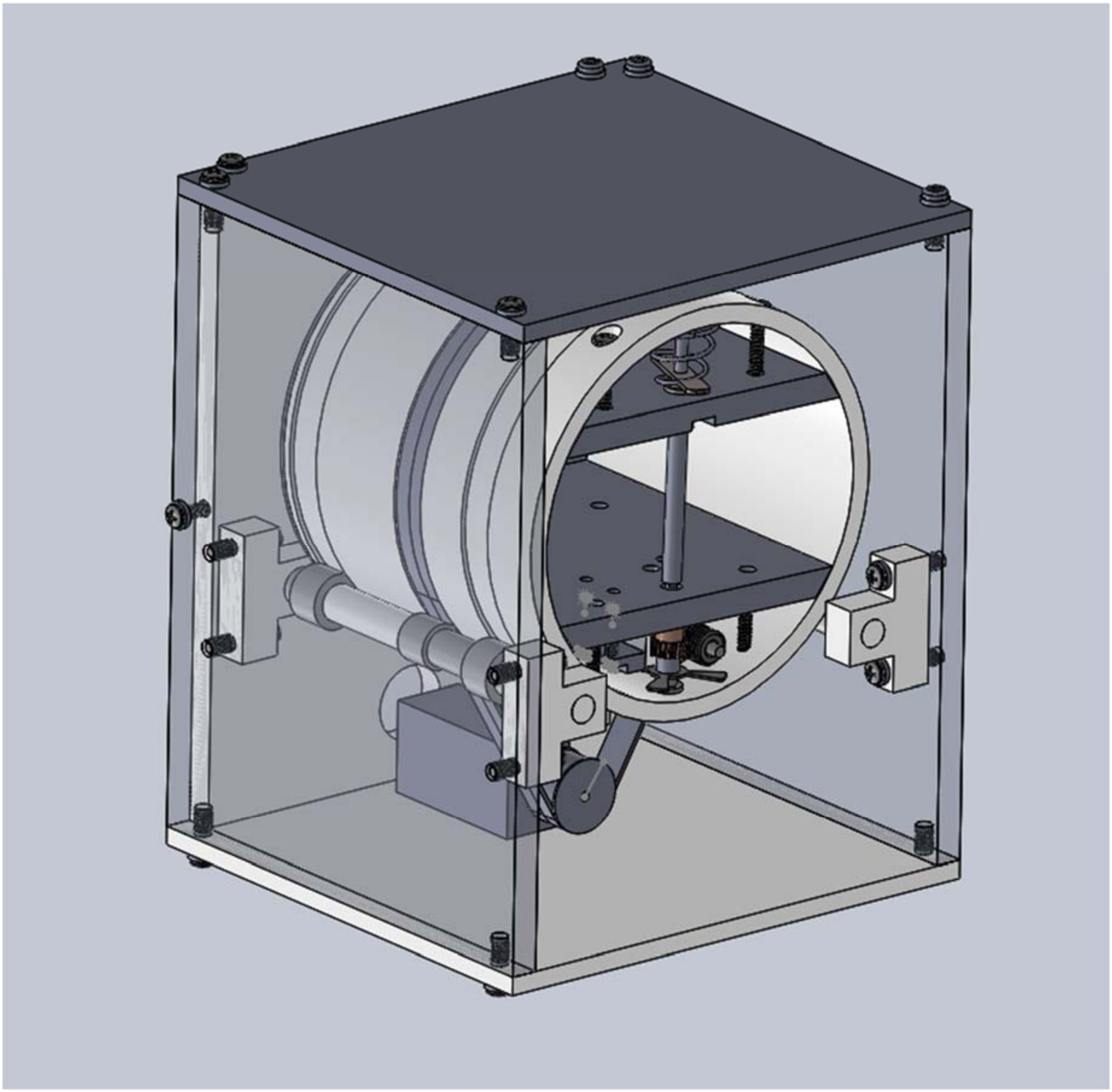

Figure 41 – The final design for the twisting mechanism called the E-Diff (Electronic Differential)

The Electronic Differential makes use of two motors, one internal and one external, to power both the twisting and spooling movement. The external motor works in the same way a rotary clothes dryer does: the cylinder is powered by a motor and belt combination. In addition to this, the cylinder rests on rollers, or in our case nylon bushings to support the component with minimal frictional losses. To prevent the cylinder from moving throughout the housing, half-inch bands will be cut into the cylinder using a lathe. This will locate the bearings to the housing and

also keep the cylinder aligned. The nylon bushings are held in place on a polypropylene shaft with the use of spacers and mounting blocks.

The spool is located inside the center of the cylinder and is powered by the same motor and components used in the bath and auxiliary roller gearbox. Using pulse width modulation, we can adjust the average power delivered to the both the internal and external motor in order to control our motor speeds with a high accuracy of 10 bits. Since the cylinder and the spool rotate around different principle axes, we get both the twisting and spooling motion we desire. Lastly, there is a spring loaded shaft in the cylinder to allow for quick and easy removal of the spool.

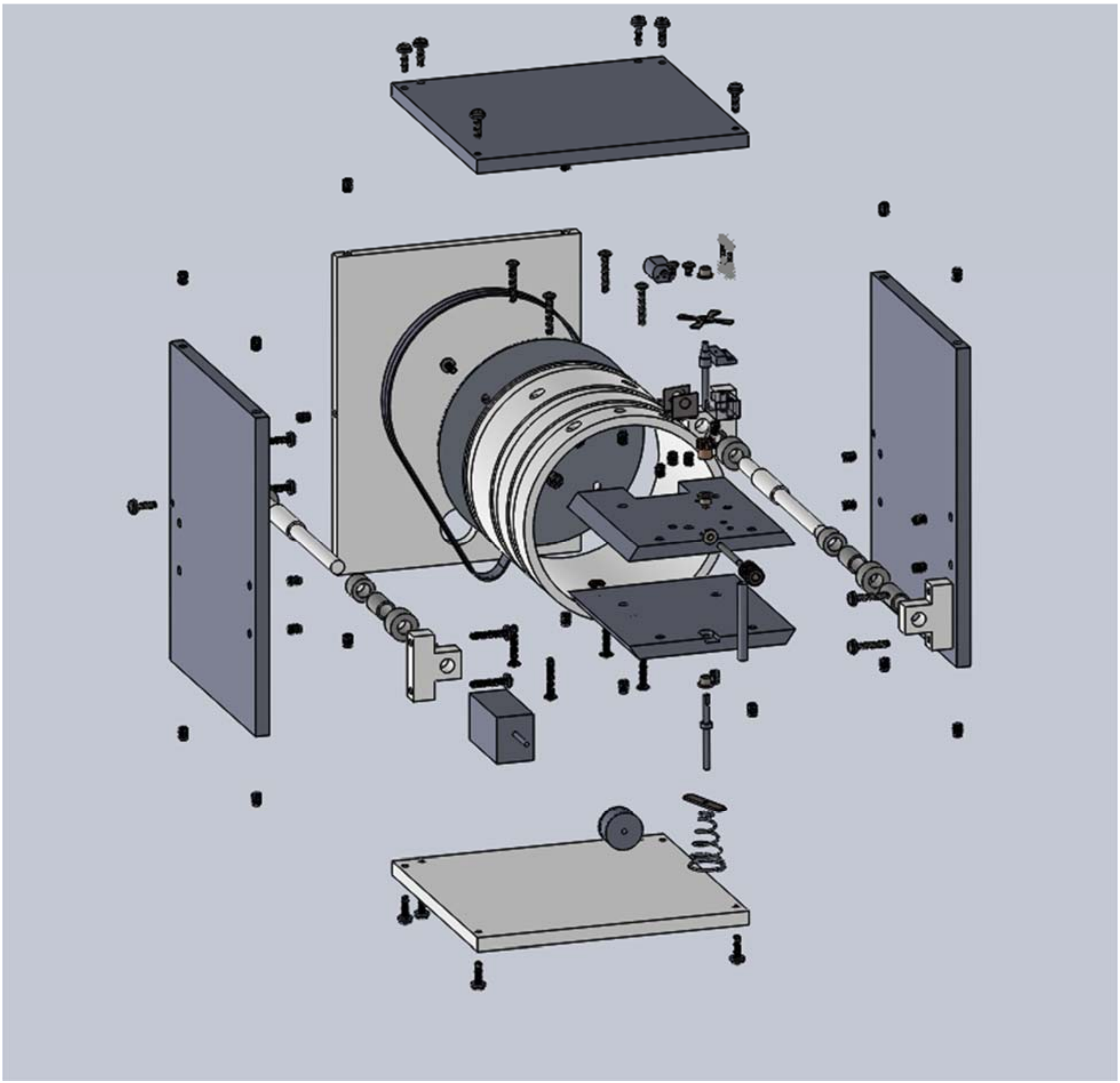

Figure 42 – Exploded view of the entire electronic differential housing assembly

The entire twisting assembly consists of 154 components. The vast majority of these are fasteners, however there are still 35 manufactured parts. Materials used for the manufactured components include PVC sheet, polypropylene round, PVC round, and aluminum sheet.

Cylinder

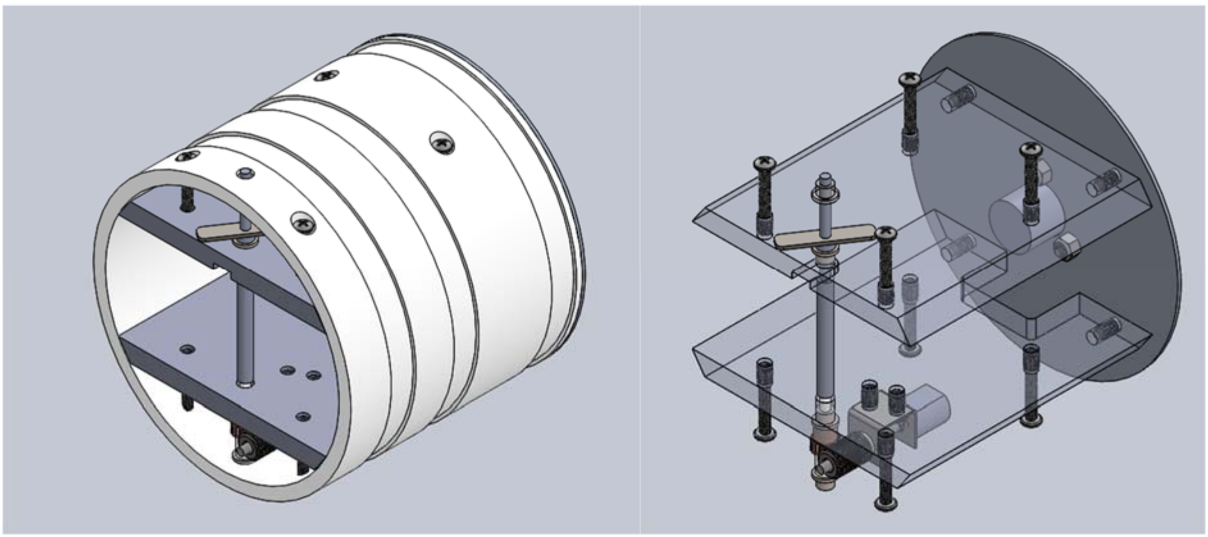

Figure 43 – The Cylinder and its internal assembly. On the right the cylinder has been hidden to show the internal components.

Two internal walls make up the mounting fixtures within the cylinder. These walls are made of 3/8-inch thick PCV sheet and will allow components to be fixed to a planar surface rather than a curved one. This improves the manufacturing process as a whole since the component alignment can be done entirely through the waterjet cutting process. The chance of holes being out of positional tolerance becomes much lower and it also avoids the issue of drill tip travel if we were to attempt to locate holes in the cylinder. One other thing that the internal wall design helps with is fixing the rotating imbalance within the cylinder since the walls can have extra weight attached or removed.

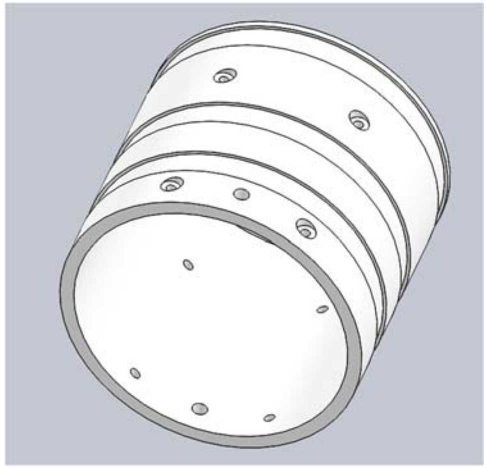

Figure 44 – The 5.5-inch outer diameter PVC Cylinder that twists the spool and fiber as well as locates the mounting plates.

The cylinder is made from a piece of 5.5-inch outer diameter, 5-inch inner diameter PVC pipe that is 5 inches long. The groves that circle the outside of the cylinder are 0.5 inches wide and 0.0625 inches deep. The holes are a #8-32 clearance hole with a 5/16^{ths} counter bore to prevent the screws from sticking off of the side of the part and interfering with the rollers the cylinder spins on. One thing that also had to be kept in mind is to not make the counter bores too deep as the walls of the cylinder become very thin in those areas. To machine this part, the lathe operation would need to come first in order to face the cylinder to the correct length of 5.00 inches. Next, the groves would be faced into the cylinder. The last step would be to drill the holes into the outer walls using a manual mill. Toe-clamps are necessary to prevent the cylinder from spinning or moving out of alignment. The cost for 1 foot of 5" nominal PVC pipe is $9.71.

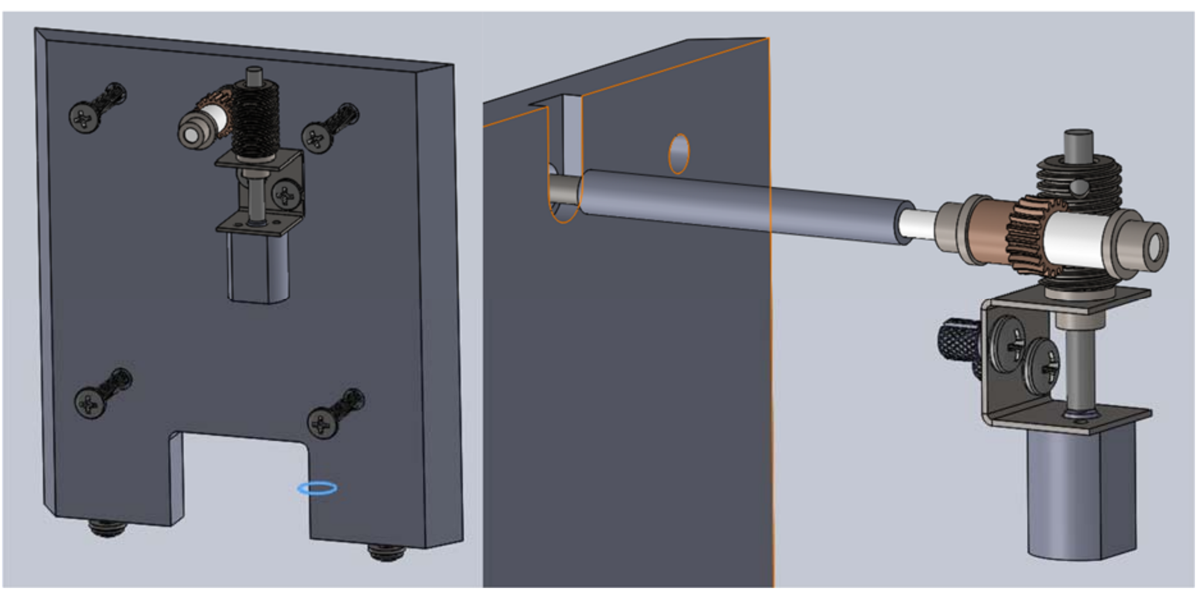

Figure 45 – The motor assembly that dives the spool in the housing. On the left we see the assembly mounted to the internal cylinder wall. On the right we see how the assembly connects to the spool.

The cylinder motor assembly is pictured above. This is the same $3 motor used in both the bath and the auxiliary roller. This assembly also uses the same worm, gear, and motor coupler combination, with a 20:1 reduction. The only two parts that differ from the other motor assembly in the bath are the white shaft, which the gear is mounted on, and the sheet metal part. The mounting wall is also a unique component which the entire assembly mounts to. This can be seen in the right picture of figure 45. The mounting walls in the cylinder are both made out of 3/8ths PVC sheet in order to match the bath. The 3/8ths thickness allows for the insertion of brass threaded inserts into the wall, which provides stronger threads to fix the mounting walls to the cylinder tube. Some additional bonuses about the walls is that PVC is inexpensive and easy to machine.

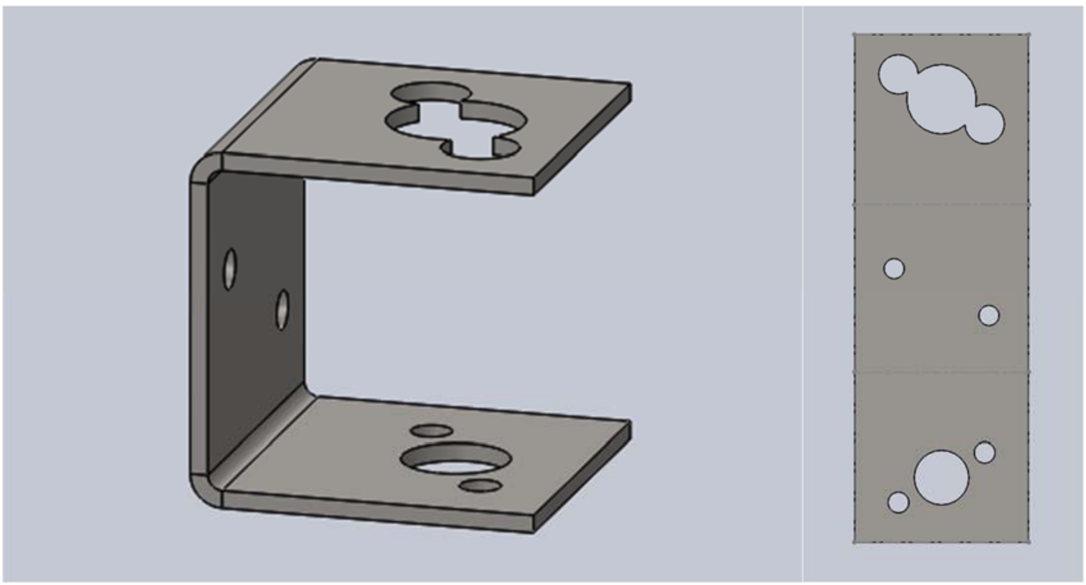

Figure 46 – Folded and flat pattern configurations of the cylinder motor mount sheet metal part

This sheet metal part differs from the one seen previously in this report in a couple of ways. First, it only contains two bends, which means it can be manufactured using the Finger Break in the Hangar machine shop. In order to make this part, the 304 sheet steel will be waterjet in the IT Department machine shop. Then the flat pattern parts can be taken to the hangar machine shop to be bent to the correct angle. The intersecting hole pattern seen on the top of the part provides access to the motor mounting holes with a screwdriver. Although this is currently the only sheet metal bracket used inside the cylinder, there is a possibility of using more brackets in order to align the gear shaft without having to drill into the side of the cylinder.

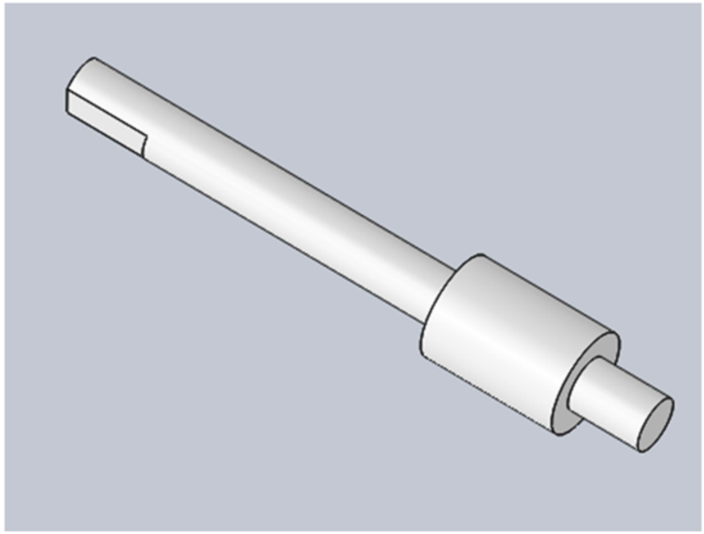

Figure 47 – The shaft that holds the gear in the worm gear assembly

This is the other unique part within the motor assembly. The shaft will be turned down on a lathe from a piece of 1/2 –inch diameter polypropylene rod. The large diameter on the shaft locates the gear within the cylinder assembly. The flat on the end is inserted into a D-shaped hole in the spool in order to drive the spool motion. Since the RPM we expect to see this shaft run at is approximately 4, we aren't concerned with fatigue or bending.

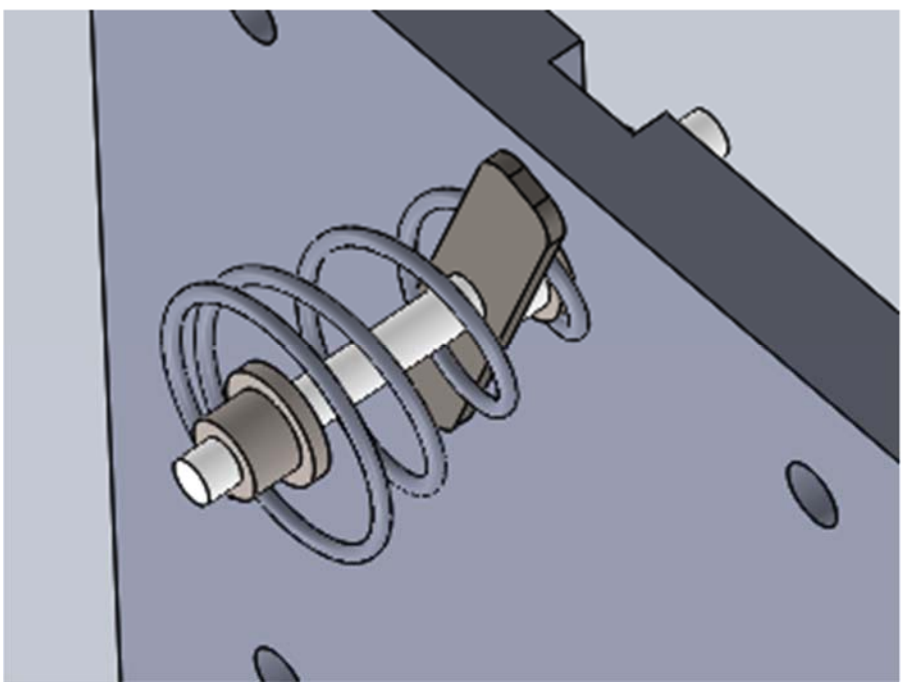

Figure 48 – The spring-lever assembly to provide quick, easy changing of spools without having to dismantle the entire assembly.

In the assembly seen in the figure above, the spring is compressed from a 0.625" length a to .1" length. By sliding the lever away from the sensor wall, the spring shaft is removed from the spool. Then the spool can be taken out of the cylinder assembly to be changed.

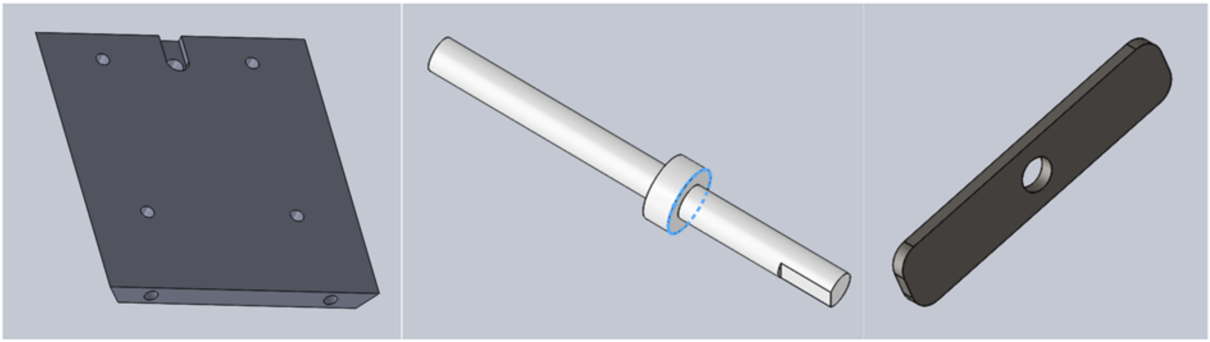
Figure 49 – The individual components that must be manufactured for the spring-loaded, spool replacement process.

The spring mounting wall pictured on the right is the same 3/8ths PVC sheet as the majority of the other components in our senior project design. Manufacturing it involves waterjet cutting the square shape and locating the holes via waterjet. Then the part needs to go to a manual mill in order to drill the two holes seen in the base as well as to cut the 5/16 slot for spool alignment. The shaft seen in the middle would be a lathe part machined out of the same ½-in polypropylene as many of the other lathe components. We would also have to spend a very small amount of time sanding the flat so that the end has a D-shaped shaft. Finally, the spring lever is a waterjet part to be made from a sheet of 0.063" 6061 T6 Aluminum. The hole in the spring lever is sized to be a slight interference fit with the spring shaft.

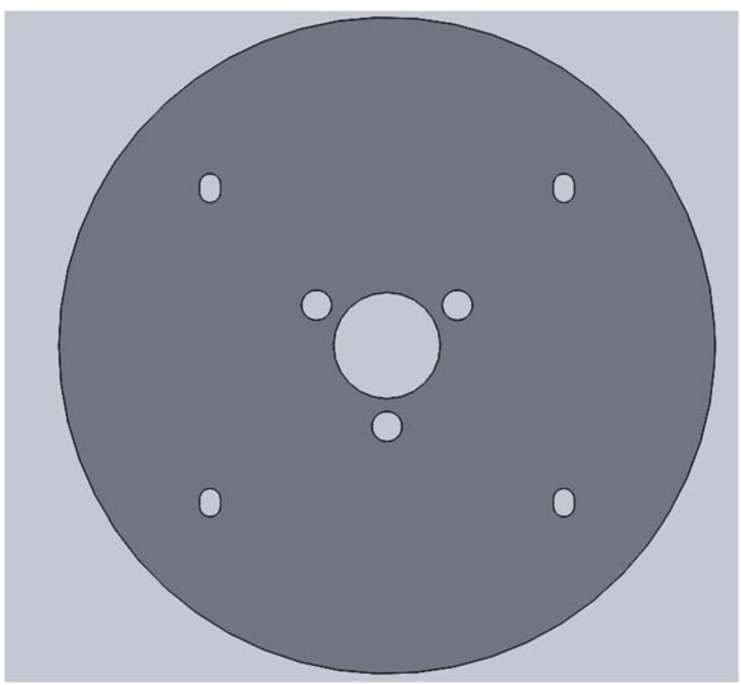
Figure 50 – The cylinder backing plate

The same sheet of 0.063” aluminum sheet used to make the spring lever will be used to make this part. This is a waterjet part that requires no post machining after it has been cut. The four holes around the perimeter are actually 1/16-inch slots to allow more room for error when aligning the backing plate and the mounting walls. The circular pattern located in the center of the plate is where we fit the slip ring.

Figure 51 – The slip ring

This is the electrical component used to power the internal motor in the electronic differential. It has an operating speed of 250 RPM so we intend to run it at that speed. There are 6 rings within this ring, however we only need two to power the motor. This slip ring is the least expensive we were able to find at $14.95. It can handle up to 2 amps at 240VAC/VDC.

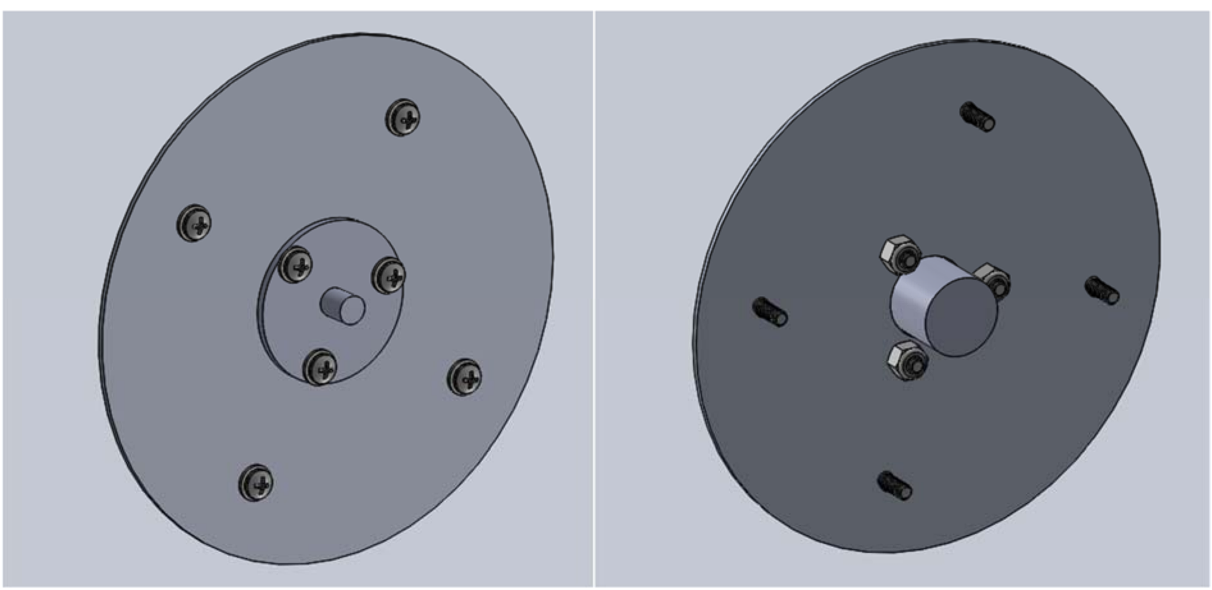
Figure 52 – The cylinder backing plate with the slip ring attached

The assembly above displays how the slip ring is attached to the cylinder backing plate. The holes in the center of the backing plate have been sized to be a clearance fit for the screws that mount the slip ring to the cylinder. Washers will be used to distribute the load of the screws into a larger area, and nylon insert locknuts clamp the slip ring into place.

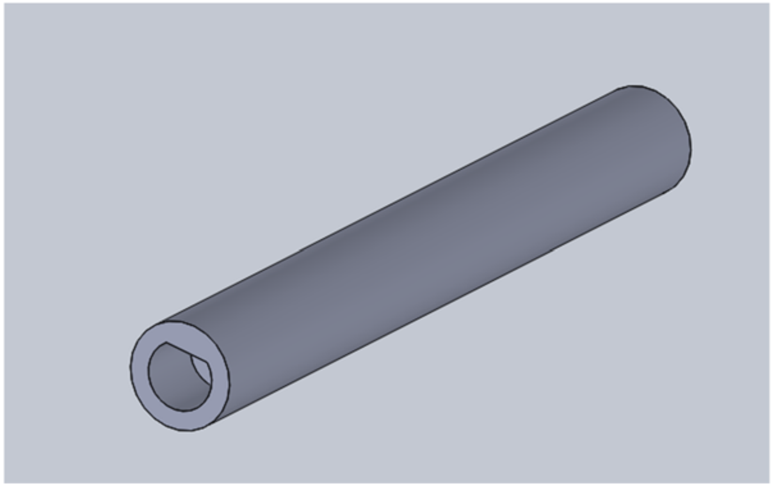

Figure 53 – The spool

The spool is 0.250 inches in dimeter and about 2 inches long. It is the only 3D printed part within our entire design. The D-Shaped holes in both ends transmit power to and from the spool and can easily be produced via 3D printing. The resources of ASME, the Innovation Sandbox, and the Machine shops all have 3D printing services. The material each of these sources uses is ABS plastic.

One concern we had with the spool was the effect of the changing diameter as the fiber is wound. Since we had such a big issue with matching spool sizes and gear ratios, we wanted to make sure that our twist ratio wouldn't be affected by the small spool diameter change that occurs. Using the same equation listed at the beginning of this section, we calculated what the spool diameter would be with a 20° and 30° twist angle. It was determined that a 20° twist angle requires 58 twists per inch and corresponds to a spool diameter of 0.324 inches. A 30° twist angle takes 92 twists per inch and would need a spool diameter of .204. Since we have a spool with diameter 0.250 inches, this means that we can have a diameter change of approximately 50 thousandths of an inch. Since our fiber diameter is roughly 0.002 inches, this means that if we wrap the fiber perfectly, we can get 250 winds in half an inch of spool. This is nearly 200 inches (16.4 ft.) of fiber for 1 layer of fiber around only 0.5 inches of spool. Since we can get approximately 18 windings around our spool before our twist angle is no longer in tolerance, that means that we would have to spool nearly 300 feet of fiber before the twist angle goes out of tolerance. Now, the fiber being wound perfectly isn't a reasonable assumption, however even if we could only get 30 feet of fiber onto one spool, we would have met our design criteria. For this reason, it was determined that the possible spool diameter change had negligible effects on our fiber twist angle.

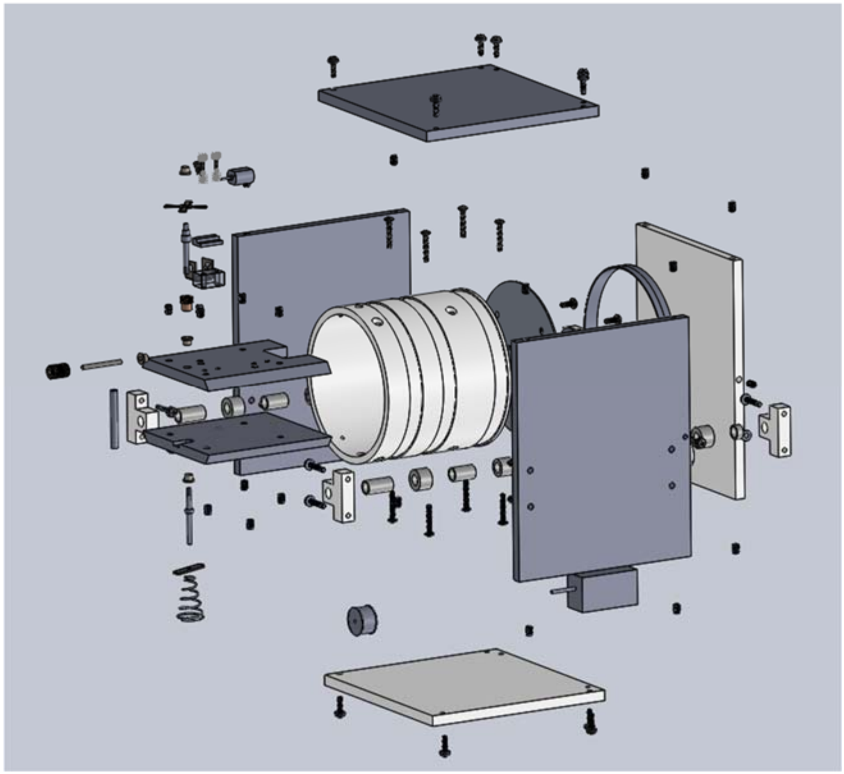

Figure 54 – Exploded View of the electronic differential

A major part of the component design for the electronic differential is the use of fasteners. Of the over 100 components used to make the above assembly, at least two thirds are fasteners. For this reason, we standardized the use of fasteners throughout our design. We used a collection of ¼, ½, ¾, and 1 inch #8-32 screws, as well as #8-32 brass threaded inserts and #8 washers. The only fasteners used in the above assembly that are not also used somewhere else in our entire design are the #8-32 nylon insert locknuts.

When designing the entire system, we also had to consider component failure. Large components like the cylinder and the mounting walls failing would have a much larger impact on the overall assembly than the failure of a small polypropylene shaft. This is also one of the considerations that went into the material choice of the minor components. We wanted any component failure to be quickly replaceable. The loads we see in our design tend to stay incredibly low so the risk of component failure due to fatigue or bending is very small, but we would rather have to replace a 2-inch roller than a 12-inch wall.

Cylinder Housing

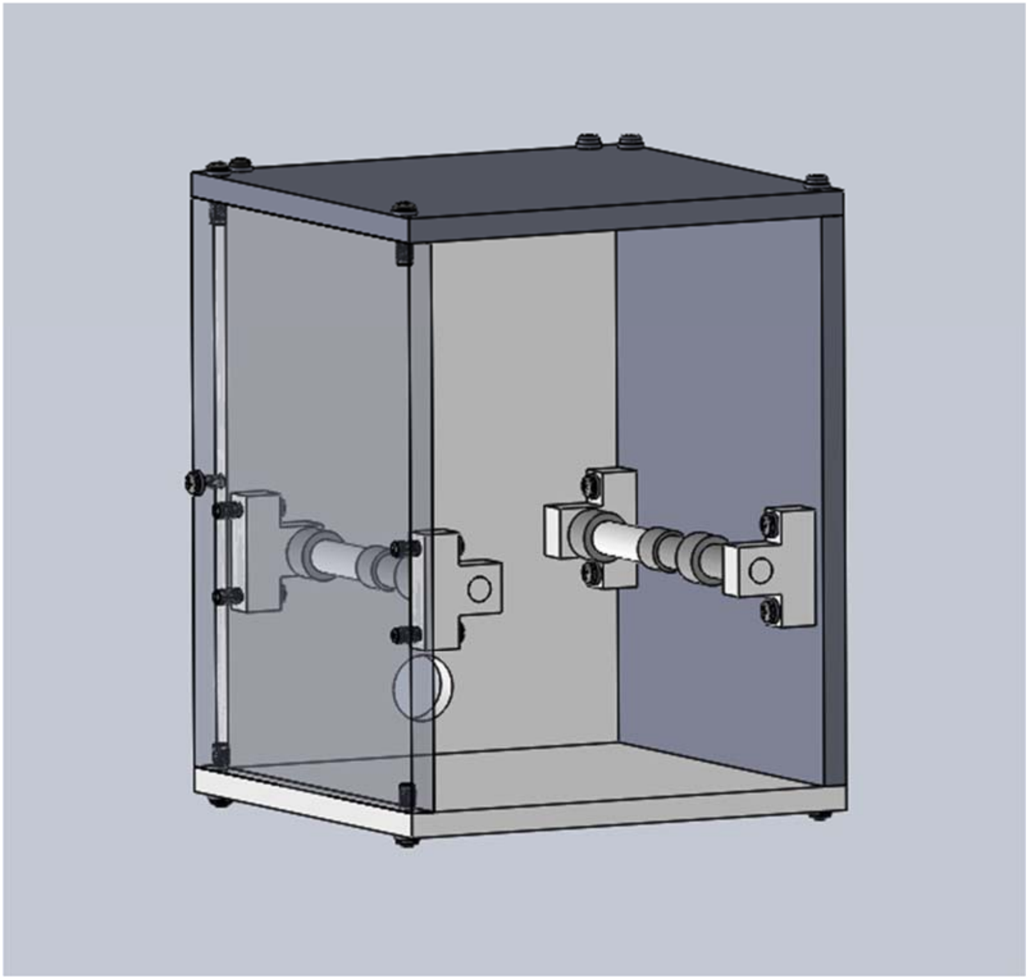

Figure 55 – Cylinder Housing

The main focus of our design for the housing was to figure out a way to spin the cylinder while still being able to transmit power to the spool motor within the cylinder concurrently. Our solution for the issue was the implementation of a slip ring centered on the back end of the rotating cylinder. This slip ring would allow the cylinder to rotate freely within the housing as well as provide power to the spool motor. We had initially thought to attach the back of the cylinder to a shaft connected to a motor which would provide the torque necessary to spin the cylinder. Yet, with the addition of the slip ring centered on the back of the cylinder and the fiber entering through the front of the cylinder, we had no room on either side to attach a motor shaft. In order to resolve this new challenge, we decided to mimic the configuration of a typical gas powered clothes dryer as seen in Fig. Similar to how a drum rests on sets of rollers in a dryer, we decided to nest the cylinder on a pair of step rods covered in sleeve bearings/rollers made with PTFE Teflon. The rotation of the cylinder is induced by a drive belt attached to a motor located directly beneath the cylinder. The force of friction between the rollers and the cylinder were also aimed to kept at a minimum, which is why we made the rollers from PTFE Teflon, which has a coefficient of friction of μ=.04.

On order to address safety concerns of the cylinder being a potential hazard as a moving part, we made it a priority to secure the movement of the cylinder within the housing as much as

possible, since unsecured moving parts can prove to be quite dangerous. Movement of the cylinder along the longitudinal direction was a consideration we chose to address with the use of spaced out rollers along the step rod with varying diameters. In order to constrain movement of the cylinder along its own axis, we designed 1/16" thick groves, .5" wide, around the diameter of the cylinder in which ¾" rollers would slot into, thus locking the cylinder's motion in the axial direction. The tension of the drive belt would also act as a securing force, keeping the cylinder in close contact with the rollers. Since the loads that the cylinder exerts on the housing are relatively low, we chose PVC along with various other plastics as the materials for the housing since they are cheap and easy to manufacture.

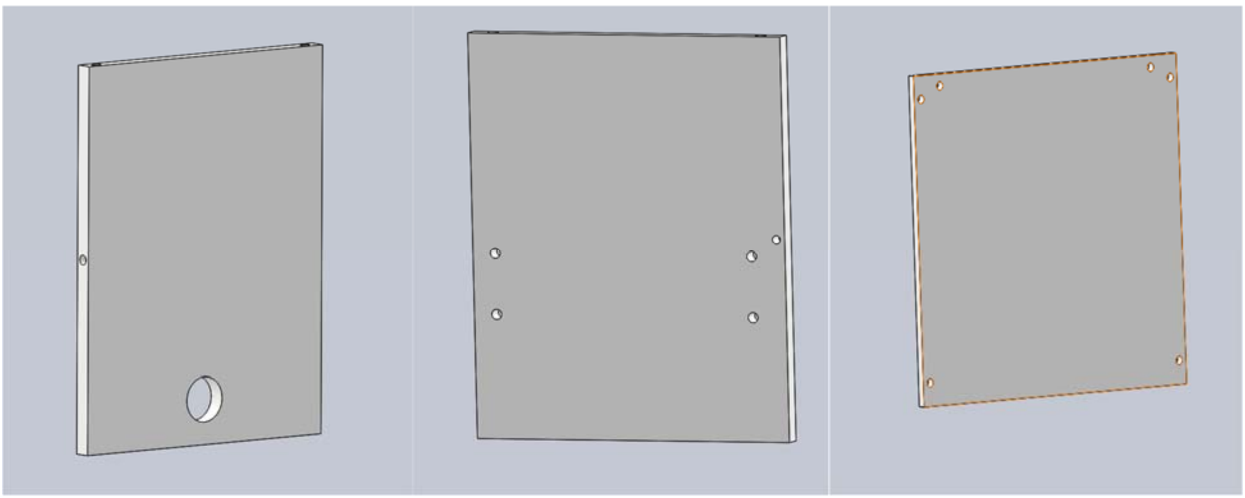

Figure 56 – Housing Frame

The frame of the housing is comprised of 3 different parts in order to keep manufacturing and assembly simple. The cover plate acts as both the top and bottom of the housing and the side plate acts as both the right and left sides of the housing. There is only one rear plate in the housing and it has a small hole centered near the bottom of it in order to allow passage for wires and circuitry. Every plate in the housing will be made from 3/8" thick Type 1 PVC which will be ordered from McMaster-Carr. Waterjet cutting from the IT Dept. will be used for the manufacturing of each plate. The rear and side plates may require additional work on a mill as well.

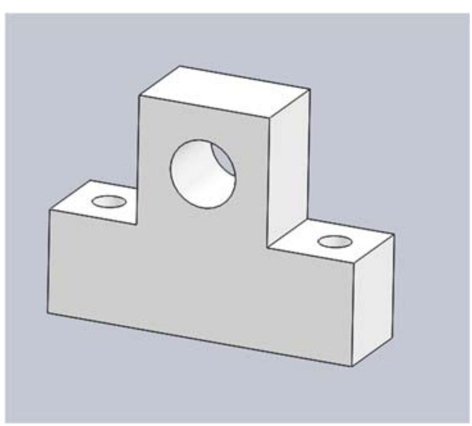

Figure 57 – Support

The 4 supports attached to the sides of the housing secure the step rods in place and are made from ½” thick Type 1 PVC ordered from McMaster-Carr. This part will be manufactured with waterjet cutting via the IT Dept., and it may require additional work on a mill as well.

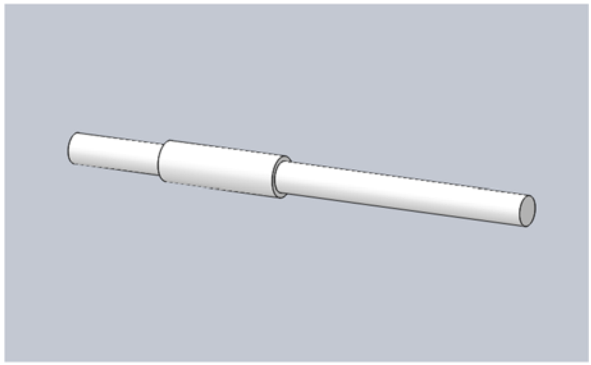

Figure 58 – Step Rod

The 2 step rods will be made from a 1/2” diameter polypropylene rod, McMaster-Carr. In order to obtain he smaller diameter of rod, a lathe will be required, which can be found at Mustang 60 or the Hangar.

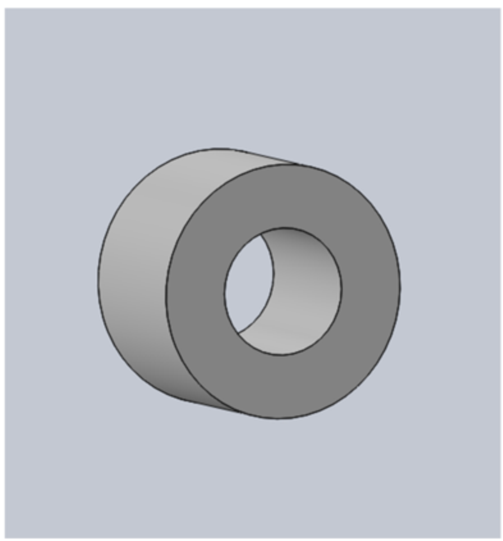

Figure 59 – Cylinder Roller

The 4 cylinder rollers (2 per step rod), will be made of PTFE Teflon, ordered from McMaster-Carr, and are meant to be the main points of contact between the housing and the rotating cylinder. This part has an ID of 3/8” and an OD of ¾”. This part will be machined with the use of a lathe in the machine shop.

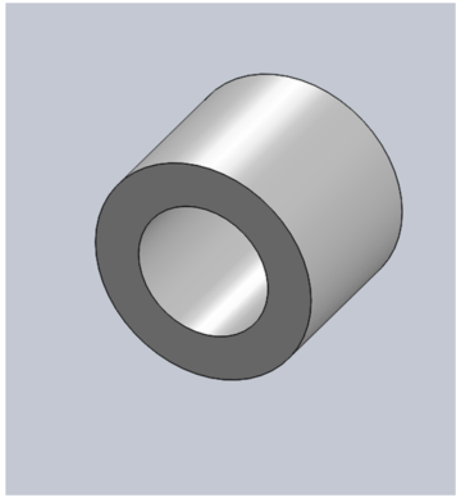

Figure 60 – Belt Roller

Since the cylinder is in direct contact with the rods along its entire length, it made it a bit difficult to run a belt around the cylinder since the space and friction between the cylinder and rods caused interference. In order to solve the problem, we located 2 belt rollers, made of PTFE Teflon, appropriately spaced to be directly in contact with the belt, reducing the friction between the belt and rods. This part has an ID of 3/8" and an OD of 5/8". This part will be machined with a lathe.

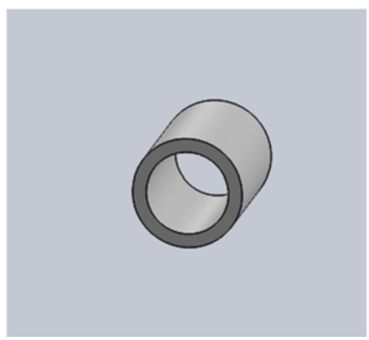

Figure 61 – Spacer#1-3

In order to accurately position the rollers along the step rod, we will be using three spacers of varying lengths. The ID of these parts is 3/8" and the OD is ½". These spacers will be made of PTFE Teflon and will be machined using a lathe.

Overall, the subassembly of the cylinder housing weighs 5.21 pounds and consists of 91 total components. Of those 91 components 66 are fasteners that will be ordered from McMaster and 25 are components that we will manufacture here at Cal Poly. The cost of raw material for the construction of the cylinder housing will be approximately $60.

Electronics

Initially, an analog voltage, closed-loop control system for the motor was going to be designed, but it was highly complex for the simple task it was doing, therefore a digital microcontroller approach was taken that vastly simplifies the extent of the electrical design.

The motors are controlled via PWM implemented by an Arduino Nano microcontroller board. Each control board, as shown below in figure [62], is able to control up to two motors. This means that for every sub assembly (bath, auxiliary roller, cylinder and housing), one board will be needed. This also helps keep the system modular so that different components can be arranged in almost any order.

The Arduino Nano microcontroller board is a small, breadboard compatible version of the popular open-source Arduino microcontroller. In this application, it will be reading an analog input voltage between 0V and 5V, then converting that to an output PWM signal to control the motor. PWM controls the motor by varying the duty cycle of a square wave signal. E.g., a 25% PWM signal produces a square wave that has is full power for one quarter of the cycle, then off for the other three quarters of the cycle. The result is that the motor runs at the average of 25% speed. The Arduino analog input has 10 bits of resolution, meaning that it can detect 1024 discrete voltage levels between 0V and 5V. Sample for code for the Arduinos is provided in Appendix M.

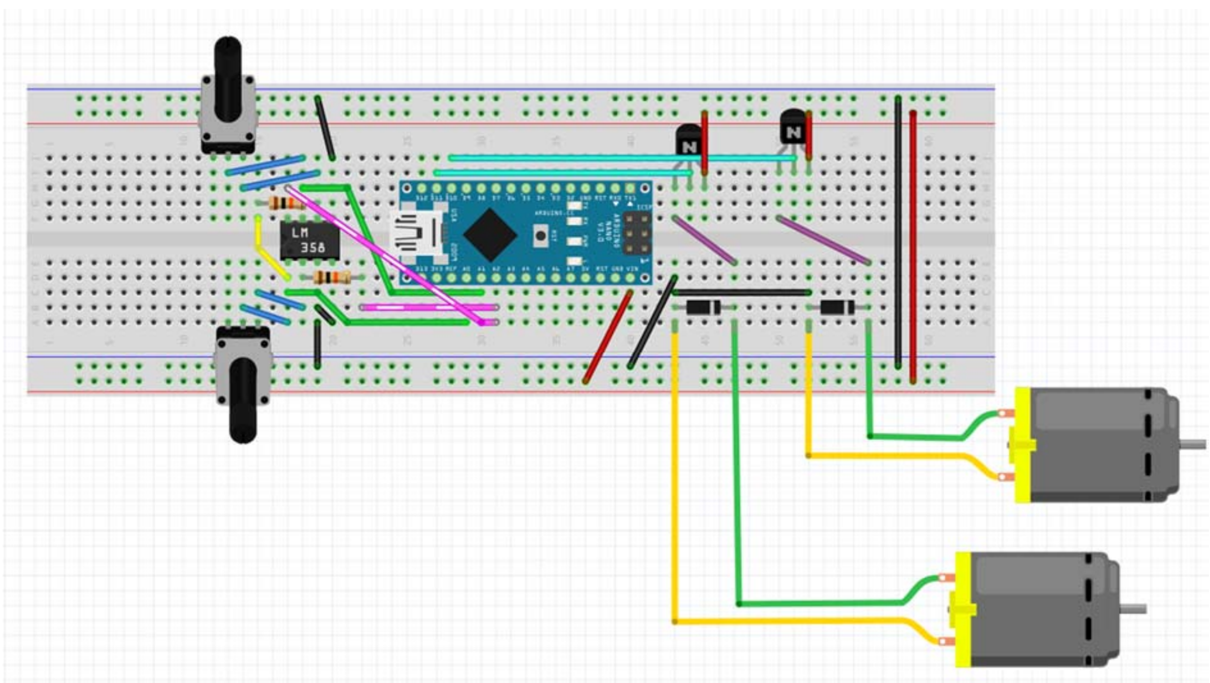

Figure 62 – Motor control board

The input signals will be generated by a linear potentiometer connected to an inverting op-amp circuit. By adjusting the ratio of the two resistors in the op-amp circuit, the input to the Arduino can be attenuated or amplified to get the desired motor speeds. By cascading the

voltages from one op-amp to the other, sequential motor speeds can be adjusted at once instead of having to adjust each motor individually. For this, a Texas Instruments RC4558 IC was used because it has two op-amp circuits per chip, meaning just one chip is needed per board.

The motor activation is handled by a NPN bipolar junction transistor (BJT) acting as a switch. When the signal from the Arduino to the BJT is high, the BJT acts as a closed switch, powering the motor. Conversely, when the Arduino signal is low, the BJT acts as an open switch, and the motor is off. Because PWM operates at a high enough frequency (500 Hz) that the resulting macroscopic action of the motor is a linear speed relationship with duty cycle, all without the need for motor modeling or closed-loop control.

The power source for all this will be a benchtop power supply unit, producing up to 30V DC at 10A off of wall outlet power. More compact, focused DC power supplies were not found that offered comparable performance for a reasonable price. Additionally, small electrical components are required, such as resistors, rectifying diodes, breadboards, and jumper wires.

Manufacturing Plan

Our manufacturing plan is centered around resources at Cal Poly. We have a total of 39 unique manufactured components between the bath, auxiliary roller, and electronic differential. These components can all be manufactured using a variety of processes available to students for free.

First and foremost, we plan to use the Industrial Technology Department's waterjet cutter to manufacture the bath walls, gearbox walls, cylinder internal walls, cylinder housing, motor mounts, cylinder backing plate, and spring lever. This means that about half of the components we need to make will be waterjet. According to the shop technicians in the IT Department, the PVC and aluminum sheets we plan to make our parts out of are very typical and almost trivial for a waterjet cutter. Not only will they be easy to convert to the necessary .DXF files needed to program the waterjet, they will also need far less time on the machine due to their soft material. In addition, waterjet cutting will also give us a much higher accuracy for the position of our holes. The computer has a tolerance within 0.003 inches, which is about the same as we would expect to be able to machine on a mill, the upside to water jetting, however, is that is cuts our manufacturing time significantly. All holes in a given part are cut relative to other features on that part, which means the waterjet is both fast and accurate. Even the holes that are too small to be cut out via waterjet can still be located on the part for easier post machining.

Our next step in the manufacturing process is to post machine some of the components on a manual mill. Thirty-three components go through the waterjet, and twenty of those parts require additional machining. This is due to the fact that the waterjet only cuts through-holes. The majority of this milling is in order to drill non-through-holes for the threaded inserts, however a few select parts like the spring wall have slots or other features that need to be cut as well.

There is a total of 26 lathe parts in our design. These parts primarily consist of the drive shafts, motor couplers, and bath rollers. They will all be turned down to size on a lathe from a piece of 1/2-inch diameter polypropylene rod. There are also some nylon bushings that need to be machined for the cylinder housing.

In addition to the lathes and mills which we can access through the Cal poly machine shops, we also have access to a laser cutter and 3D printer. The laser cutter would be used to cut out our gasket material so that it fits to the bath correctly. The 3D printer would be used in order to print the spool in the differential since it is driven through a D-shaped hole.

Shown in the table below are the manufacturing processes that will be performed to fabricate each component made by our team. The waterjet is a resource available in the IT Department machine shop, the mills, lathes, and lasers are located in the Cal Poly machine shops. 3D printers can be accessed through the Cal Poly machine shops, the Innovation Sandbox, or through Cal Poly ASME.

Table 2: Component Manufacturing Plan

Part Number	Description	Quantity	Process 1	Process 2
1201	Bath Bottom	1	Waterjet	Mill
1202	Bath End	2	Waterjet	Mill
1203	Bath Side	2	Waterjet	x
1204	Gasket	1	Laser	x
1205	Drive Roller	2	Lathe	x
1207	Roller	2	Lathe	x
1301	Back Plate	2	Waterjet	x
1302	Bottom Plate	2	Waterjet	Mill
1303	Top Plate	2	Waterjet	Mill
1304	Front Plate	2	Waterjet	x
1305	Worm Shaft	3	Lathe	x
1306	Drive Shaft	2	Lathe	x
1402	Motor Mount	2	Waterjet	Bend
2101	Gear Box Mount	1	Waterjet	x
2102	Counter Support	1	Waterjet	Mill
3130	Motor Wall	1	Waterjet	Mill
3131	Cylinder Motor Mount	1	Waterjet	Bend
3132	Gear shaft	1	Lathe	x
3134	Spool	1	3D Print	x
3135	Spring Lever	1	Waterjet	x
3136	Cylinder Backing Plate	1	Waterjet	x
3138	Spring Wall	1	Waterjet	Mill
3139	Spring Shaft	1	Lathe	x
3201	Cover Plate	2	Waterjet	x
3202	Side Plate	2	Waterjet	Mill
3203	Rear Plate	1	Waterjet	Mill
3204	Rod Support	6	Waterjet	Mill

3205	Step Rod	2	Lathe	x
3206	Cylinder Roller	4	Lathe	x
3207	Spacer#1	2	Lathe	x
3208	Spacer#2	2	Lathe	x
3209	Spacer#3	2	Lathe	x
3210	Belt Roller	2	Lathe	x
3102	Cylinder	1	Lathe	Mill

Table 3: Projected manufacturing schedule.

Deadlines	Tasks
14-Feb	Order Materials
21-Feb	Create .DXF files for Waterjet
2-Mar	Finish Water Jetting
23-Mar	Finish Housings
6-Apr	Finish All Lathe Parts
27-Apr	Finish Manufacturing
30-Apr	Assemble

It is expected to take around two weeks for all of the materials we order to reach us. We plan to use the time waiting for parts to arrive to create our DXF files for water jetting. Since most of our early components rely on the IT Department's waterjet, and since the waterjet will most likely be the least available resource for our team, we would like to get started on the waterjet parts as soon as possible. Once the parts have been waterjet we can easily access the Cal Poly machine shops to begin post-machining components since one of our group members can open them for our team to use after hours. This will allow us to have access to the mills, lathes, and laser without worrying about the accessibility of such machines during regular hours.

Design Verification Plan

In order to verify the effectiveness of our final design, we have developed a series of tests that will demonstrate the design's ability to meet the pre-established customer requirements. This testing will be conducted between the period of April 06- June 01. The specifications that the design will be tested on have been narrowed down to 10 and can be seen outlined in the DVP table provided Appendix G. The progression of our testing timeline can also be seen in our Gantt Chart in Appendix F

Since the objective of the design is to effectively draw and twist GF, we have framed various tests around the characteristics of the final output fiber and its comparison to the desired output. The desired output characteristics of the graphene fiber, as outlined by Dr. Zhang, are to be an angle of twist along the fiber's axis of 25±5°, a resulting fiber diameter of 50µm±%5, a fiber tensile strength of 200±50Mpa, and a throughput of 30 ml/hr. The angle of twist and fiber diameter will be measured with the use of a SEM, Fig.A, courtesy of the Cal Poly MATE

Department. Ten different GF samples will be observed under the SEM to evaluate both angle and diameter characteristics. In order to ensure availability of the SEM during our testing phase, we plan on scheduling an appointment in advance with the MATE Dept., in order to set apart a time slot of about 3 hours for us to adequately use the SEM to conduct all of our measurements. We also plan on having a MATE grad. student or professor present during the testing in order to ensure that we follow the correct procedures when operating the SEM and obtain as accurate of measurements as possible.

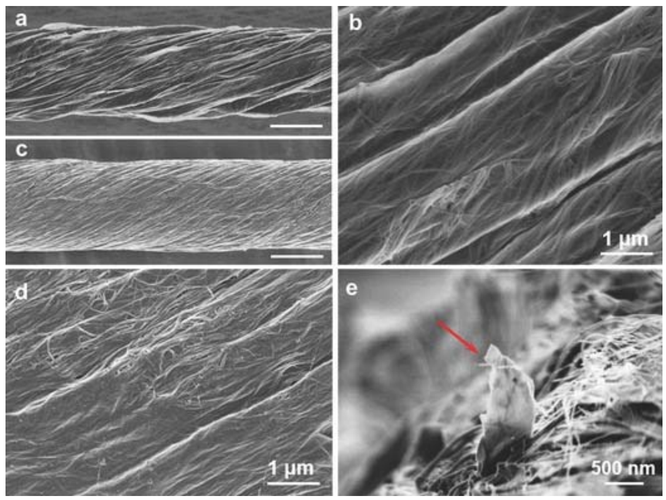

Figure 63 – SEM Images of GO/CNT composite nanofibers

The tensile strength of the fiber will be measured with the use of an Instron device. A quantity of 10 samples of GF will be tested on the Instron in order to properly evaluate the average output in fiber strength. In order to gain access to an Instron device we plan on contacting either the Chem or MATE Dept. in order to set apart a time for us to use the Instron for a period of 3 hours on order for us to properly obtain our measurements. For this test the GF is attached to a paper template in order to properly secure the fiber on the Instron and is subsequently applied with a tensile load until failure as shown in FIG.B. We plan on having a MATE/CHEM grad. student or professor present during this testing in order to ensure that the correct procedures are followed and accurate measurements obtained.

The throughput of the process will be measured by observing the final length of the spooled fiber over the period of one hour, this test will be carried out with the use of a meter stick and simple stop watch. This test on throughput will be conducted 3 times and should span the length of 3 hours.

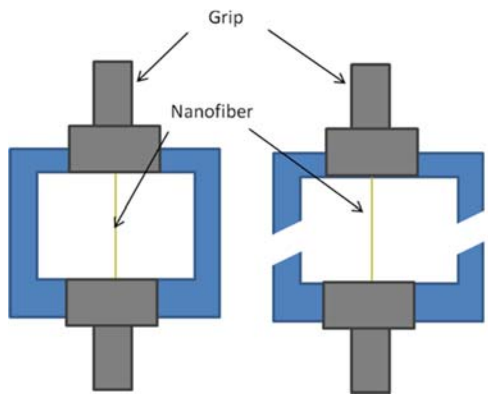

Figure 64 – Instron device testing Nanofiber

Aside from testing the output GF characteristics, we will also be conducting tests on the characteristics of the final assembly as well, including set up time and lab room constraint requirements. Three set up trials with a stop watch will be conducted with the final assembly to see if the average set up time falls within the desired 20 minutes. The trials on the set up time should span an approximate time of about an hour. In order to test the lab room constraints, we will simply measure the resulting dimensions and of the final assembly and its overall weight. This test will only be conducted once to see if the assembly falls below 500lbs in weight and below 10 ft^2 in volume.

We will also be conducting various component tests over the course of the manufacturing and assembly process. These include the testing of the bath rollers for minimal friction force exerted on the fiber, below 0.4 N, to prevent the breaking of the fiber. Gear alignment, shaft rotations, and spool sizes will also be checked in order to ensure proper functioning within the assembly and each sub assembly. The acceptance criteria for these component tests will be either pass or fail, either the component will effectively function within the assembly or not.

The testing to be carried out will have relatively no cost. Fortunately, none of our tests require the expenditure of consumable items and all the devices and resources that are necessary to conduct testing can be found conveniently within the confines of Cal Poly.

Design Realization

The manufacturing process consisted largely of five separate phases: purchasing, waterjet cutting, secondary machining, assembly, and electronics assembly. This schedule commenced immediately following Dr. Zhang's approval of the CDR and lasted through the end of the project. Testing was heavily condensed due to manufacturing overruns. These slowdowns occurred mostly with the waterjet cutting, secondary machining, and assembly sections. Therefore, our overall manufacturing timeline extended into the latter weeks of May.

After Dr. Zhang approved our budget and bill of materials, Celine DiBernardo in the Cal Poly Chemistry Department handled the bulk of our purchasing. Our primary vendors were McMaster-Carr for hardware and raw materials, and Digi-Key for our electronics components. A few other specialty vendors were used for select pieces. A full bill of materials, budget, and list

of vendors is presented in Appendix H. Some hardware pieces that could be locally sourced were bought from a local hardware store instead of buying a large quantity from McMaster at a higher price.

The waterjet cutting process is where we ran into our first and most significant manufacturing slowdown. We planned to make use of the Cal Poly IT Department’s waterjet cutter, however due to the high demand and the length of time needed to cut our pieces and clean up afterwards, they were unable to accommodate us. It took a couple of weeks to come to this conclusion, as were often told to come back the next available day, when were again unable able to use the machine. This went on through the end of winter quarter, and coming back from spring break, after being denied again, we opted to pay to use a local machine instead. This used roughly a fifth of our overall budget, however it took us less than 72 hours from sending the first email to picking up our finished parts. Once we had the pieces waterjet cut, we were able to pick up with the rest of the manufacturing schedule.

Besides waterjet cutting, all of our machining and assembly was done on the Cal Poly campus in either the Mustang ’60 or Aero Hangar machine shops. After the waterjet cutting, all pieces had to undergo some degree of additional machining. This included drilling counterbores, holes on different planes, and drilling holes made by the waterjet to be the correct diameter. Most of this machining was done using mills to be able to locate the new holes, as shown in figure 65.

Figure 65 – (left) Gear box components being machined on a mill. (right) One of the walls of the twisting housing on a mill.

Fixtures were set up to help reduce the amount of time spent zeroing the mill and cut down on overall manufacturing time. Drilling out the existing holes was accomplished using a drill press, since the holes were already located. During this time, we also began manufacturing any parts that could be made on a lathe. We discovered that the polypropylene we planned on using for our shafts was not stiff enough to machine easily. Therefore, we switched to a stiffer material that was also chemical compatible with calcium chloride and methanol, which was 304 stainless steel. This represents one of the largest departures from our planned design. Additional 5/32 inch PVC rod was purchased to be used as shafts for the gear boxes instead of the stainless steel. The PVC cylinder was machined using a rotary chuck mounted to a mill table. We encountered difficult because as the cylinder was clamped by the chuck, it began to deform. A special plastic plug had to be cut and inserted into the cylinder to keep it round as it was machined.

As pieces were machined, we began putting together the subassemblies. We quickly began noticing issues with shaft alignment on the assembled pieces. While we had earlier believed that the waterjet's tolerances of roughly 0.002" would not be an issue, as the tolerances began to stack up in the assembly we began to have issues with shafts binding. For the baths, the rollers had to be turned down to a slightly smaller diameter in order to roll smoothly in their bearings. In the gearboxes, a slightly compliant shaft material was sufficient to allow rotation. When assembling the gear boxes, we found that the shafts had a diameter of approximately 4mm, but the worm had an inside bore diameter of 5mm. Mounting directly to the shaft created an eccentricity that bound the gear train and prevented function. To fix this, a small sleeve was fit in between the two components, fixing the misalignment. The bath gasket was laser cut from a sheet of silicon rubber. However, the design is for a gasket 20 inches long, but our ordered material was a foot square. We solved this by cutting the design in half and cutting four halves. The baths were sealed with a silicon gasket compound. Neither the split gasket or the sealing compound have sown leak issues when properly tightened. The fastening method worked

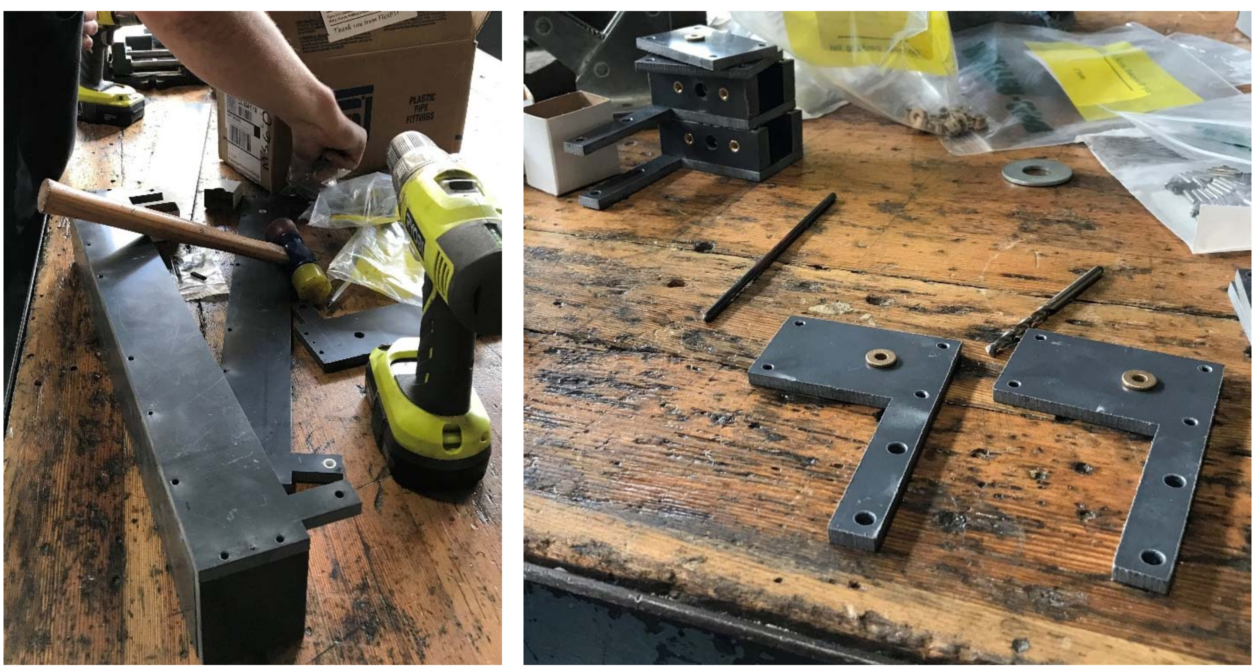

Figure 66 – (left) One of the baths being assembled on a workbench. (right) Gear box components being prepared for assembly.

sufficiently well, however the brass inserts were prone to pulling out of the base material when too much torque was applied. Care should be taken when assembling these fasteners to not overtighten them. Also, the process of inserting the screws into the brass inserts generated a large degree of heat. Screw heads were often hot to the touch after tightening. This task was best accomplished with an impact driver, so as to not strip the screw heads. Additionally, a rubber mallet was useful for driving alignment pins and then separating the bath halves if necessary. This process is shown in figure 66.

The electronics are largely wired per the diagram. Slight modifications were made to properly ground the potentiometers and to change how the motors were wired. Also, wires were added or removed slightly depending on how that board fit in with the rest of the system. (e.g. the board for the twisting mechanism only has one potentiometer, since the cylinder will be rotating at full speed regardless). One unfortunate ordering mix-up that occurred is that out of the four colors of wire ordered, only one was solid core, with the rest being stranded. While serviceable, the stranded wire proved very difficult to use with the breadboards and the solid core wire was used exclusively. As a result, all of the breadboard wiring is green, but this is more of an atheistic flaw than a functional issue. We did, however, encountered issues with the motor control not being as proportional or linear as was planned. The reason for this is currently unknown and a source for future improvement. A picture of the wiring in process is shown in figure 67.

Some aspects of our design did not get manufactured fully due to lack of manufacturing time. Instead of sheet metal brackets for attaching the motors, they had to be attached using adhesive. Additionally, instead of a flexible coupling for the motors and gear shafts, they have a rigid coupling with the motor shaft interfacing directly with the shaft via an interference fit. If additional work is done on this prototype, the motor mounts should be manufactured to their intended design. Similarly, the spools in the auxiliary roller and the inside of the twisting cylinder do not have the as-designed quick-release mechanisms that make changing spools fast and efficient for a more rapid testing process. In the future, this should be corrected and made to the design. Finally, the elastic bands connecting the open and submerged rollers added too much friction on the rollers, causing the motor torque to be insufficient. If the motors are replaced with stronger ones, the bands should be restored to cut down on the load transferred through the graphene fiber. These issues would possibly have been resolved had the manufacturing schedule not been delayed by three weeks at the beginning, and given the time it is infeasible to fix them now. These should be top priorities for anyone continuing to iterate off this design.

Design Verification

With the manufacturing delays we encountered, our testing schedule was significantly cut. As a result, the only testing we were able to do was mechanical functionality testing to resolve issues that arose during manufacturing. We had to remove slight amounts of material in the gear boxes to alleviate friction due to misalignment. Leak testing of the bath assemblies showed no leaking, proving that the silicon gasket and sealant are holding as expected. The prototype also passed the test for falling under the prescribed dimensions, (under 500 lbs and under 10 ft^2), and the full assembly is capable of being place in a lab setting, on a table surface. The twisting mechanism did not pass the test of achieving the desired RPM of 250 since it was not able to turn due to complications with mounting the motor to the cylinder housing. The gear

Figure 67 – The electronics wiring in-process

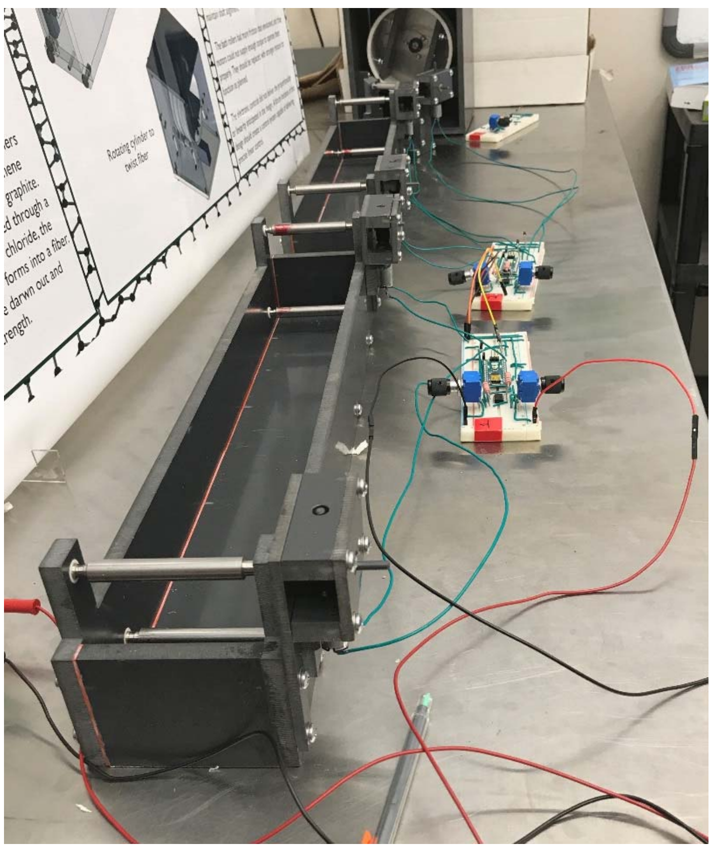

Figure 68 – System test of the drawing baths and auxiliary roller motors

boxes passed their functionality test after a bit of innovative manufacturing. All gearboxes were able to be up and running and fully functional.

Plotting the Arduino output on an oscilloscope indicated the degree of the non-linearity of the controls. Combining the scope with a voltmeter let us pinpoint the op-amp as the source of the problem. Unfortunately, with the limited time schedule there was not enough time to fix that before the conclusion of the project. As covered later, the controls system is one of the primary items that future teams should seek to improve. In all, a significant amount of our testing time was spent resolving issues that caused non-functionality.

With the system connected together, we ran a functionality test of the two baths plus the auxiliary roller in series, powered through the control boards, as shown in Figure 68. Due to misalignment, the roller speeds oscillated significantly, creating a "pulsing" effect of the rollers slowing down then speeding up. Also, the system drew roughly 2.26 amps at 5.8 volts, as can be seen in Figure 69. This power also oscillated over time. After running for 2 minutes, all five motors were very hot to the touch, indicating that the energy drawn to overcome friction was being turned into waste heat. A significant improvement in the quality of the gear boxes will be necessary to improve system efficiency and energy usage.

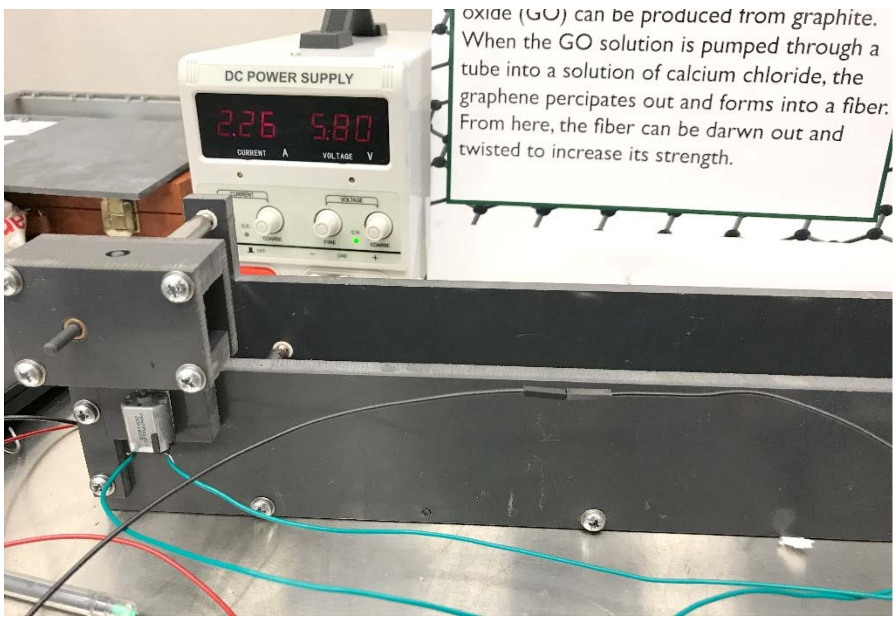

Figure 69 – Large power draw observed during our system level testing

The total amount spent on the project was $1260.10 compared to our initial estimate of $925.38. Had we not had to pay $300 for waterjet cutting, we would have only gone over our estimate by 3.75%. The test for falling within the project budget was a pass since the total available budget was $1500. Additionally, we had to order components at different dates to fix issues that arose in manufacturing, which led to increased shipping costs, particularly from McMaster. Had we ordered everything at once, we would have cut down on shipping costs.

Conclusions and Future Work

Currently, the prototype is not ready to be put into use. Due to manufacturing delays, our testing schedule became compressed and there was not enough time to fix larger component issues. As such, the finished prototype has several areas that could use further improvement in future iterations. Misalignment due to manufacturing tolerances and theoretical divergence in our electronics led to loss of expected function. For all of these issues, there are specific remedies that can resolve the issues in later iterations.

The primary cause of function loss is due to friction in the powertrain mechanisms. As mentioned before, this stemmed from the waterjet process. To improve this, waterjet cutting should be used for outer profiles, however all holes should be located using more precise methods, such as a mill. Additionally, the gear box axle holes should be drilled after the boxes are assembled, to further reduce the risk of misalignment due to tolerance stack-up. Removing this misalignment would significantly reduce load on the motor and allow improved functionality.

Beyond just fixing misalignment issues, the bronze bushings created a higher amount of friction than anticipated. These should be replaced with conventional ball bearings – or thrust bearings as appropriate – to further reduce friction. This would allow more torque to be delivered to the shafts, and thus give more control over the motor speed. Using ball bearings may not be possible due to the chemical environment in the bath, however reducing the friction in the gear boxes would be a significant fix.

As mentioned before, the electronic control system did not deliver the response characteristics as planned. The Arduino Nano components functioned as anticipated, however the voltage modulation in the op-amps diverged from theoretical expectations. In order to simplify the circuitry, replacing the potentiometer with fixed resistors should reduce or eliminate the nonlinearity. A switching circuit could be devised to select between different valued resistors would allow changing voltages and speeds, without introducing non-linearity. Further in-depth analysis pertaining to specifically the controls system could allow more refined and precise speed control of the rollers, yielding better control of the resulting graphene fibers.

Supplemental to redesigning the control system, a dedicated enclosure for the electronics should be created. Currently, the electronics are mounted on breadboards that are exposed to any spills from the baths. These should be isolated and contained, as well as have a labeled control board for operator friendliness.

The motors themselves proved to be undersized for the load being placed on them in the bath. They should be replaced with motors capable of delivering higher torque. Because fixing misalignment issues may sufficiently resolve frictional issues in the baths, the motor sizing should be reevaluated after fixing the gear boxes. Should the motors still prove underpowered, replacing them would be the next prudent step. Because the motor mounting brackets were an issue, the attachment method would have to be reworked depending on the size of the new motors. With the motors appropriately sized and the controls reworked, the system would deliver the requisite performance.

Overall, the produced prototype is based upon a sound mechanical design, however the manufacturing execution led to delays and tolerance stack-ups. A future iteration implementing subtle design changes would lead to better performance and satisfaction of the project's stated goals. The majority of these changes can be implemented using existing components and equipment.

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Appendices

A. Patent # 0111449 A1
B. QFD Matrix
C. Drawing Pugh Decision Matrix
D. Twisting Pugh Decision Matrix
E. Design Safety Hazard Checklist
F. Gantt Chart
G. DVP&R Plan
H. Bill of Materials and Final Budget
I. Engineering Drawings
J. Spec Sheets for Off-The-Shelf Components
K. User Manual
L. Chemical Resistance Chart
M. Arduino Nano Sample Code

US 20150111449A1

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(12) **Patent Application Publication**

Cruz-Silva et al.

(10) **Pub. No.: US 2015/0111449 A1**

(43) **Pub. Date: Apr. 23, 2015**

(54) **METHOD FOR PREPARING GRAPHENE OXIDE FILMS AND FIBERS**

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(72) Inventors: **Rodolfo Cruz-Silva**, Nagano City (JP); **Aaron Morelos**, Nagano City (JP); **Mauricio Terrones**, State College, PA (US); **Ana Laura Elias**, State College, PA (US); **Nestor Perea-Lopez**, State College, PA (US); **Morinobu Endo**, Nagano City (JP)

(21) Appl. No.: **14/519,937**

(22) Filed: **Oct. 21, 2014**

Related U.S. Application Data

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Publication Classification

(51) **Int. Cl.**

C01B 31/04	(2006.01)
B01D 39/20	(2006.01)
C09D 5/24	(2006.01)
H01B 1/04	(2006.01)
H01B 13/00	(2006.01)

(52) **U.S. Cl.**

CPC ***C01B 31/043*** (2013.01); ***H01B 1/04*** (2013.01); ***H01B 13/0026*** (2013.01); ***C09D 5/24*** (2013.01); ***B01D 39/2055*** (2013.01)

(57) **ABSTRACT**

We report a method of preparation of highly elastic graphene oxide films, and their transformation into graphene oxide fibers and electrically conductive graphene fibers by spinning. Methods typically include: 1) oxidation of graphite to graphene oxide, 2) preparation of graphene oxide slurry with high solid contents and residues of sulfuric acid impurities. 3) preparation of large area films by bar-coating or dropcasting the graphene oxide dispersion and drying at low temperature. 4) spinning the graphene oxide film into a fiber, and 5) thermal or chemical reduction of the graphene oxide fiber into an electrically conductive graphene fiber. The resulting films and fiber have excellent mechanical properties, improved morphology as compared with current graphene oxide fibers, high electrical conductivity upon thermal reduction, and improved field emission properties.

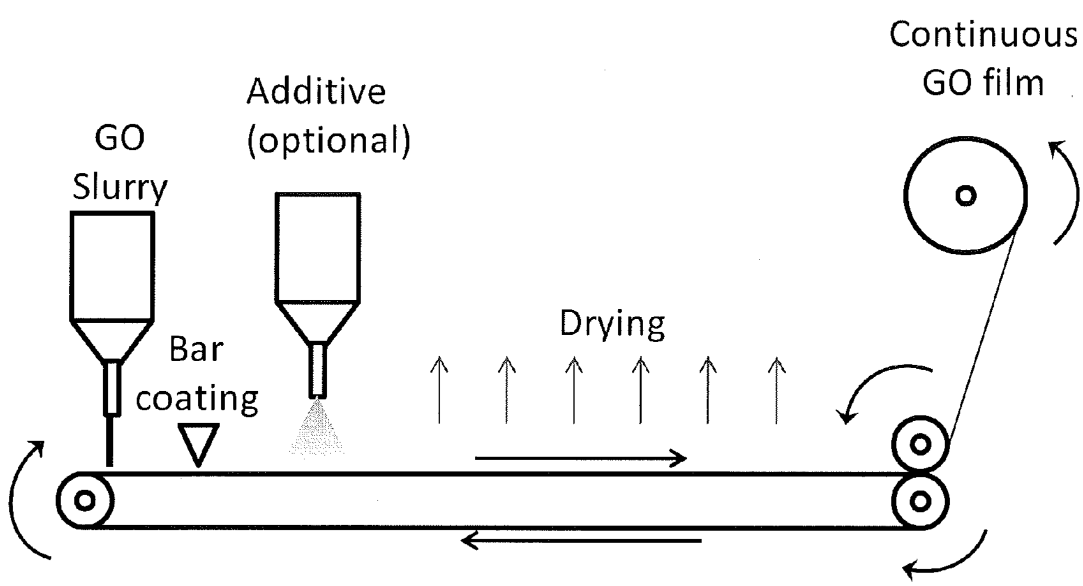


FIG. 1A FIG. 1B FIG. 1C

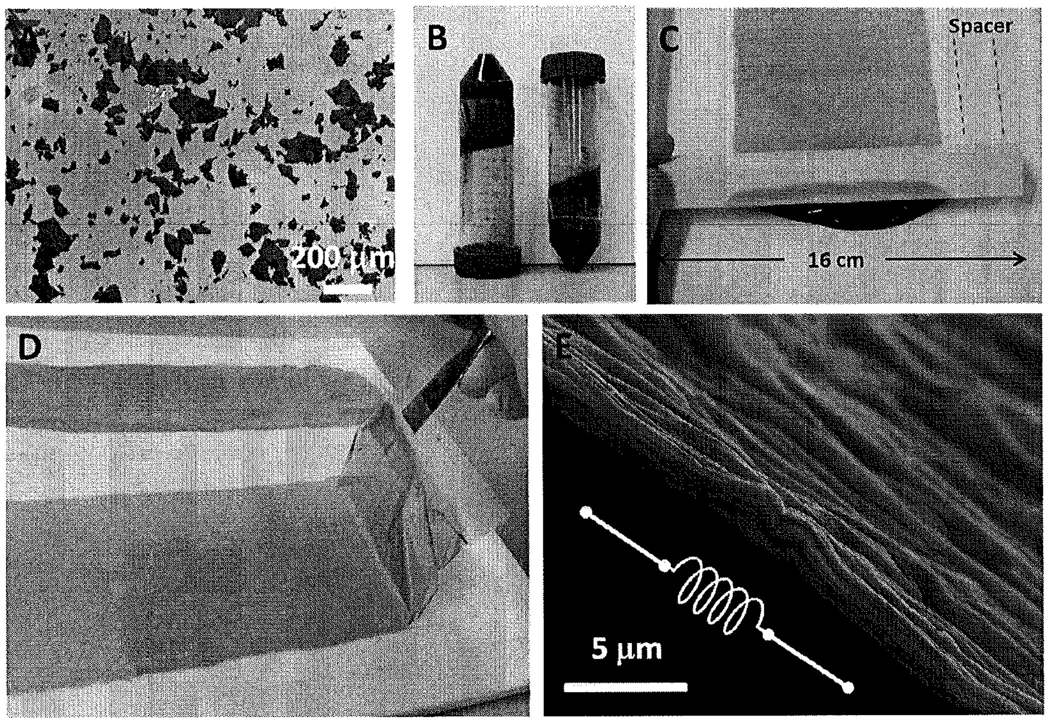


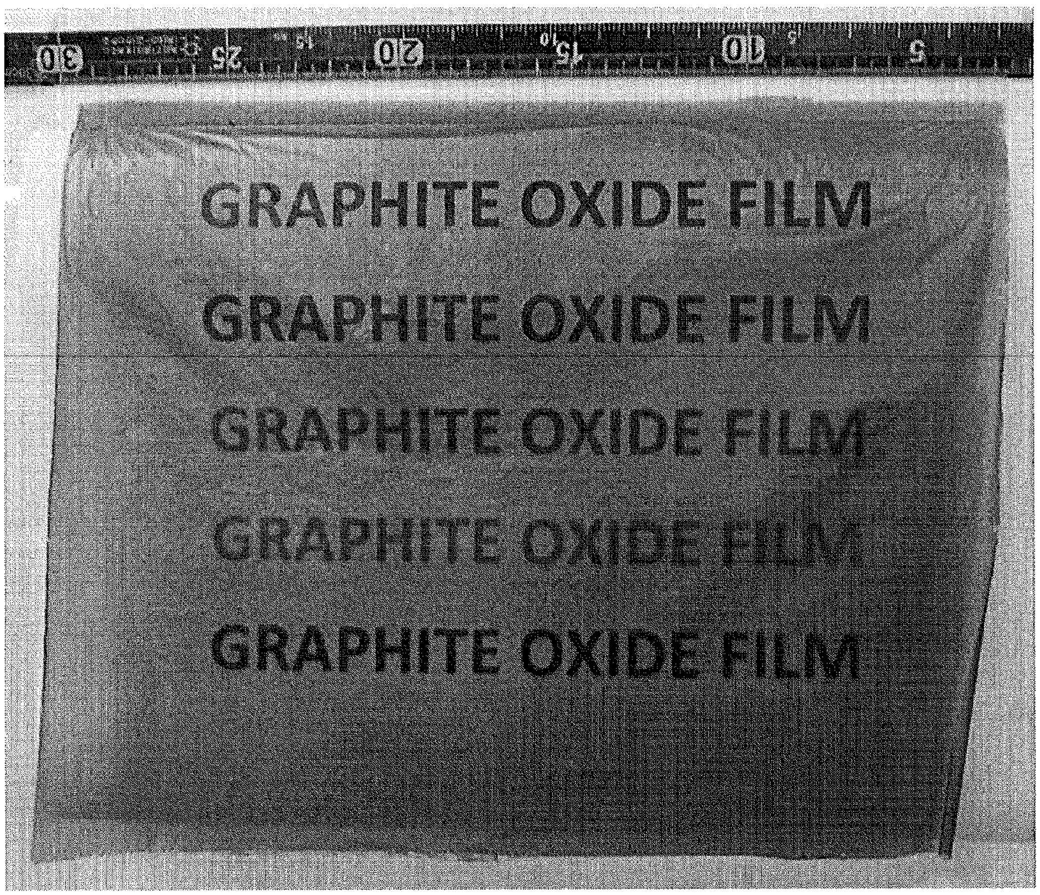
FIG. 1D FIG. 1E

The following conditions were used for SEM analysis:

FIG. 1A: Uncoated samples drop casted on silicon. Accelerating voltage: 15 kV. Working distance 9.6 mm. Scale bar 200 μm.

FIG.1E: Uncoated film. Accelerating voltage: 15 kV. Working distance 8.6 mm. Scale bar 5 μm.

FIG.2


GRAPHITE OXIDE FILM
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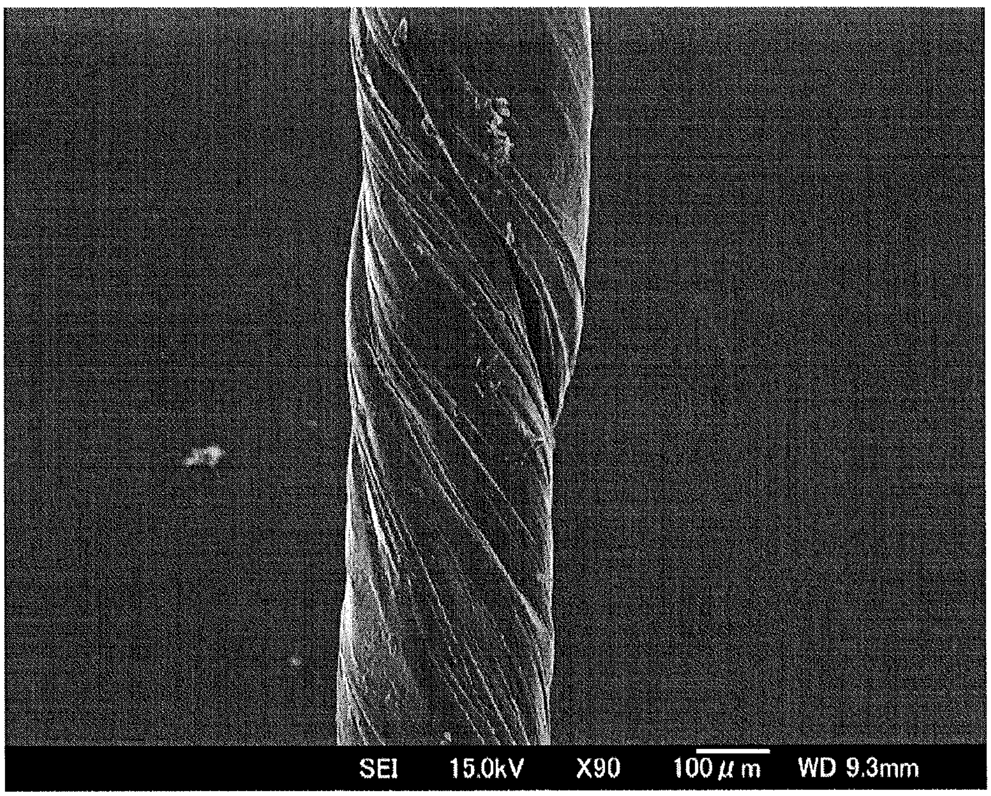
GRAPHITE OXIDE FILM

FIG. 3



The following conditions were used for SEM analysis as reflected in the attached pictures: Uncoated samples. Accelerating voltage: 15 kV. Working distance 9.3 mm. Scale bar 100 mm.

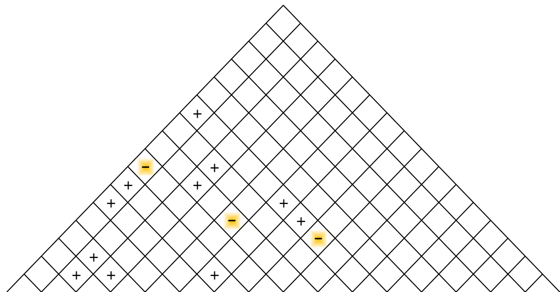
Appendix B - QFD Matrix

QFD: House of Quality
Project: Drawing and Twisting of Graphene Fibers
Revision: 01
Date: 10/18/16

Correlations	
Positive	+
Negative	−
No Correlation	

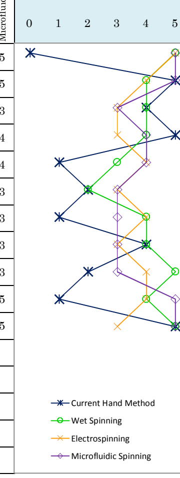
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers — NOW: Current Product Assesment - Customer Requirements

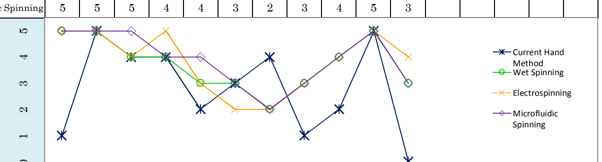
Row #	Weight Chart	Relative Weight	Dr. Zhang & Research Group	Composites Community	Chemistry Department		Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Output Fiber Length	Machine Weight	Cost	Table Area	Throughput	Fiber Tensile Strength	Twist Angle	Tensile Strength Standard Deviation	Service Time	Protective Equipment	Output Control						Current Hand Method	Wet Spinning	Electrospinning	Microfluidic Spinning	Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16					
								Direction of Improvement	▲	▼	▼	▼	▲	▲	◇	▼	▼	▼	▲										
1		10%	7	8	1		9	Continuous	●				●	○	○	○			○						0	5	5	5	1
2		7%	4	1	5		9	Weight		●	○	○													5	4	4	5	2
3		9%	2	1	8		9	Cost		▽	●	○						▽							4	4	3	3	3
4		7%	4	1	5		9	Size	○	▽		●					▽								5	4	3	4	4
5		8%	8	5	1		9	Reliability					●	○	▽		▽								1	3	4	4	5
6		12%	9	9	1		9	Drawing and Twisting					○	●	●										2	2	3	3	6
7		7%	6	4	1		9	Adjustable Output					▽	○	○				●						1	4	4	3	7
8		7%	7	4	1		9	Servicable									●	▽							4	4	3	3	8
9		9%	7	4	3		3	Durability				○													2	5	4	3	9
10		9%	7	6	1		9	Consistency	○				○	●	○	●									1	4	4	5	10
11		15%	7	5	9		9	Safety		○		▽						●							5	5	3	5	11
12		0%																											12
13		0%																											13
14		0%																											14
15		0%																											15
16		0%																											16



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	15 in	500 lbs	$1,200	10 sq ft	30 mL/hr	200 Mpa	20 degrees	50 Mpa	20 minutes setup	Goggles and gloves	Yes					
Max Relationship	9	9	9	9	9	9	9	9	9	9	9					
Technical Importance Rating	136.64	127.64	103.59	156.86	231.07	255.64	187.85	106.45	79.82	153.35	89.542					
Relative Weight	8%	8%	6%	10%	14%	16%	12%	7%	5%	9%	5%					
Weight Chart																

Current Product Assesment - Engineering Specifications

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Current Hand Method	1	5	4	4	2	3	4	1	2	5	0					
Wet Spinning	5	5	4	4	3	3	2	3	4	5	3					
Electrospinning	5	5	4	5	3	2	2	3	4	5	4					
Microfluidic Spinning	5	5	5	4	4	3	2	3	4	5	3					



Column # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Appendix C - Drawing Pugh Decision Matrix

Decision Matrix: Drawing Processes													
Criteria	Score Modifier	Two Rollers		Grinding Wheel		Conic Drawing		Fluid Crossflow		Microfluidic Drawing		Actuating Roller	
	[Out of 1]	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Performance	0.8	5	4.0	1	0.8	2	1.6	3	2.4	5	4.0	3	2.4
Continuous	0.7	5	3.5	3	2.1	3	2.1	5	3.5	4	2.8	5	3.5
Feasibility	0.6	5	3.0	4	2.4	1	0.6	3	1.8	5	3.0	3	1.8
Reliability	0.5	4	2.0	4	2.0	1	0.5	3	1.5	4	2.0	2	1.0
Servicability	0.5	5	2.5	5	2.5	4	2.0	2	1.0	4	2.0	3	1.5
Consistency	0.5	4	2.0	1	0.5	1	0.5	2	1.0	5	2.5	2	1.0
Automated	0.5	4	2.0	4	2.0	2	1.0	4	2.0	4	2.0	4	2.0
Adjustable Output	0.3	5	1.5	2	0.6	2	0.6	3	0.9	4	1.2	4	1.2
Lightweight (lbs)	0.2	4	0.8	3	0.6	3	0.6	2	0.4	5	1.0	4	0.8
Cost	0.2	4	0.8	3	0.6	2	0.4	2	0.4	3	0.6	3	0.6
Safety	0.2	4	0.8	4	0.8	4	0.8	3	0.6	5	1.0	3	0.6
Size	0.1	3	0.3	3	0.3	4	0.4	2	0.2	5	0.5	3	0.3
Durability	0.1	4	0.4	4	0.4	4	0.4	3	0.3	4	0.4	3	0.3
Weighted Totals			23.6		15.6		11.5		16		23		17

Appendix D - Twisting Pugh Decision Matrix

Decision Matrix: Twisting Processes													
Criteria	Score Modifier	Differential		Bobbin and Flyer		L-arm spool		Off-Center Hole		Double Rollers		Microfluidic Spinning	
	[Out of 1]	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Performance	0.8	5	4	4	3.2	4	3.2	2	1.6	2	1.6	3	2.4
Continuous	0.7	4	2.8	4	2.8	4	2.8	4	2.8	3	2.1	4	2.8
Feasibility	0.6	5	3	3	1.8	4	2.4	5	3	2	1.2	1	0.6
Reliability	0.5	5	2.5	2	1	4	2	3	1.5	1	0.5	2	1
Servicability	0.5	4	2	4	2	5	2.5	5	2.5	5	2.5	3	1.5
Consistency	0.5	5	2.5	4	2	4	2	4	2	3	1.5	4	2
Automated	0.5	4	2	2	1	4	2	3	1.5	2	1	5	2.5
Adjustable Output	0.3	3	0.9	5	1.5	3	0.9	5	1.5	5	1.5	1	0.3
Lightweight (lbs)	0.2	1	0.2	2	0.4	2	0.4	4	0.8	3	0.6	3	0.6
Cost	0.2	2	0.4	3	0.6	4	0.8	5	1	3	0.6	2	0.4
Safety	0.2	4	0.8	3	0.6	3	0.6	5	1	4	0.8	3	0.6
Size	0.1	2	0.2	3	0.3	3	0.3	4	0.4	2	0.2	3	0.3
Durability	0.1	5	0.5	3	0.3	4	0.4	4	0.4	2	0.2	4	0.4
Weighted Totals			21.8		17.5		20.3		20		14.3		15.4

DESIGN HAZARD CHECKLIST

Team: Graphene Twisters Advisor: Dr. Schuster

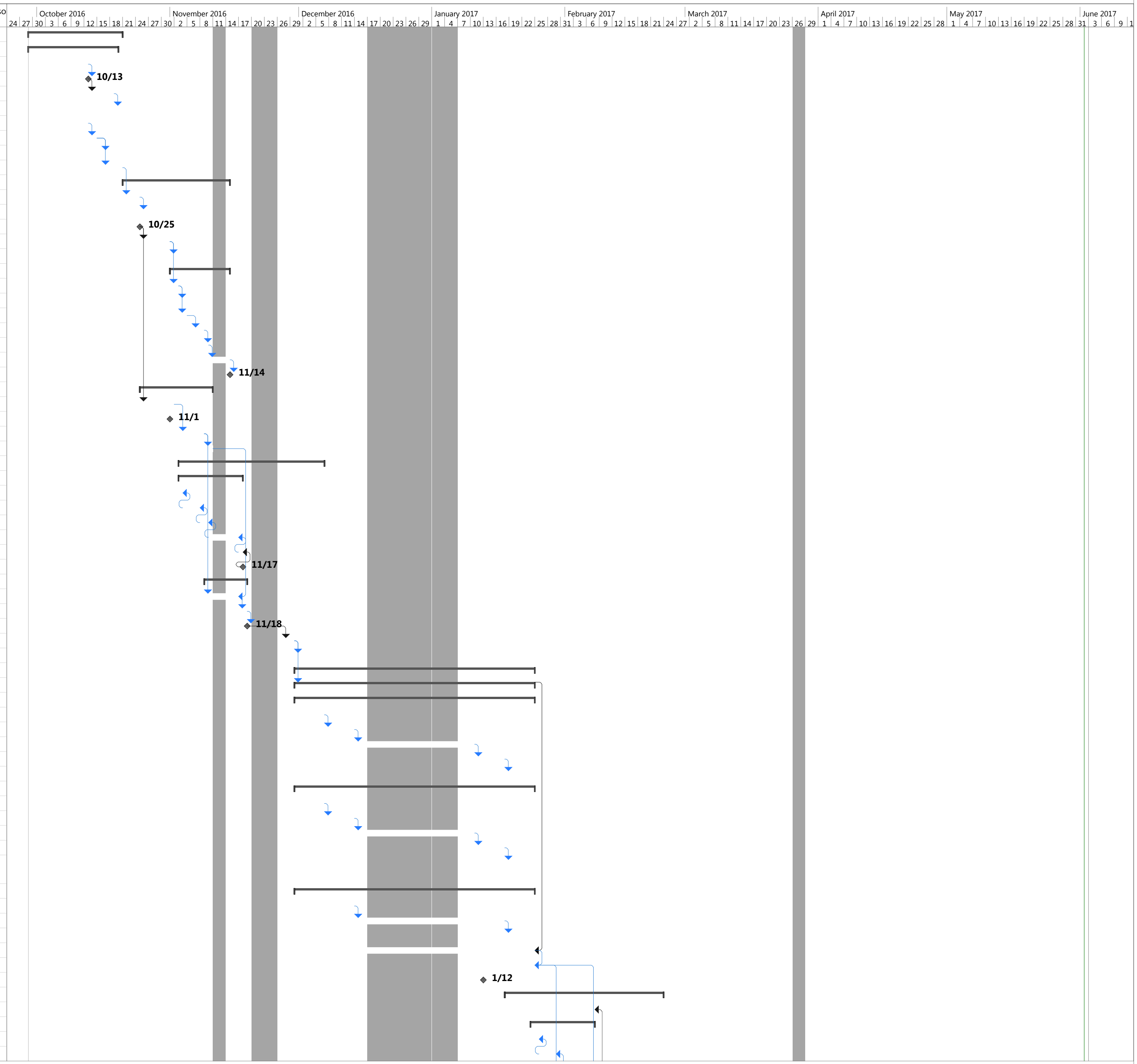
Y	N	
☒	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☒	2. Can any part of the design undergo high accelerations/decelerations?
☐	☒	3. Will the system have any large moving masses or large forces?
☐	☒	4. Will the system produce a projectile?
☐	☒	5. Would it be possible for the system to fall under gravity creating injury?
☐	☒	6. Will a user be exposed to overhanging weights as part of the design?
☐	☒	7. Will the system have any sharp edges?
☐	☒	8. Will any part of the electrical systems not be grounded?
☒	☐	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	☒	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☒	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☒	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	☒	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☒	14. Can the system generate high levels of noise?
☐	☒	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☐	☒	16. Is it possible for the system to be used in an unsafe manner?
☒	☐	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The rotating gears in our twisting differential create pinch points that could be hazardous to the user if hair, fingers, etc. were to get caught in the mechanism.	All possible pinch points will be encased so that they are not readily accessible in a manner which could cause injury.	2/7/17	
The rotatory motion of the design will be supplied by small motors which will run off inverted 120V AC wall power.	All electrical components will be shielded to prevent shorting or accidental user contact.	2/7/17	
The chemicals used in the process can be hazardous to humans.	Similar to the procedures already in place for the chemistry department, googles and nitrile gloves are to be worn during operation to prevent user contact.	2/7/17	

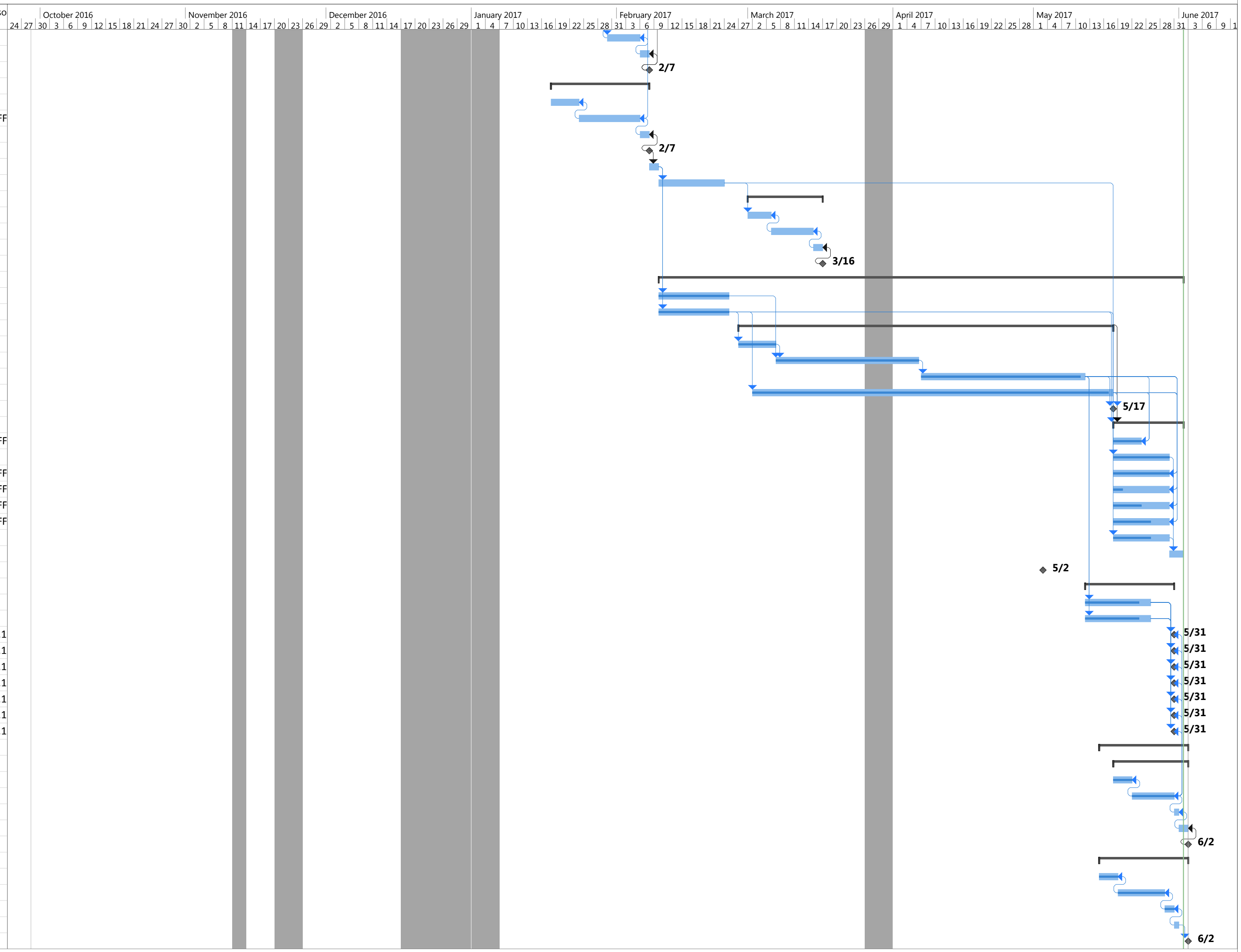
Appendix F - Gantt Chart

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Background Research**	**16 days**	**Thu 9/29/**	**Thu 10**	
2	**Team Contract**	**15 days**	**Thu 9/29/**	**Wed 1**	
3	Draft of Contract	10 days	Thu 9/29/	Wed 1	
4	Submit Contract	0 days	Thu 10/13	Thu 10	3
5	Contract Feedback	4 days	Thu 10/13	Tue 10	4
6	Contract Revision	1 day	Wed 10/1	Wed 1	5
7	Problem Statement	2 days	Tue 10/11	Wed 1	
8	Needs List	2 days	Thu 10/13	Fri 10/	7
9	Benchmarking	4 days	Mon 10/1	Thu 10	8
10	QFD	4 days	Mon 10/1	Thu 10	8
11	**Proposal**	**16 days**	**Fri 10/21/**	**Mon 1**	
12	First Draft	2 days	Fri 10/21/	Mon 1	10
13	Revision	1 day	Tue 10/25	Tue 10	12
14	Submit Proposal	0 days	Tue 10/25	Tue 10	
15	Proposal Feedback	1 wk	Tue 10/25	Mon 1	14
16	Proposal Revision	1 wk	Tue 11/1/	Mon 1	15
17	**Funding Proposal**	**9 days**	**Tue 11/1/**	**Mon 1**	
18	Proposal Outline	2 days	Tue 11/1/	Wed 1	15
19	Proposal Draft	2 days	Thu 11/3/	Fri 11/	18
20	Budget	2 days	Thu 11/3/	Fri 11/	18
21	Revision	2 days	Mon 11/7	Tue 11	20
22	Final Proposal	1 day	Wed 11/9	Wed 1	21
23	Dr. Schuster's Signature	2 days	Thu 11/10	Mon 1	22
24	Submit Funding Proposal	0 days	Mon 11/1	Mon 1	23
25	**Idea Evaluation**	**13 days**	**Tue 10/25**	**Thu 11**	
26	Ideation	1.2 wks	Tue 10/25	Tue 11	14
27	Concept Modeling	0 days	Tue 11/1/	Tue 11	
28	Pugh Matricies	0.6 wks	Fri 11/4/1	Tue 11	26
29	Final Decision Matrix	0.4 wks	Wed 11/9	Thu 11	28
30	**PDR**	**18 days**	**Thu 11/3/**	**Tue 12**	
31	**Presentation**	**10 days**	**Thu 11/3/**	**Thu 11**	
32	Template	1 day	Thu 11/3/	Fri 11/	33SF
33	Detailed Outline	2 days	Fri 11/4/1	Tue 11	34SF
34	Storyboard	2 days	Tue 11/8/	Thu 11	35SF
35	Develop Presentation	4 days	Thu 11/10	Thu 11	36SF
36	Rehearse	1 day	Thu 11/17	Thu 11	37SF
37	PDR Presentation	0 days	Thu 11/17	Thu 11	
38	**Report**	**7 days**	**Wed 11/9**	**Fri 11/**	
39	Report First draft	5 days	Wed 11/9	Wed 1	28,29FF
40	Revision	2 days	Thu 11/17	Fri 11/	39
41	Submit PDR Report	0 days	Fri 11/18/	Fri 11/	40
42	PDR Feedback	2 days	Mon 11/2	Tue 11	41
43	Report Revision	1 wk	Wed 11/3	Tue 12	42
44	**Detail Design**	**25 days**	**Wed 11/3**	**Tue 1/**	
45	**Analysis**	**25 days**	**Wed 11/3**	**Tue 1/**	**42**
46	**Drawing**	**25 days**	**Wed 11/3**	**Tue 1/**	
47	Roller Speeds	1 wk	Wed 11/3	Tue 12	
48	Roller Powertrain	1 wk	Wed 12/7	Tue 12	47
49	Bath Sizing	1 wk	Wed 12/1	Tue 1/	48
50	System Configuration	1 wk	Wed 1/11	Tue 1/	49
51	System Integration	1 wk	Wed 1/18	Tue 1/	50
52	**Twisting**	**25 days**	**Wed 11/3**	**Tue 1/**	
53	Gear Ratio	1 wk	Wed 11/3	Tue 12	
54	Spool Kinematics	1 wk	Wed 12/7	Tue 12	53
55	Differential Housing	1 wk	Wed 12/1	Tue 1/	54
56	System Configuration	1 wk	Wed 1/11	Tue 1/	55
57	Differential Powertrain	1 wk	Wed 1/18/17	Tue 1/24/1	56
58	**Integration**	**25 days**	**Wed 11/3**	**Tue 1/**	
59	Overall Configuration	2 wks	Wed 11/3	Tue 12	
60	Extrusion Integration	2 wks	Wed 12/1	Tue 1/	59
61	Intermediate Rollers	1 wk	Wed 1/18	Tue 1/	60
62	CAD Drafting	2.6 wks	Fri 12/16/	Tue 1/	45FF
63	Bill of Materials	2 wks	Wed 1/11	Tue 1/	62FF
64	Long-Lead Parts Ordered	0 days	Thu 1/12/	Thu 1/	
65	**CDR**	**27 days**	**Wed 1/18**	**Thu 2/**	
66	Budget	4 days	Thu 2/2/1	Tue 2/	72SF
67	**Presentation**	**11 days**	**Tue 1/24/**	**Tue 2/**	
68	Template	2 days	Tue 1/24/	Thu 1/	69SF
69	Detailed Outline	2 days	Thu 1/26/	Mon 1	70SF



Appendix F - Gantt Chart

ID	Task Name	Duration	Start	Finish	Predecesso
70	Develop Presentation	5 days	Mon 1/30	Mon 2	71SF,63
71	Rehearse	2 days	Mon 2/6/	Tue 2/	72SF
72	CDR Presentation	0 days	Tue 2/7/1	Tue 2/	
73	**Report**	**15 days**	**Wed 1/18**	**Tue 2/**	
74	Detailed Outline	4 days	Wed 1/18	Tue 1/	75SF
75	Report First Draft	9 days	Tue 1/24/	Mon 2	76SF,63FF
76	Revision	2 days	Mon 2/6/	Tue 2/	77SF
77	Submit CDR Report	0 days	Tue 2/7/1	Tue 2/	
78	CDR Feedback	2 days	Wed 2/8/	Thu 2/	77
79	Report Revision	2 wks	Fri 2/10/1	Thu 2/	78
80	**Project Update report**	**12 days**	**Wed 3/1/**	**Thu 3/**	
81	Detailed Outline	3 days	Wed 3/1/	Mon 3	79,82SF
82	Report First draft	7 days	Mon 3/6/	Wed 3	83SF
83	Revision	2 days	Wed 3/15	Thu 3/	84SF
84	Submit Update Report	0 days	Thu 3/16/	Thu 3/	
85	**Manufacturing**	**75 days**	**Fri 2/10/1**	**Thu 6/**	
86	Material Procurement	2.2 wks	Fri 2/10/1	Fri 2/2	78
87	Order Components	2.2 wks	Fri 2/10/1	Fri 2/2	78
88	**Fabricate Components**	**53 days**	**Mon 2/27**	**Wed 5**	
89	.DXF files for Waterjet	6 days	Mon 2/27	Mon 3	87
90	Waterjet necessary parts	17.5 days	Tue 3/7/1	Thu 4/	89,87
91	Post Machine Housings	25 days	Fri 4/7/17	Thu 5/	90
92	Lathe Parts	50 days	Thu 3/2/1	Wed 5	87
93	Finish Manufacturing	0 days	Wed 5/17	Wed 5	91,92
94	**Assembly**	**11 days**	**Thu 5/18/**	**Thu 6/**	**87,88**
95	Gear Boxes	4 days	Thu 5/18/	Tue 5/	91FF,92FF
96	Arduino coding	8 days	Thu 5/18/	Mon 5	79
97	Bath	8 days	Thu 5/18/	Mon 5	91FF,92FF
98	Aux Roller	8 days	Thu 5/18/	Mon 5	91FF,92FF
99	Cylinder	8 days	Thu 5/18/	Mon 5	91FF,92FF
100	Housing	8 days	Thu 5/18/	Mon 5	91FF,92FF
101	Circuit wiring	8 days	Thu 5/18/	Mon 5	87
102	System Assembly	3 days	Tue 5/30/	Thu 6/	101,96
103	Hardware and Safety Demo	0 days	Tue 5/2/1	Tue 5/	
104	**Testing**	**13 days**	**Fri 5/12/1**	**Wed 5**	
105	Cylinder Rotation	10 days	Fri 5/12/1	Thu 5/	91
106	Gear Box Functioning	10 days	Fri 5/12/1	Thu 5/	91
107	Lab Room Appropriate	0 days	Wed 5/31	Wed 5	105,106,1
108	20 Minute Setup Time	0 days	Wed 5/31	Wed 5	105,106,1
109	Throughput	0 days	Wed 5/31	Wed 5	105,106,1
110	Minimal Tension	0 days	Wed 5/31	Wed 5	105,106,1
111	25 Degree Twist Angle	0 days	Wed 5/31	Wed 5	105,106,1
112	Fiber Diameter	0 days	Wed 5/31	Wed 5	105,106,1
113	Fiber Strength	0 days	Wed 5/31	Wed 5	105,106,1
114	**Final Report**	**15 days**	**Mon 5/15**	**Fri 6/2**	
115	**Report**	**12 days**	**Thu 5/18/**	**Fri 6/2**	
116	Report Outline	2 days	Thu 5/18/	Mon 5	117SF
117	Draft report	7 days	Mon 5/22	Wed 5	118SF
118	Revision	1 day	Wed 5/31	Thu 6/	119SF
119	Final Draft	2 days	Thu 6/1/1	Fri 6/2	120SF
120	Submit Final Report	0 days	Fri 6/2/17	Fri 6/2	
121	**Expo**	**15 days**	**Mon 5/15**	**Fri 6/2**	
122	Outline Expo Board	4 days	Mon 5/15	Fri 5/1	123SF
123	Board Layout	6 days	Fri 5/19/1	Mon 5	124SF
124	Board Revision	2 days	Mon 5/29	Tue 5/	125SF
125	Print Expo Board	1 day	Wed 5/31	Wed 5	
126	Expo	0 days	Fri 6/2/17	Fri 6/2	125



ME428 DVP&R Graphene Twisters

Report Date	11/30/2016			Sponsor	Dr. Zhang					Component/Assembly			GF Draw&Twist	REPORTING ENGINEER:	Isaias	
TEST PLAN													**TEST REPORT**			
Item No	Specification or Clause Reference	Test Description	Equipment	Location	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING			TEST RESULTS			NOTES
								Quantity	Type	Start date	Finish date	% Completed	Test Result	Quantity Pass	Quantity Fail	
1	$1500 production cost	Analyze final costs including shipping and taxes. Maximum availible budget from the chemistry departmetn is $1500.	Excel	Cal Poly	Pass/Fail	Isaias	DV	1	B	11/30/2016	2/7/2107	100.00	Pass	1	0	.The total amount spent on the project was $1260.1 compared to our initial estimate of $925.38. Had we not had to pay for waterjet cutting , we would have only gone ove our estimate by 3.75%
2	20 minute set up time	Time to set up process (properly allocating fiber along rollers and attaching to differental), stopwatch will be used as measurement device.	Timer	CP Chemistry (Baker Lab)	Pass/Fail	Robert	DV, PV	10	B, C	5/2/2017	5/8/2017	0.00	N/A	N/A	N/A	Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group.
3	25 degree twist angle	The final fiber should have a twist angle around 25 degrees measured via SEM (Scanning Electron Microscope).	SEM (Scanning Electron Microscope)	CP Chemistry	"+-5 deg"	Isaias	PV	10	C	5/9/2017	5/15/2017	0.00	N/A	N/A	N/A	Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group.
4	50 micron fiber diameter	The final fiber should have a desired diameter of around 50 microns measured via SEM (Scanning Electron Microscope).	SEM (Scanning Electron Microscope)	CP Chemistry	"+-5%"	Greg	PV	10	C	5/9/2017	5/15/2017	0.00	N/A	N/A	N/A	.Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group
5	LabRoom appropriate	Make sure that the machine is able to be used in a regular Cal Poly Chemistry Lab, weight measured by scale and product dimesnions will be used in test.	Observation	CP Chemstry (Baker Lab)	Under 500 lbs and under 10 ft^2	Greg	CV, PV,DV	1	A, C,B	5/2/2017	5/8/2017	100.00	Pass	1	0	The full prototype weighed undrer 500 lbs and can all be located on a table top.
6	Fiber strength	Evaluate the effectiveness of the drawing process by observing the resulting fiber strength, measured via an Instron (Owned by Chem. Dept.)	Instron	CP MATE	200 Mpa "+-50PMa"	Isaias	PV	10	C	5/4/2017	5/9/2017	0.00	N/A	N/A	N/A	Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group.
7	Minimal tension	Need to have as minimal amout of tension (including friction force) as possible exerted on the fiber, measured via observation of fiber continuity.	Observation	Cal Poly	fiber tension <.4N (Fiber does not break)	Robert	CV, DV	10	A,B	5/2/2016	5/4/2017	0.00	N/A	N/A	N/A	Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group.
8	Throughput	Measure the feedrate by measuring the amount of fiber continously being processed (mL) over the course of an hour (Hr).	Meter Stick, Timer	Cal Poly (Baker Lab)	30 ml/hr	Isaias	DV	3	B	5/2/2017	5/8/2017	0.00	N/A	N/A	N/A	Due to time constraints this test was not conducted. Testing of this can be continuted or carried on by future engineering groups or Dr. Zhang and his study group.
12	Cylinder Rotation	Cylinder reaches desired RPM at reasonable transient time. Use laser tachometer to derive speed from frequency.	Laser Tachometer	Cal Poly	250 RPM+-5RPM	Isaias	DV, PV	3	B, C	4/6/2017	5/1/2017	0.00	Fail	1	0	The twsiting mechanism was not able to turn due to complications with mounting the motor to the cylinder housing.
15	GearBox Functioning	.'Bath gearbox functions as designed	Gearbox	Cal Poly	Pass/Fail	Greg	DV, PV	5	B, C	4/6/2017	5/1/2017	0.00	Pass	5	0	The gearboxes all were able to function after slight adjustment of shaft diameters.

Appendix H

Graphene Twisters - Budget Analysis

Total Cost Estimate:	**$925.38**	**Available Budget:**	**$1,500.00**	**Overspent (Underspent):**	**$ 334.72**	**Status:** Over Estimate
Total Spent:	**$1,260.10**	**Remaining Budget:**	**$239.90**	**Percentage of Estimate:**	**36.17%**	Under Budget

Raw Material

Description	Category	Vendor	Vendor P/N	Part Qty	Cost	Per	Qty.	Ext Proj Cost	Actual Cost	Ordered	Recieved
3/8" Thick Type 1 PVC, Gray, 36"x36"	Bath	McMaster	8747K184	1	$86.82	1	1	$86.82	$86.82	2-23-17	2-27-17
3/16" Type 1 PVC, Gray, 12"x12"	Gear Box	McMaster	8747K113	1	$7.90	1	1	$7.90	$7.90	2-23-17	2-28-17
1/2" Dia X 8' Long Polypropylene Rod	Bath	McMaster	8658K53	8	$1.26	1	8	$10.08	$10.08	2-23-17	2-27-17
0.036" Thick, 6" x 12" 304 Stainless Steel Sheet	Gear Box	McMaster	8983K123	1	$5.59	1	1	$5.59	$5.59	2-23-17	2-28-17
1/16" Thick, 12" x 12" Silicon Gasket Sheet	Bath	McMaster	8525T41	1	$9.93	1	1	$9.93	$9.93	2-23-17	2-28-17
0.005" Thick, 12" x 12" Adhesive-Back UHMW Film	Aux Roller	McMaster	1441T12	2	$4.57	1	2	$9.14	$9.14	2-23-17	2-28-17
3/4" Dia, 1' Long Teflon PTFE Rod	Aux Roller	McMaster	8546K15	2	$15.49	1	2	$30.98	$30.98	2-23-17	2-28-17
5" Dia, 1' Long PVC Pipe Schedule 40	Twisting	FlexPVC	SDR26 5 inch	1	$9.71	1	1	$9.71	$9.71	2-23-17	3-7-17
0.063" 6061 T6 Aluminum Sheet, 12" x 12"	Twisting	McMaster	89015K37	1	$16.98	1	1	$16.98	$16.98	2-23-17	2-28-17
5/32" Type 1 PVC Rod, 5 ft long	Gear Box	McMaster	8745K12	1	$4.50	1	1	$0.00	$4.10	4-18-17	4-20-17
3/8"304 Stainless Steel Rod, 12ft	Bath	B&B Surplus	-----	1	$12.50	1	1	$0.00	$12.50	-----	3-16-17
						Total Raw Material Cost		**$187.13**	**$203.73**		

Hardware

Part Number	Description	Category	Vendor	Vendor P/N	Part Qty	Cost	Per	Package Qty	Ext Proj Cost	Actual Cost	Ordered	Recieved
1206	Drive Belt, 1/8" Dia, 7" OD	Bath	McMaster	3044K503	4	$4.18	1	4	$16.72	$16.72	2-23-17	2-28-17
1208	Sleeve Bearing, Rulon 641	Bath	MSC Direct	91569152	16	$3.07	1	16	$49.12	$48.46	2-23-17	3-20-17
1209	Dowel Pin, Black-Oxide Alloy Steel, 1/8" Diameter, 3/4" Long	Bath	McMaster	98381A308	18	$6.39	25	1	$6.39	$6.39	2-23-17	2-28-17
1308	Worm Gear	Gear Box	KHK Gears	SW0.5-R1	6	$8.82	1	6	$52.92	$52.92	2-23-17	2-28-17
1309	Spur Gear	Gear Box	KHK Gears	DG0.5-20R1	6	$6.95	1	6	$41.70	$41.70	2-23-17	2-28-17
1310	Sleeve Bearing, 4mm Shaft Dia, SAE 841 Bronze	Gear Box	McMaster	6659K65	25	$1.75	1	25	$43.75	$43.75	2-23-17	2-28-17
1401	Motor, PPN7PA12C1	Gear Box	DigiKey	P14355-ND	7	$3.05	1	7	$21.38	$21.38	2-23-17	3-3-17
2105	E-Clip, 1/4" Shaft Dia, Black Finish Steel	Aux Roller	Miner's	-----	2	$0.23	1	2	$0.46	$0.46	-----	3-1-17
2108	Conical Spring, 1.5" Long, 0.975" Lg OD, 0.375" Sm OD	Aux Roller	McMaster	1692K62	2	$2.94	1	2	$5.88	$5.88	2-23-17	2-28-17
3103	Drive Belt, 1/16" Dia, 21" OD	Twisting	McMaster	6075K12	1	$3.41	1	1	$3.41	$3.36	2-23-17	3-7-17
4101	Pan Head Screw, Phillips, #8-32, 1/4" Long, Zinc Plated Steel	Fastener	McMaster	90272A190	14	$2.62	100	1	$2.62	$2.62	2-23-17	2-28-17
4102	Pan Head Screw, Phillips, #8-32, 1/2" Long, Zinc Plated Steel	Fastener	McMaster	90272A194	29	$3.14	100	1	$3.14	$3.14	2-23-17	2-28-17
4103	Pan Head Screw, Phillips, #8-32, 3/4" Long, Zinc Plated Steel	Fastener	McMaster	90272A197	50	$3.70	100	1	$3.70	$4.10	2-23-17	2-28-17
4104	Pan Head Screw, Phillips, #8-32, 1" Long, Zinc Plated Steel	Fastener	Miner's	-----	20	$0.11	1	20	$2.20	$2.20	-----	3-1-17
4105	Pan Head Screw, Phillips, M2, 3mm Long, Zinc Plated Steel	Fastener	McMaster	92005A011	12	$5.04	100	1	$5.04	$5.04	2-23-17	2-28-17
4201	Flat Washer, #8, 18-8 Stainless Steel	Fastener	McMaster	92141A009	70	$2.00	100	1	$2.00	$2.00	2-23-17	2-28-17
4202	Flat Washer, M2, 18-8 Stainless Steel	Fastener	McMaster	93475A195	12	$1.06	100	1	$1.06	$1.06	2-23-17	2-28-17
4301	Threaded Insert, #8-32, Brass	Fastener	McMaster	92395A114	104	$12.60	50	3	$37.80	$37.80	2-23-17	2-28-17
4401	Slotted Roll Pin, 1/8", 1/2" Long, 18-8 Stainless Steel	Fastener	McMaster	92373A177	20	$4.69	100	1	$4.69	$4.69	2-23-17	2-28-17
4302	Nylon Insert Locknut, #8-32 Steel	Fastener	Miner's	-----	5	$0.11	1	5	$0.55	$0.55	-----	3-1-17
4402	PVC Heat Shrink Tubing, 0.19" ID	Fastener	McMaster	7132K513	1	$2.76	5	1	$2.76	$2.76	2-23-17	2-28-17
-----	Urethane Flat Belt, 1/2" wide, 0.062" Thick, 21" OD	Twisting	McMaster	9485T12	1	$14.49	1	1	$0.00	$14.49	2-24-17	3-9-17

Total Hardware Cost		**$307.29**	**$321.47**

Electronics

Part Number	Description	Category	Vendor	Vendor P/N	Part Qty	Cost	Per	Package Qty	Ext Proj Cost	Actual Cost	Ordered	Recieved
5101	Arduino Nano	Motor Control	DigiKey	1050-1001-ND	4	$21.49	1	4	$85.96	$85.96	2-23-17	3-7-17
5102	Texas Instruments RC4558 Op-Amp	Motor Control	DigiKey	296-1414-5-ND	4	$0.39	1	4	$1.56	$1.56	2-23-17	3-3-17
5103	Bourns 10K Ohm Potentiometer	Motor Control	DigiKey	91C1A-D20-B15L-ND	3	$4.98	1	3	$14.94	$14.94	2-23-17	3-3-17
5104	10K Ohm Potentiometer Knob	Motor Control	DigiKey	226-1096-ND	3	$6.01	1	3	$18.03	$18.03	2-23-17	3-3-17
5105	Bourns 50K Ohm Potentiometer	Motor Control	DigiKey	91A1A-B28-B18L-ND	2	$5.91	1	2	$11.82	$11.82	2-23-17	3-3-17
5106	50K Ohm Potentiometer Knob	Motor Control	DigiKey	226-1100-ND	2	$6.01	1	2	$12.02	$12.02	2-23-17	3-3-17
5107	10K Ohm, 3W Resistor	Motor Control	DigiKey	10KAXCT-ND	15	$0.23	1	15	$3.51	$3.51	2-23-17	3-3-17
5108	NPN 50V, 10A Transistor	Motor Control	DigiKey	2SC6017-EOS-ND	10	$0.55	1	10	$5.52	$5.52	2-23-17	3-3-17
5109	50V, 1A 1N4001 Rectifying Diode	Motor Control	DigiKey	1N4001DICT-ND	10	$0.12	1	10	$1.24	$1.24	2-23-17	3-3-17
5110	830 Tie Breadboard	Motor Control	DigiKey	BKGS-830-ND	4	$8.25	1	4	$33.00	$0.00	-----	5-2-17
5111	Yescom 30V, 10A, 110V DC Power Supply	Motor Control	Newegg	9SIA8SK3T28065	1	$59.99	1	1	$59.99	$59.99	2-23-17	3-1-17
5112	Banana to Socket - Red	Motor Control	DigiKey	501-1655-ND	1	$8.49	1	1	$8.49	$8.49	2-23-17	3-3-17
5113	Banana to Socket - Black	Motor Control	DigiKey	501-1643-ND	1	$8.49	1	1	$8.49	$8.49	2-23-17	3-3-17
5114	15cm Male to Male Jumper Wire 10 Pack	Motor Control	DigiKey	1471-1232-ND	1	$3.06	1	1	$3.06	$3.06	2-23-17	3-3-17
5115	22 AWG Hookup Wire - Black	Motor Control	DigiKey	1528-1753-ND	1	$2.95	1	1	$2.95	$2.95	2-23-17	3-3-17
5116	22 AWG Hookup Wire - Red	Motor Control	DigiKey	1528-1769-ND	1	$2.95	1	1	$2.95	$2.95	2-23-17	3-3-17
5117	22 AWG Hookup Wire - Green	Motor Control	DigiKey	1528-1764-ND	1	$2.95	1	1	$2.95	$2.95	2-23-17	3-3-17
5118	22 AWG Hookup Wire - Blue	Motor Control	DigiKey	1528-1757-ND	1	$2.95	1	1	$2.95	$2.95	2-23-17	3-3-17
5119	Zip ties	Motor Control	Miner's	-----	1	$2.99	1	1	$2.99	$2.99	-----	3-1-17
5120	Adhesive Cable Mount	Electronics	McMaster	7566K73	25	$3.53	25	1	$3.53	$3.53	2-23-17	2-28-17
5201	Slip Ring	Electronics	DigiKey	1528-1152-ND	1	$14.95	1	1	$14.95	$14.95	2-23-17	3-3-17

Total Electronics Cost		**$300.90**	**$267.90**

Shipping and Tax

Vendor	Projected Cost	Actual Cost
McMaster	$75.00	$93.33
DigiKey	$15.00	$37.24
KHK	$20.00	$18.92
MSC Direct	$12.00	$3.78
Newegg	$0.00	$4.35
FlexPVC	$8.06	$7.25
Miner's	$0.00	$1.13
B&B Surplus	$0.00	$1.00
Total Shipping and Tax	**$130.06**	**$167.00**

Manufacturing

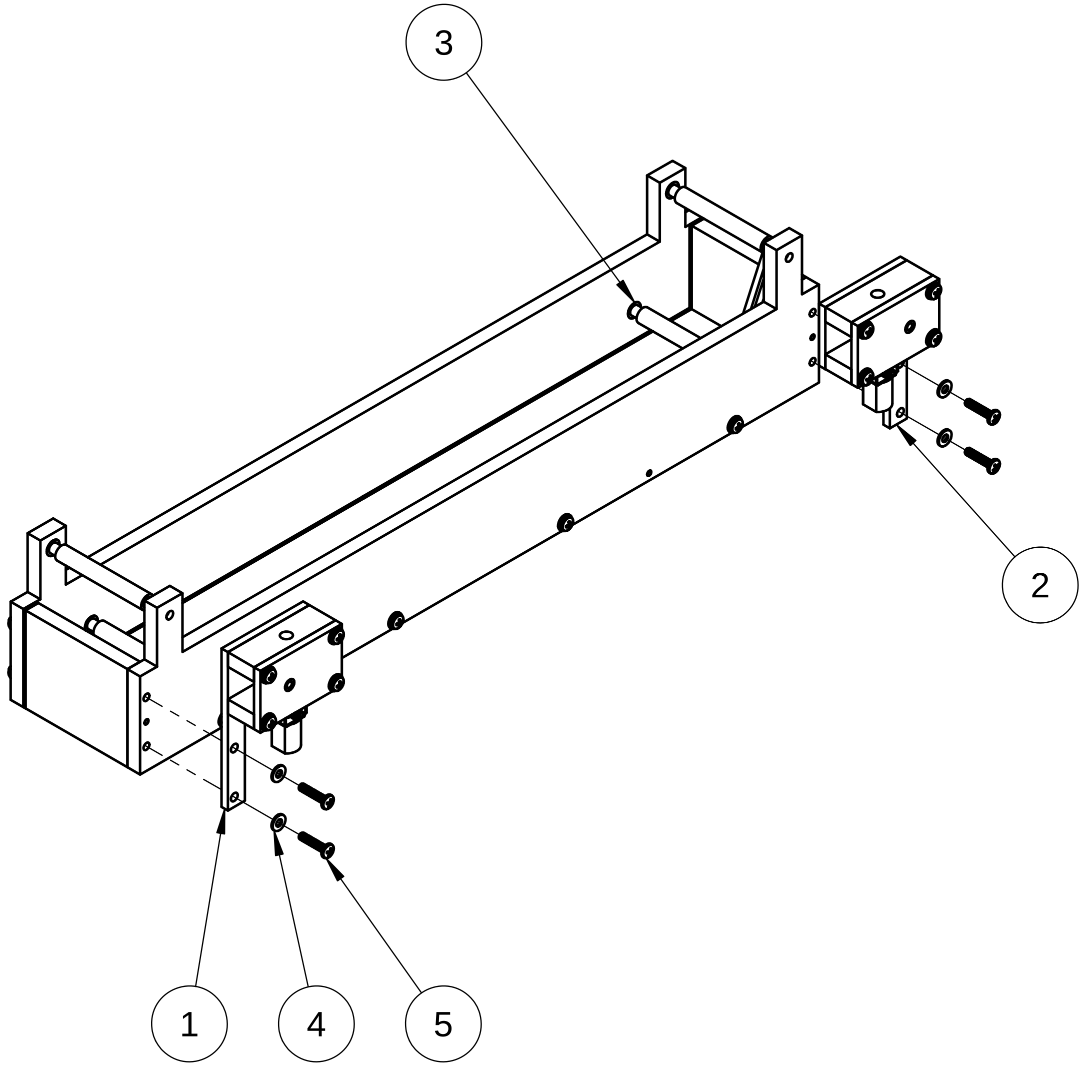
Waterjet Cutting	$0.00	$300.00
Total Manufacturing	**$0.00**	**$300.00**

Appendix I

Graphene Twisters Engineering Drawings

I-44	3139	Spring Shaft
I-45	3201	Cover Plate
I-46	3202	Side Plate
I-47	3203	Rear Plate
I-48	3204	Rod Support
I-49	3205	Step Rod
I-50	3206	Cylinder Roller
I-51	3207	Spacer#1
I-52	3208	Spacer#2
I-53	3209	Spacer#3
I-54	3210	Belt Roller
I-55	4101	Pan Head Screw, Phillips, #8-32, 1/4" Long, Zinc Plated Steel
I-56	4102	Pan Head Screw, Phillips, #8-32, 1/2" Long, Zinc Plated Steel
I-57	4103	Pan Head Screw, Phillips, #8-32, 3/4" Long, Zinc Plated Steel
I-58	4104	Pan Head Screw, Phillips, #8-32, 1" Long, Zinc Plated Steel
I-59	4105	Pan Head Screw, Phillips, M2, 3mm Long, Zinc Plated Steel
I-60	4201	Flat Washer, #8, 18-8 Stainless Steel
I-61	4202	Flat Washer, M2, 18-8 Stainless Steel
I-62	4301	Threaded Insert, #8-32, Brass
I-63	4302	Nylon Insert Locknut, #8-32 Steel
I-64	4401	Slotted Roll Pin, 1/8", 3/4" Long, 18-8 Stainless Steel

ITEM NO.	PART No.	DESCRIPTION	QTY.
1	1102	GEAR BOX - LEFT	1
2	1102	GEAR BOX - RIGHT	1
3	1101	BATH SUBASSEMBLY	1
4	4202	#8 FLAT WASHER	4
5	4105	#8-32 PHILLIPS SCREW, 3/4" LG	4



	NAME	DATE
DRAWN	GTL	2/2/17

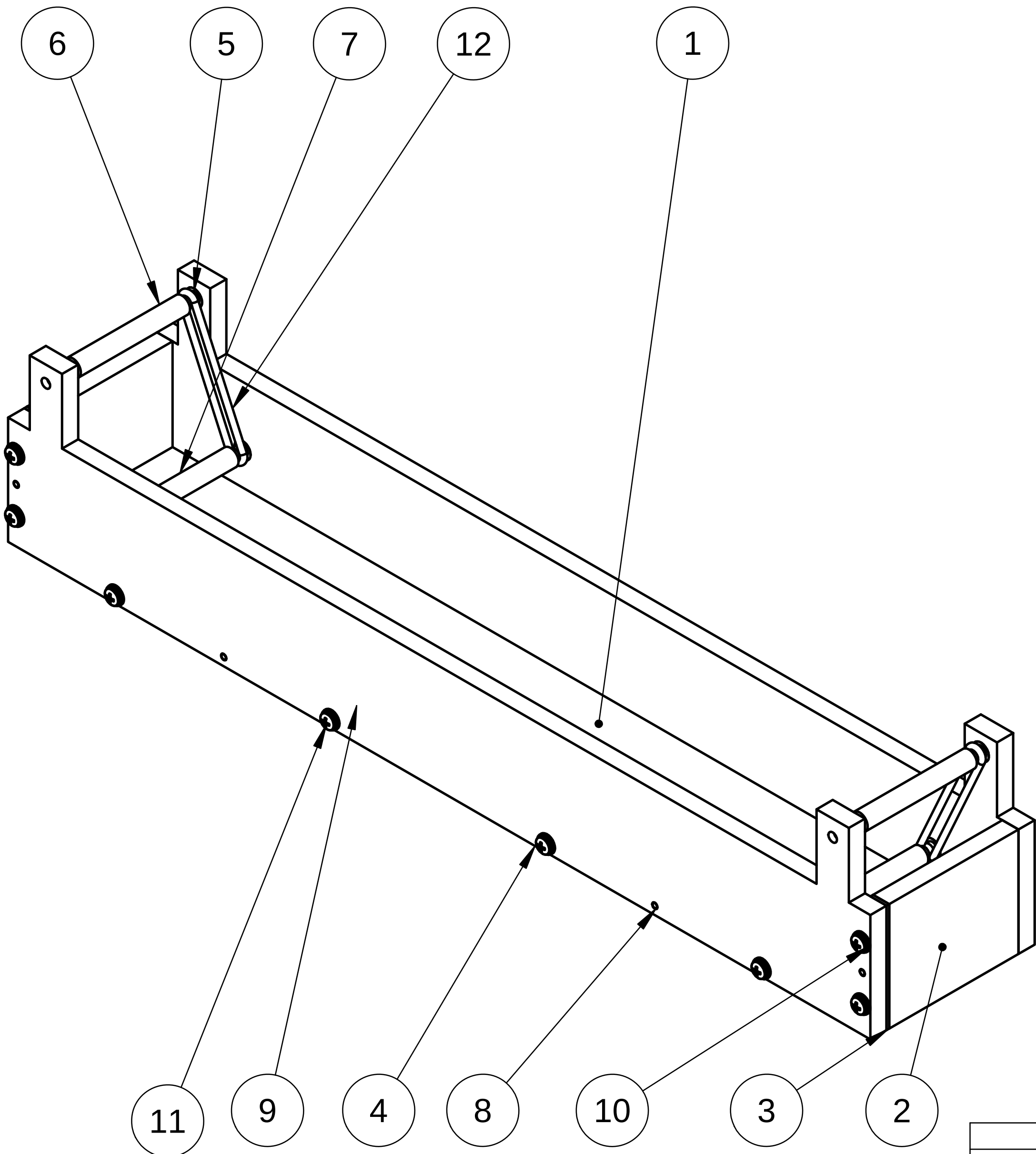
MATERIAL
VARIES

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
BATH

SIZE	PART NO.	REV
A	1000	

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1201	BOTTOM	1
2	1202	END CAP	2
3	1204	GASKET	2
4	1203	SIDE	2
5	1208	SLEEVE BEARING	8
6	1205	DRIVE ROLLER	2
7	1207	ROLLER	2
8	1209	ALIGNMENT PIN	8
9	4301	#8-32 THREADED INSERT	16
10	4201	#8 FLAT WASHER	12
11	4103	#8-32 PHILLIPS HEAD SCREW, 3/4" LG	12
12	1206	DRIVE BELT	2

	NAME	DATE
DRAWN	GTL	1/31/17

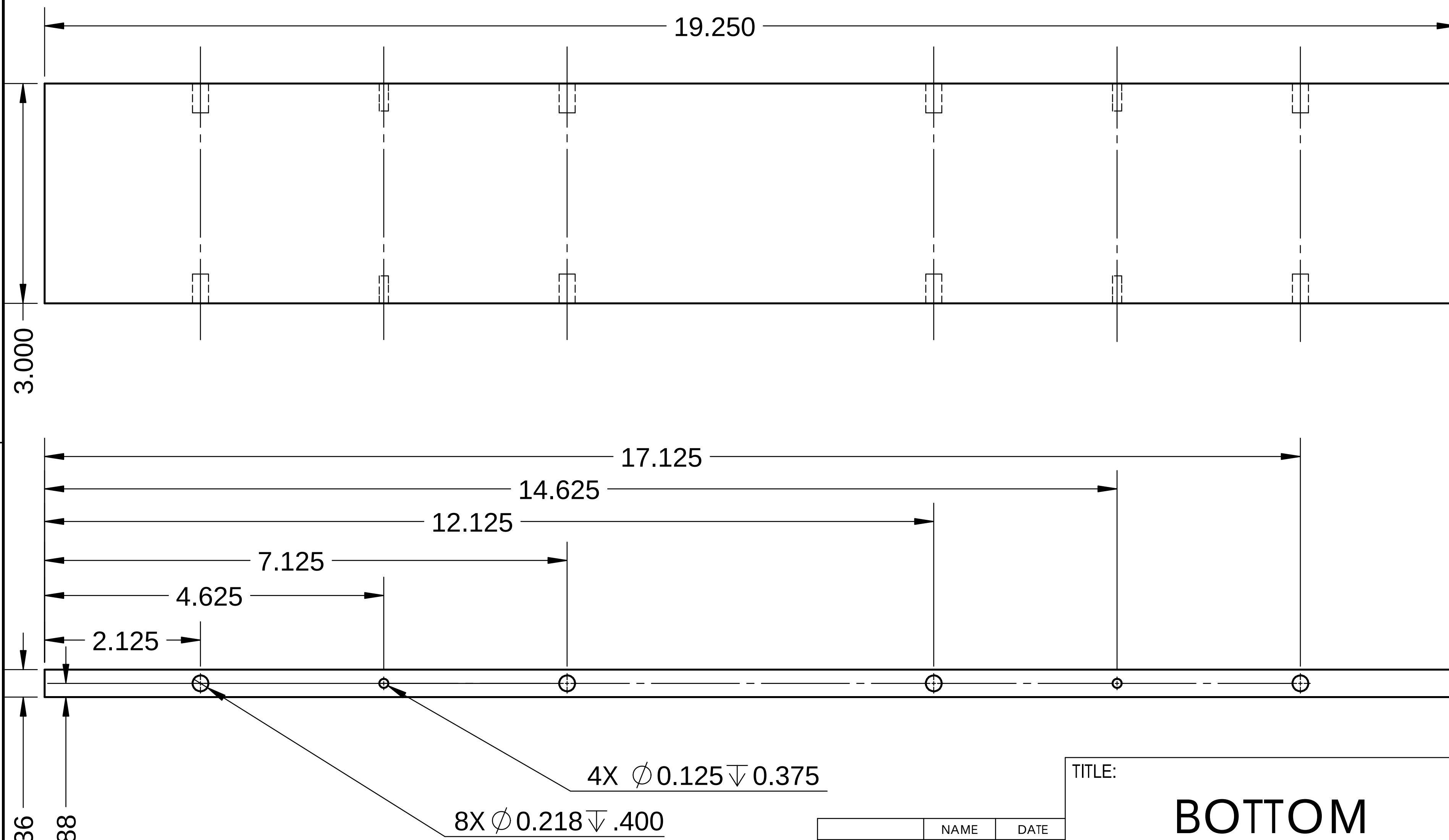
MATERIAL
VARRIES

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
BATH SUBASSEMBLY

SIZE A | PART NO. 1101 | REV

SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1



TITLE:

BOTTOM

	NAME	DATE
DRAWN	GTL	1/31/17

UNLESS OTHERWISE SPECIFIED:

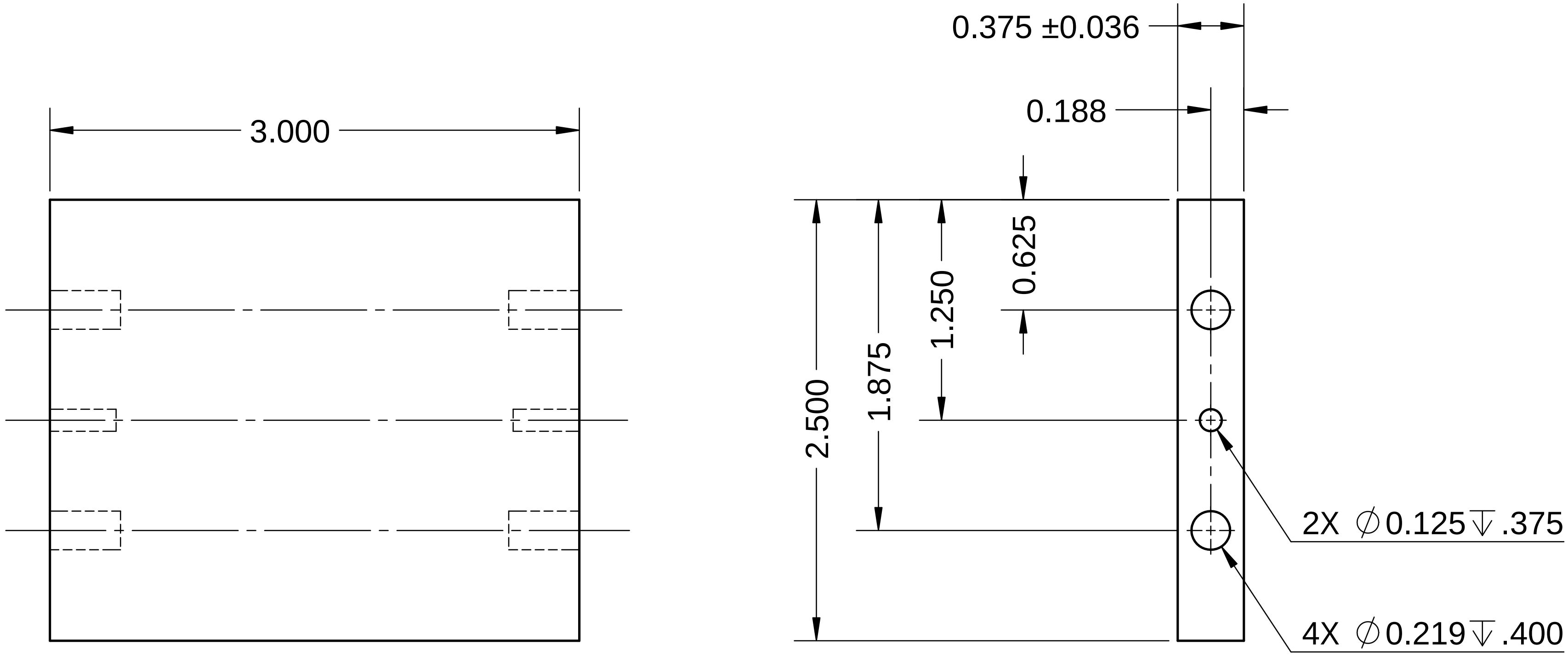
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	1201	

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	GTL	1/31/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

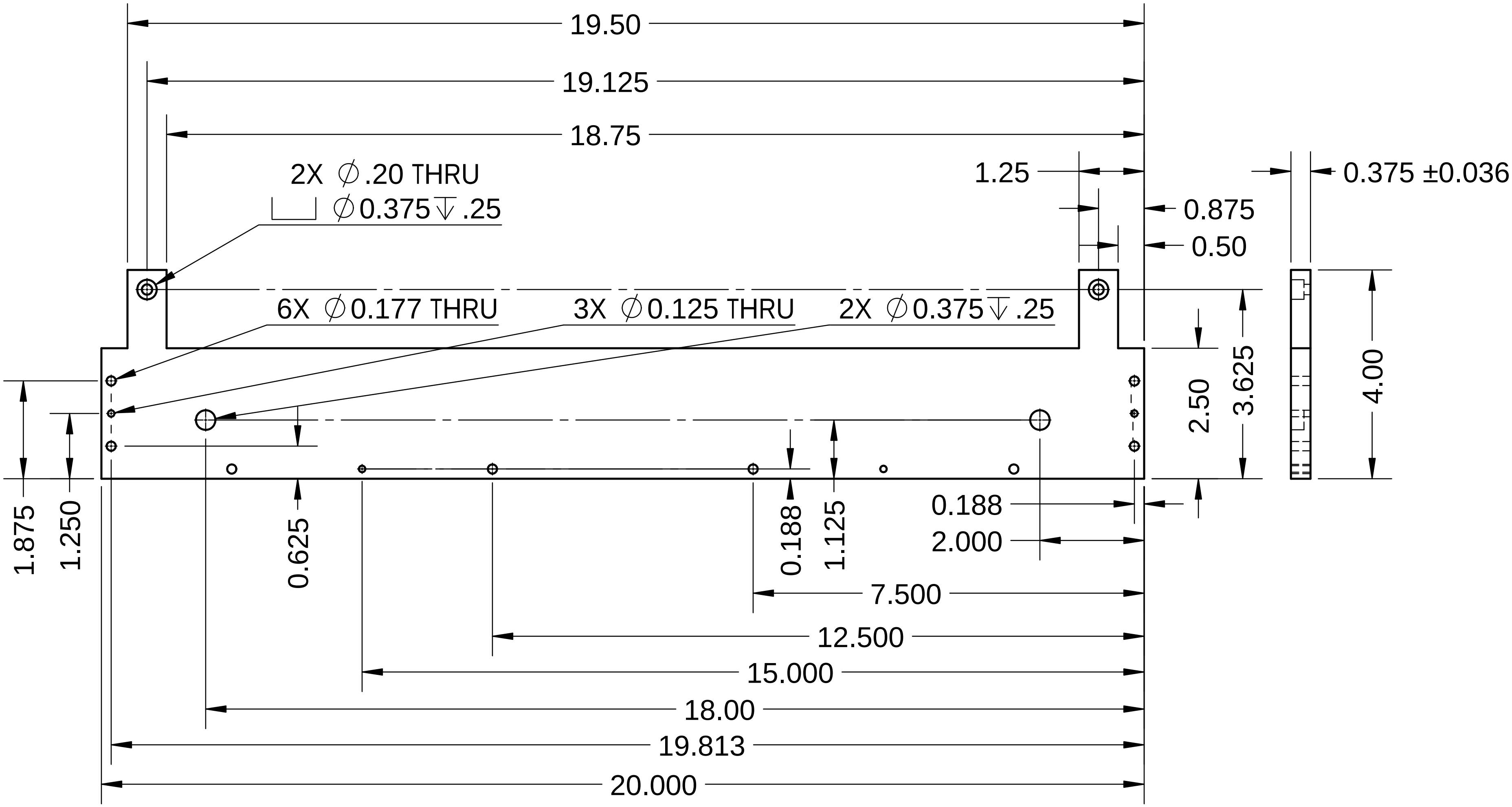
MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
END CAP

SIZE	PART NO.	REV
A	1202	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



TITLE: SIDE

	NAME	DATE
DRAWN	GTL	1/31/17

UNLESS OTHERWISE SPECIFIED:

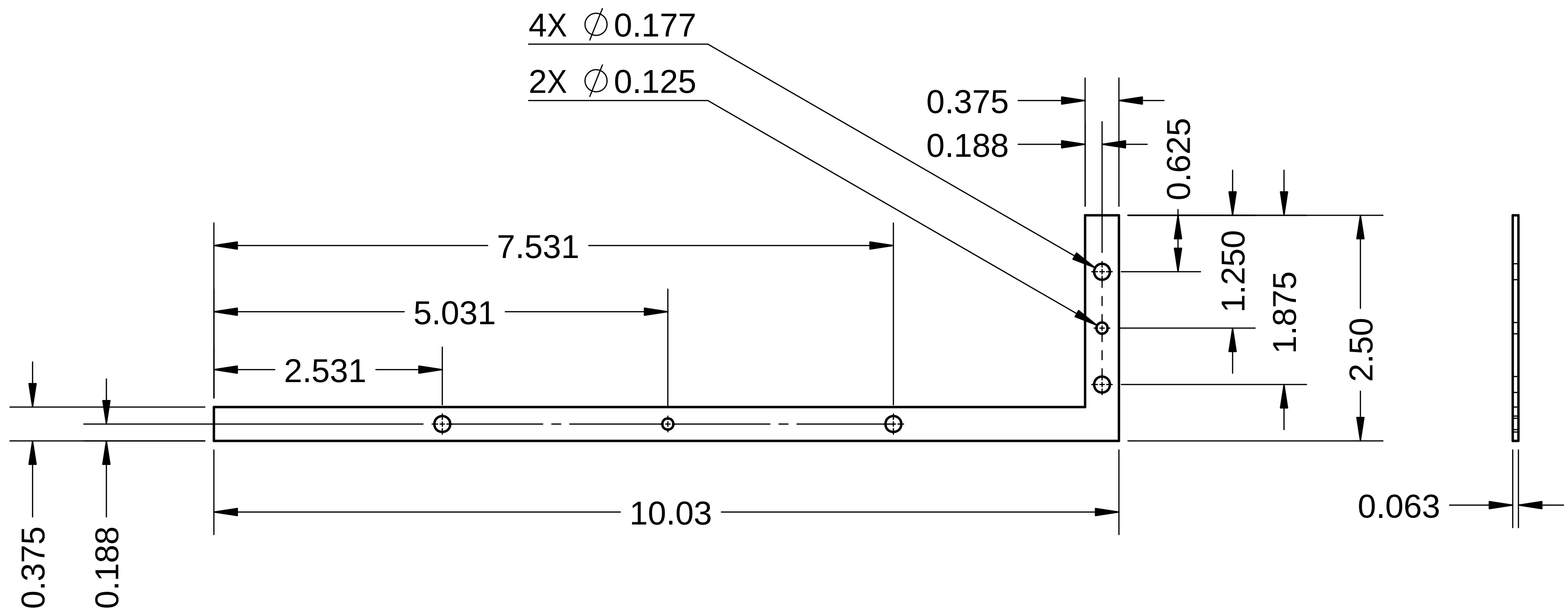
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

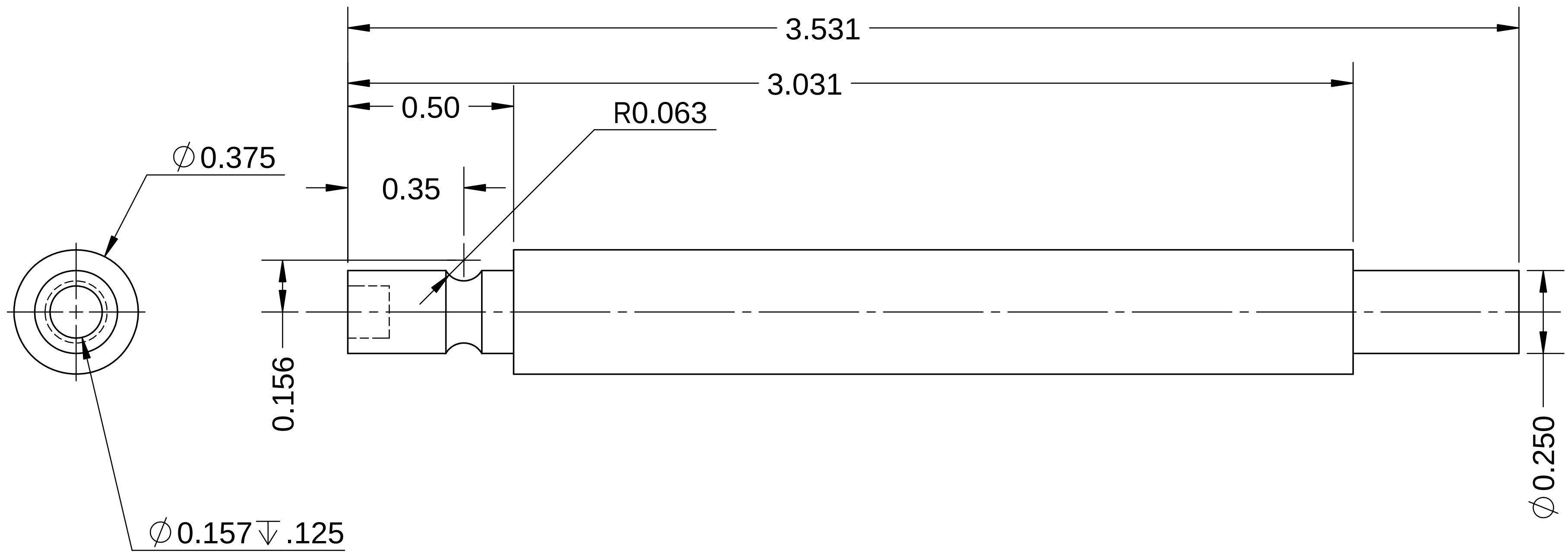
SIZE: A | PART NO.: 1203 | REV:

SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME / DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	DRAWN	GTL / 1/31/17
	MATERIAL SILICONE	
	COMMENTS: DO NOT SCALE DRAWING	

TITLE: GASKET		
SIZE A	PART NO. 1204	REV
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	GTL	1/31/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL
304 STAINLESS STEEL

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
Drive Roller

SIZE **A** | PART NO. 1205 | REV

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

McMASTER-CARR®

Urethane Round Belt

Clear, 1/8" Diameter, 4" to 12" Outer Circle

Usually ships in 3 days.
$4.18 Each
3044K503

Diameter	1/8"
Outer Circle	4"- 12"
Core Construction	Solid
Color	Clear
Material	Urethane
Outer Circle (OC)	7" in.

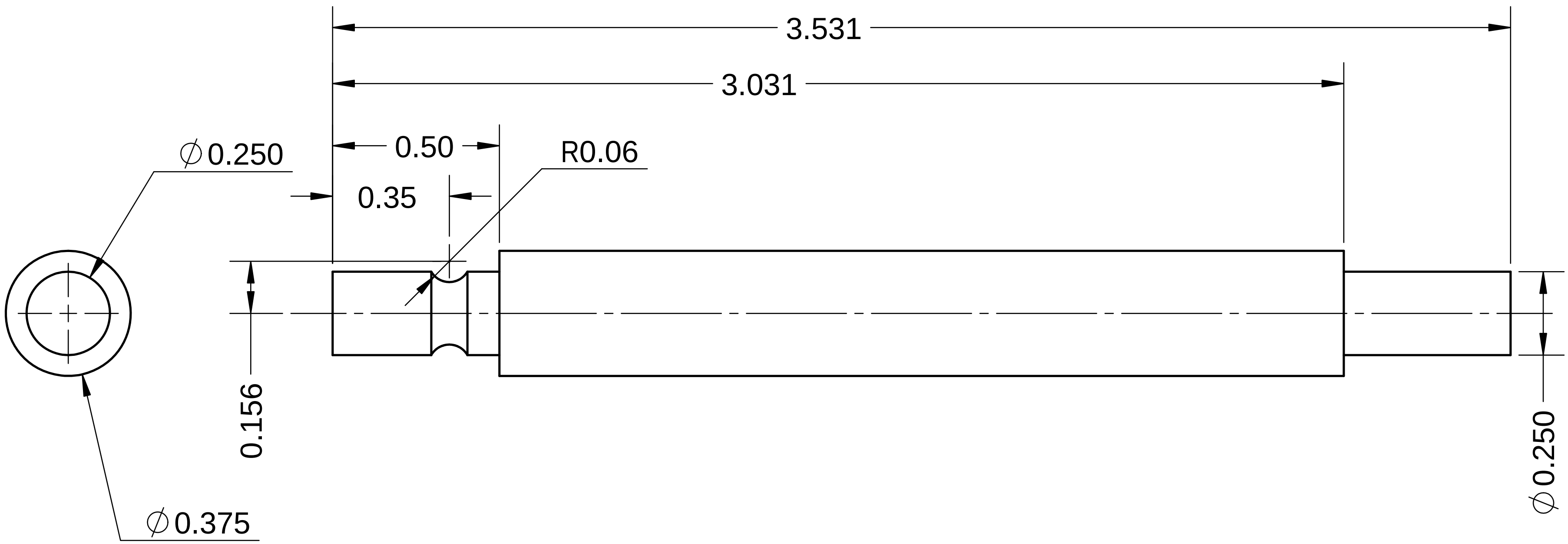
Also known as O-ring and endless belts, these come ready to use.

Urethane—All urethane belts are chemical and abrasion resistant. Standard urethane belts are made from FDA-listed material for use with food and beverage. Inch sizes are made from FDA-listed material for use with food and beverage.

Choose outer circle (OC) in 1/4" increments.

2 1

B



B

A A

TITLE:

ROLLER

	NAME	DATE
DRAWN	GTL	1/31/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

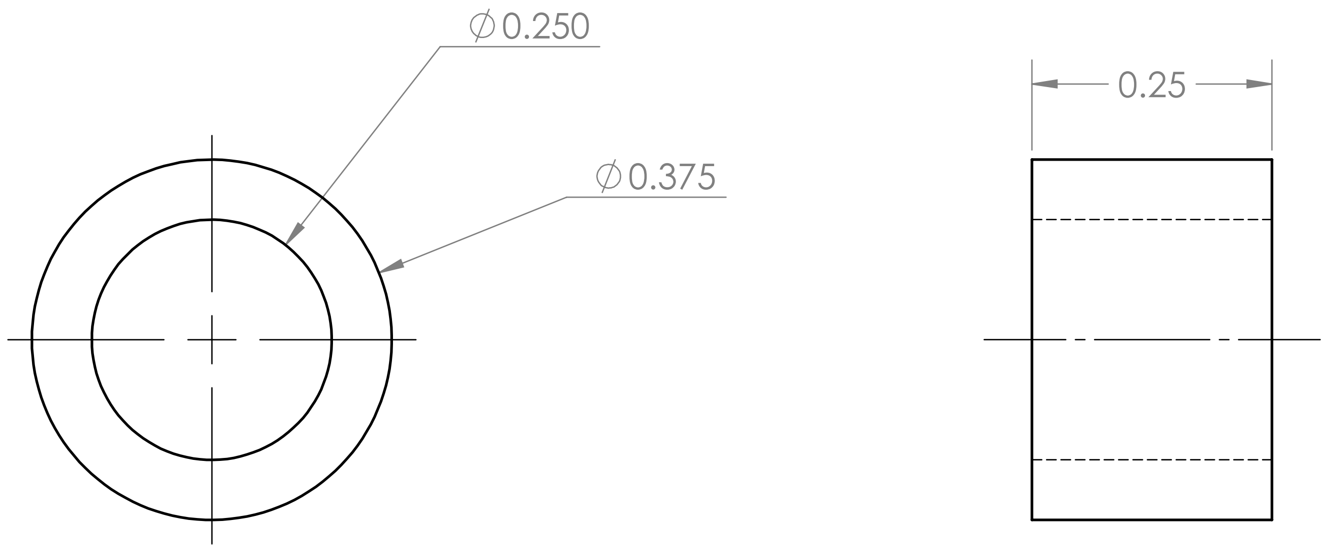
MATERIAL
304 STAINLESS STEEL

COMMENTS:
DO NOT SCALE DRAWING

SIZE **A** | PART NO. 1207 | REV

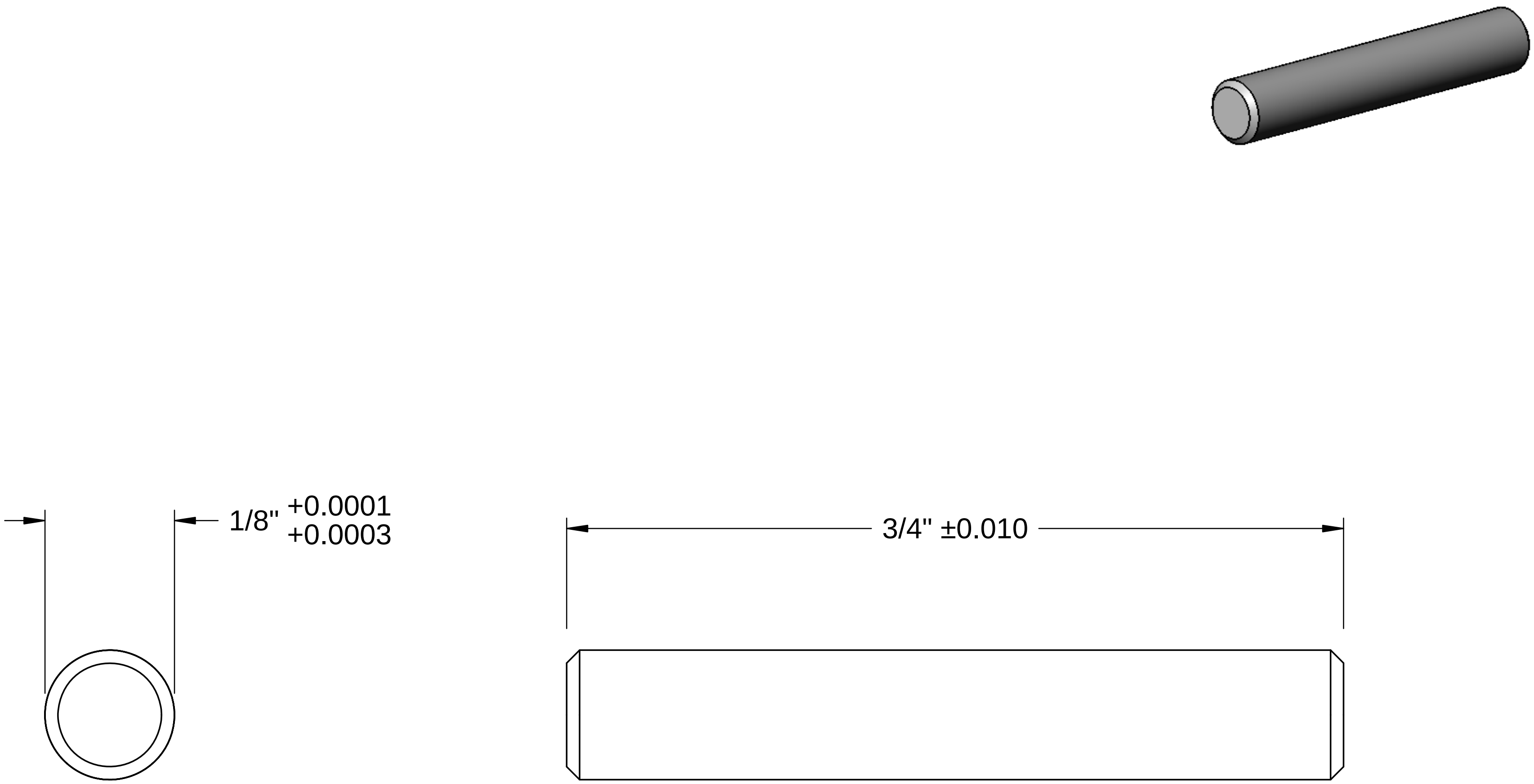
SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DRAWN	GTL	1/31/17
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	MATERIAL RULON 641		
	COMMENTS: DO NOT SCALE DRAWING		

TITLE: SLEEVE BEARING		
SIZE A	PART NO. 1208	REV
SCALE: 5:1	WEIGHT:	SHEET 1 OF 1

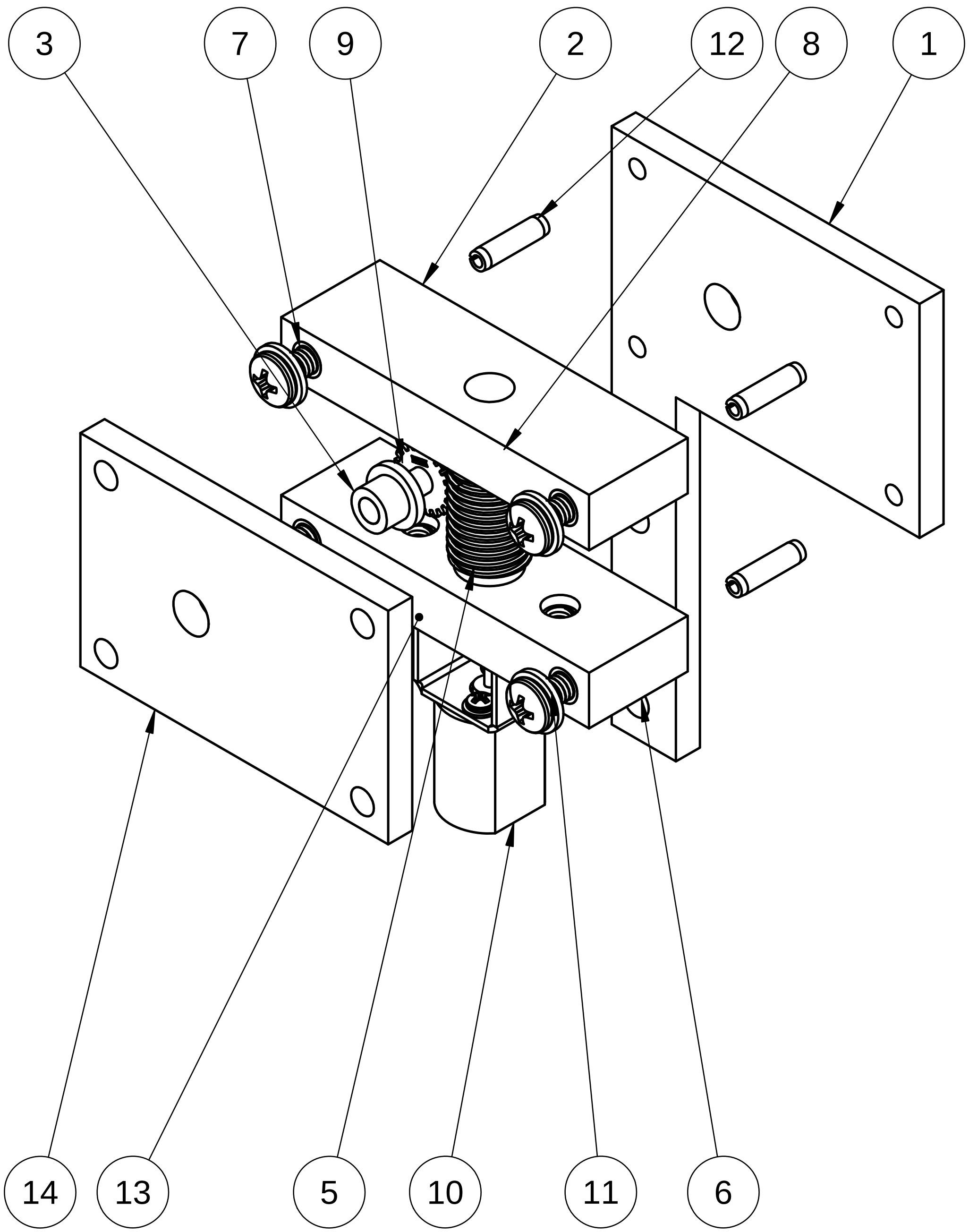


McMASTER-CARR® CAD

PART NUMBER	1209

http://www.mcmaster.com

18-8 Stainless Steel
Dowel Pin



ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1301	BACK PLATE	1
2	1303	TOP PLATE	1
3	1310	FLANGE BEARING	4
4	1309	SPUR GEAR	1
5	1308	WORM GEAR	1
6	1302	BOTTOM PLATE	1
7	4301	#8-32 THREADED INSERT	6
8	1305	WORM SHAFT	1
9	1306	DRIVE SHAFT	1
10	1311	MOTOR ASSEMBLY	1
11	4201	#8 18-8 FLAT WASHER	6
12	4401	ROLL PIN	4
13	4101	#8-32 PHILLIPS SCREW, 1/4" LG	2
14	1304	FRONT PLATE	1
15	4102	#8-32 PHILLIPS SCREW, 1/2" LG	4

	NAME	DATE
DRAWN	GTL	2/2/17

MATERIAL
VARIES

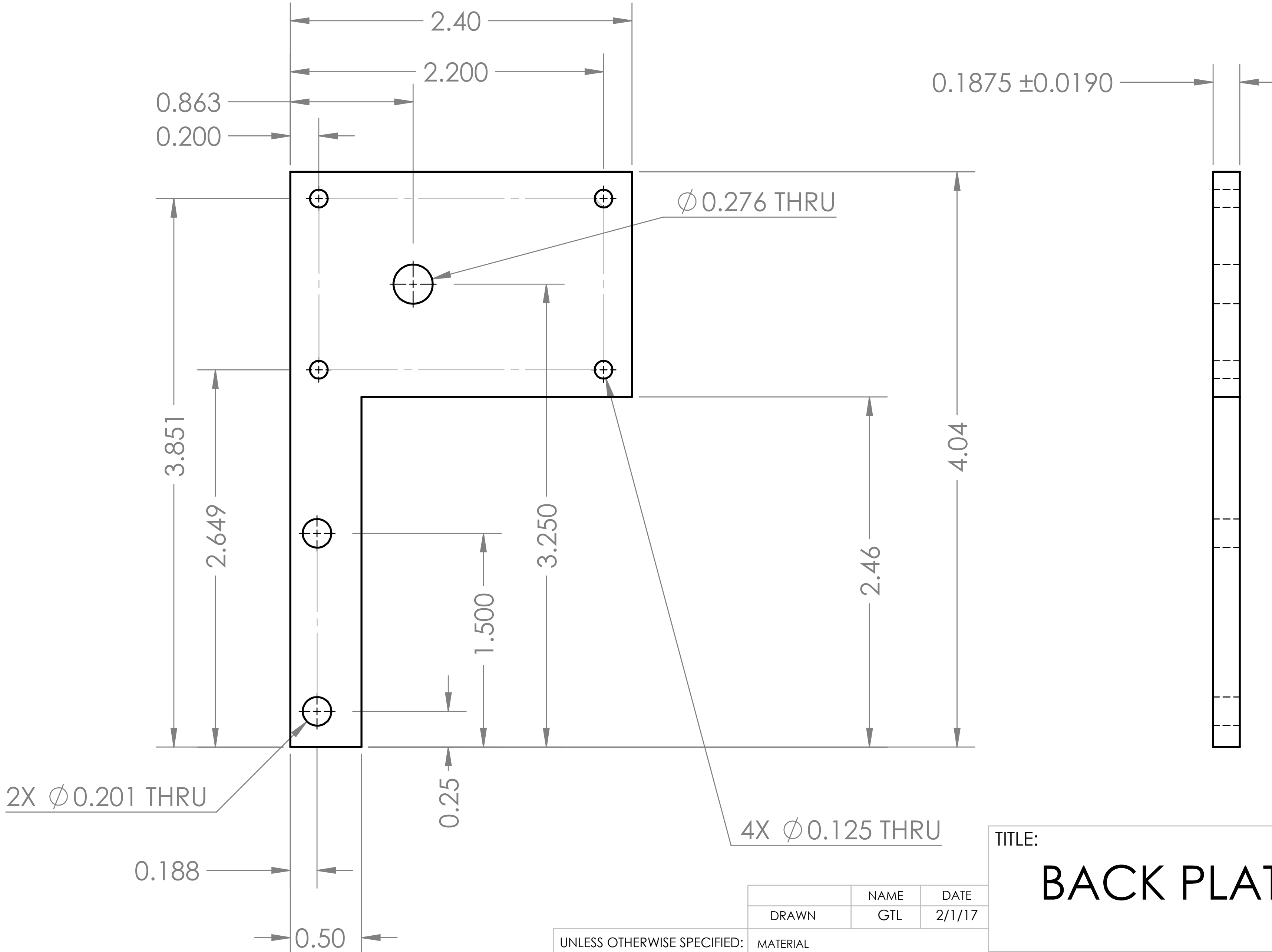
COMMENTS:
DO NOT SCALE DRAWING

TITLE:
GEAR BOX

SIZE A | PART NO. 1102 | REV

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

2 1 B A



	NAME	DATE
DRAWN	GTL	2/1/17

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

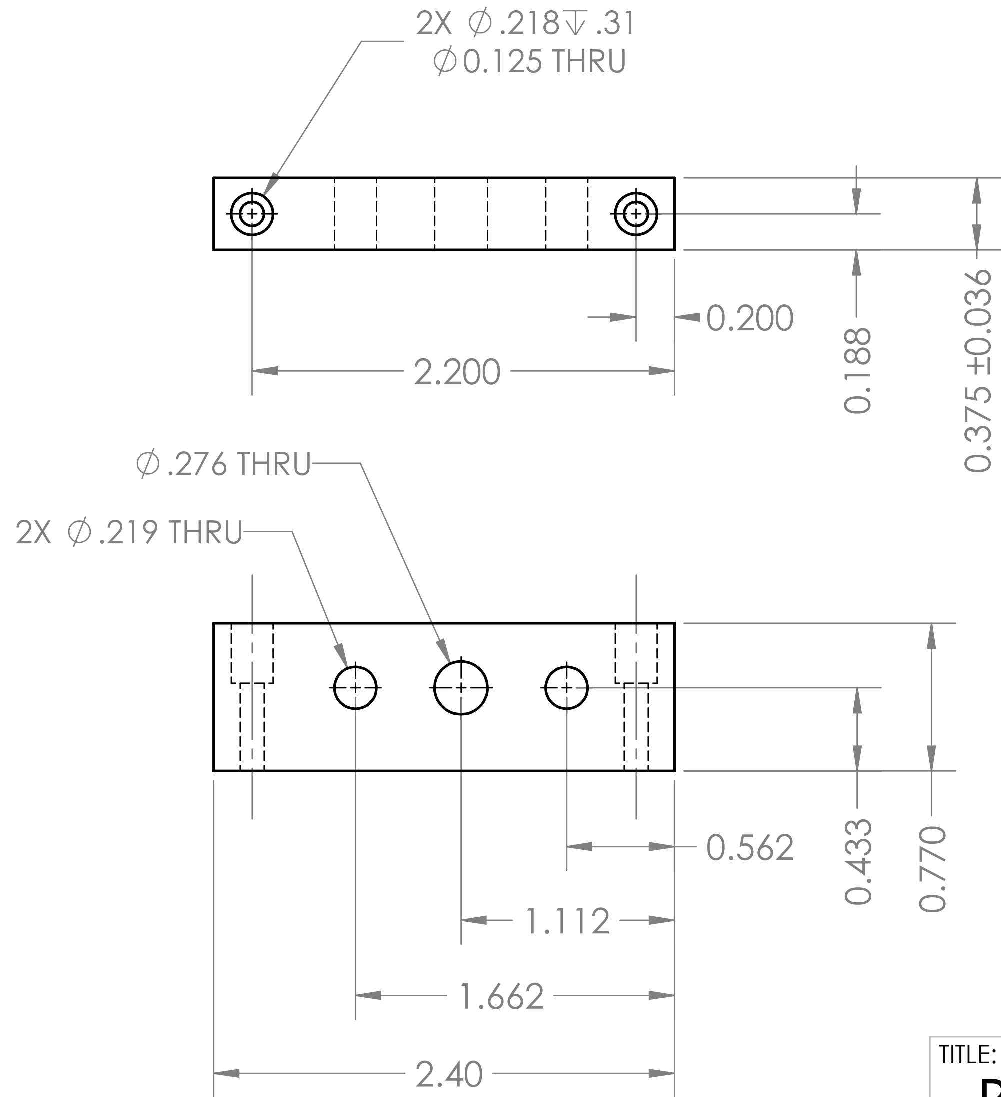
MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
BACK PLATE

SIZE	PART NO.	REV
A	1301	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	GTL	2/1/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

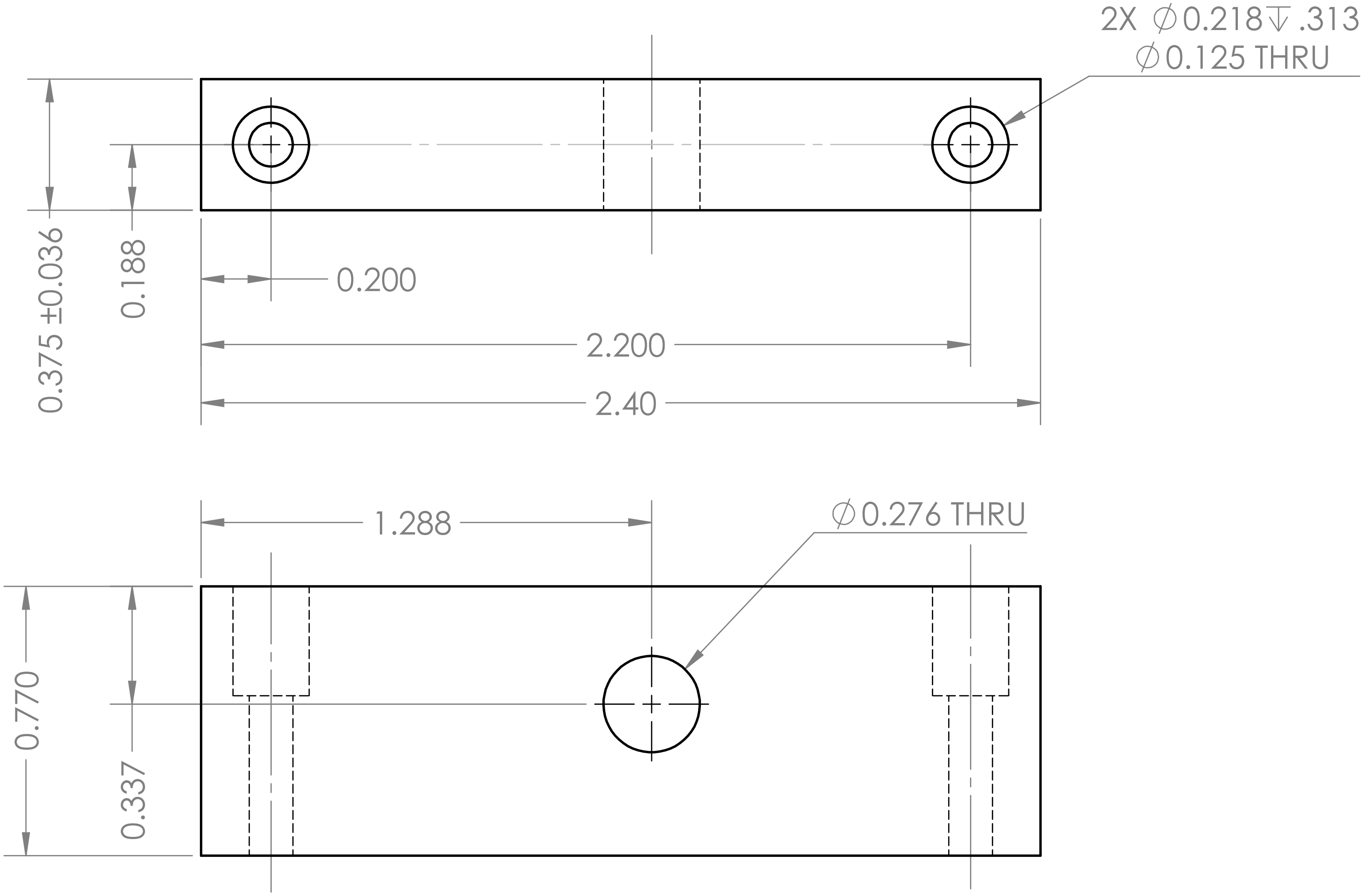
MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
BOTTOM PLATE

SIZE	PART NO.	REV
A	1302	

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



	NAME	DATE
DRAWN	GTL	2/1/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

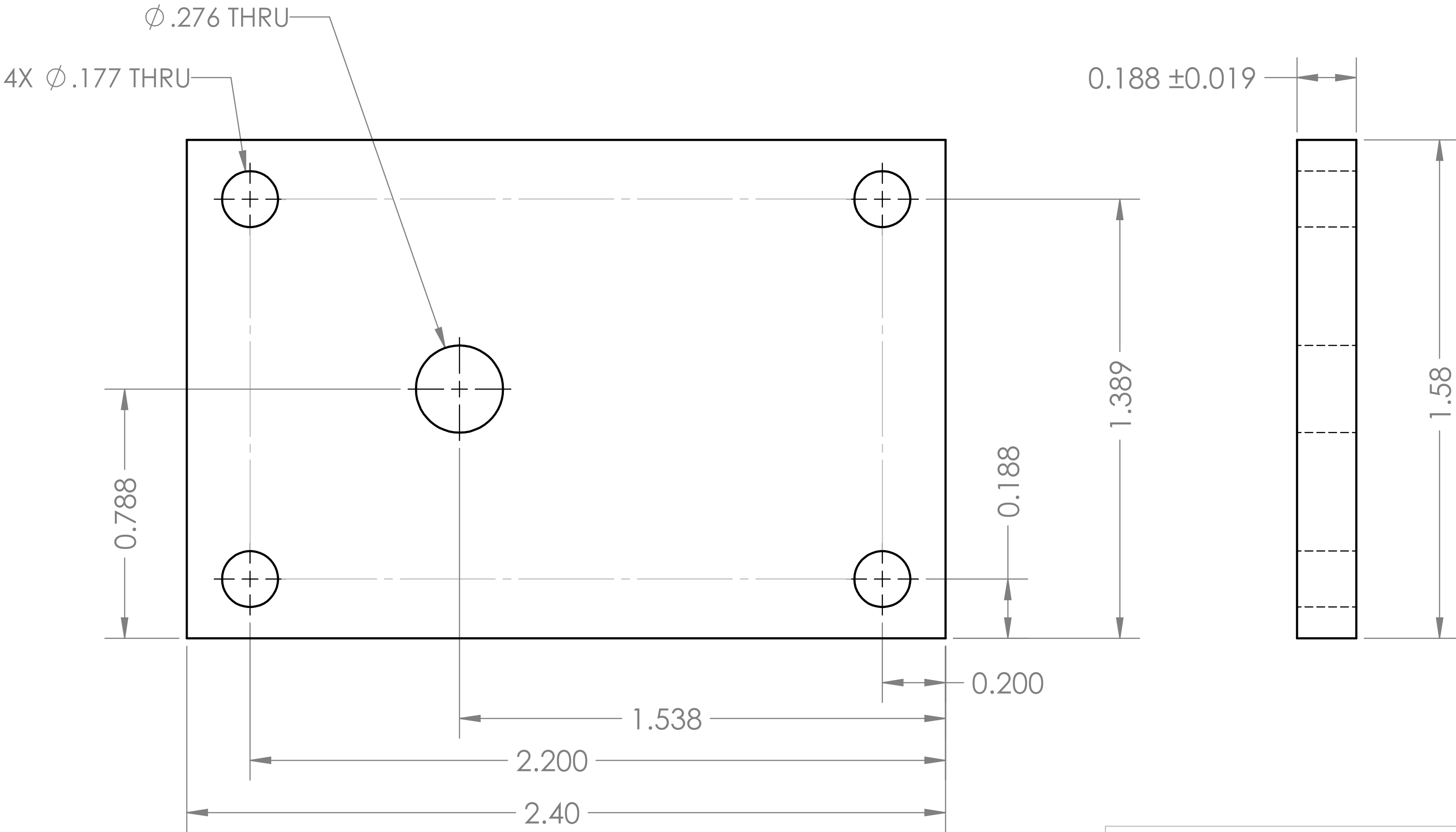
MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
TOP PLATE

SIZE A | PART NO. 1303 | REV

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



TITLE:

FRONT PLATE

	NAME	DATE
DRAWN	GTL	2/1/17

UNLESS OTHERWISE SPECIFIED:

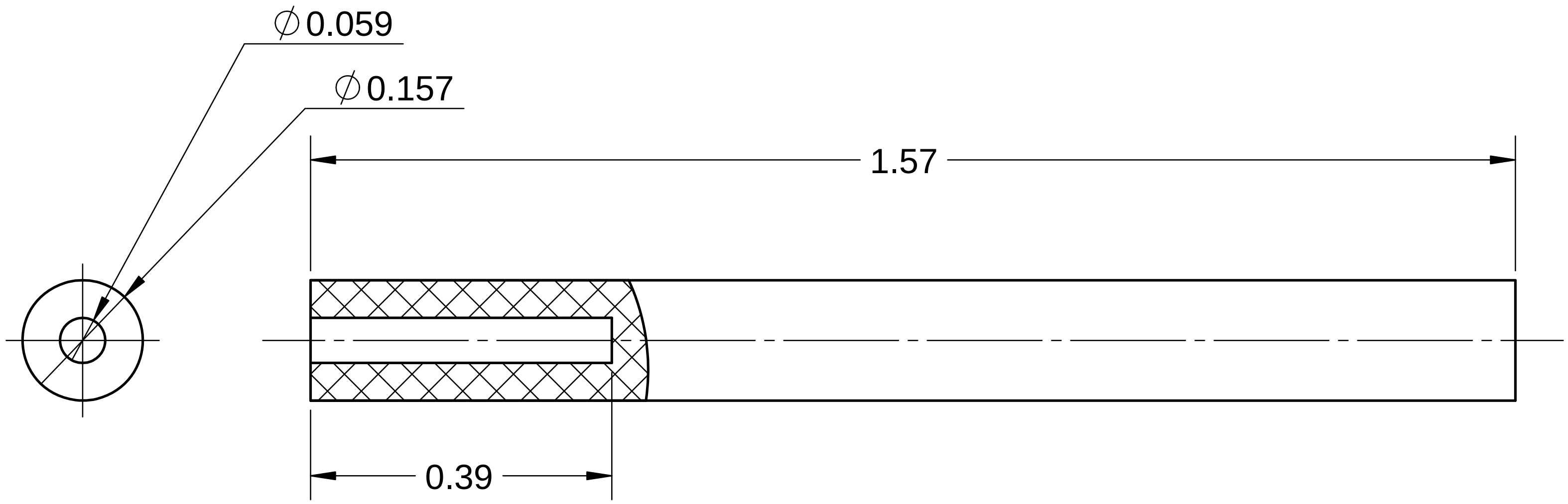
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	1304	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	GTL	2/1/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

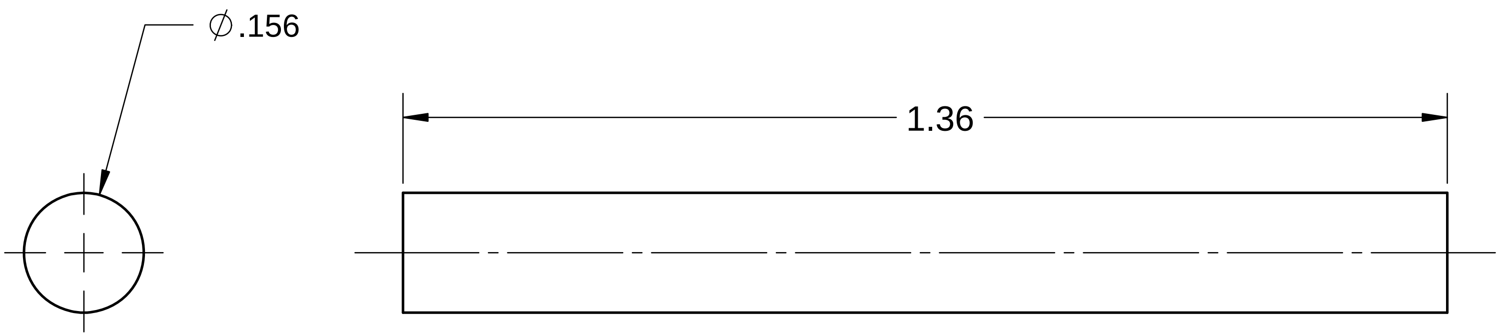
MATERIAL
TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
WORM SHAFT

SIZE **A** PART NO. 1305 REV

SCALE: 4:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

	NAME	DATE
DRAWN	GTL	2/1/17

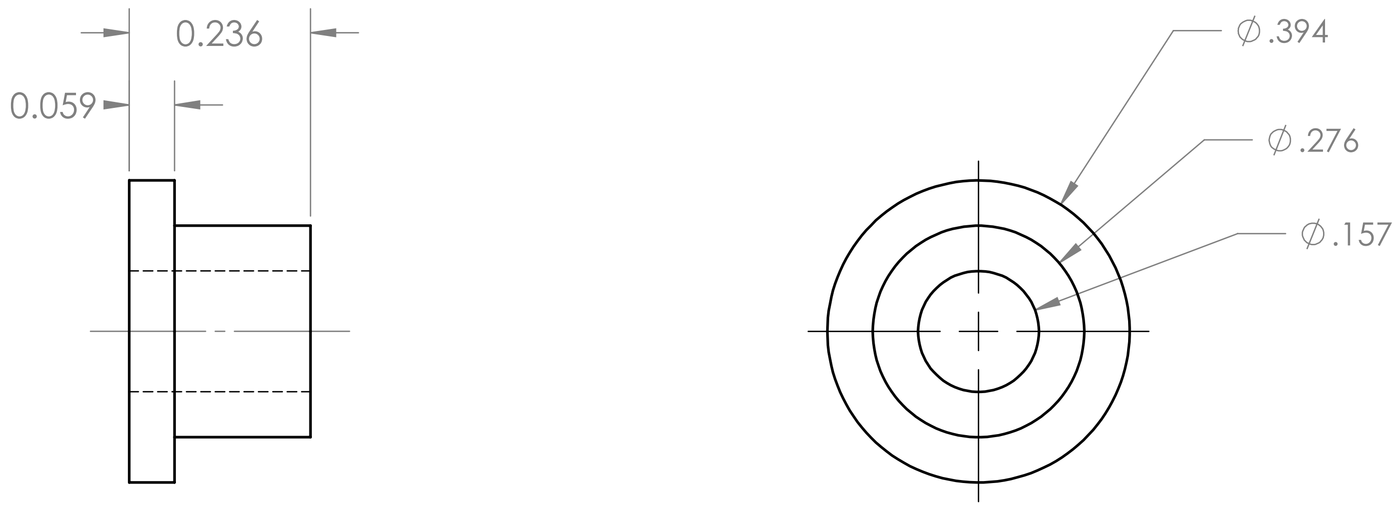
MATERIAL: TYPE 1 PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
DRIVE SHAFT

SIZE	PART NO.	REV
A	1306	

SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

	NAME	DATE
DRAWN	GTL	2/1/17

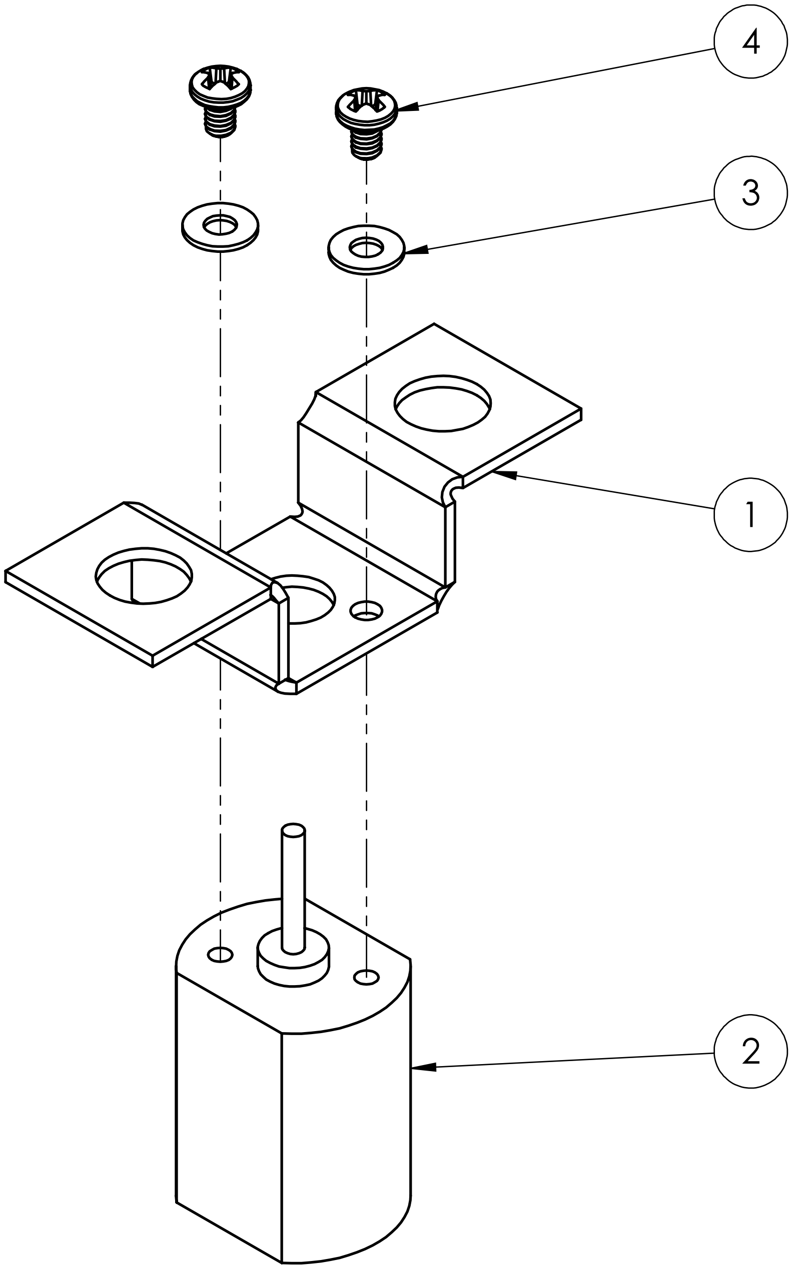
MATERIAL
SAE 841 BRONZE

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
FLANGE BEARING

SIZE	PART NO.	REV
A	1310	

SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1402	MOTOR MOUNT	1
2	1401	MOTOR, PPN7PA12C1	1
3	4202	M2 FLAT WASHER	2
4	4105	M2 PHILLIPS HEAD SCREW, 3MM LG	2

	NAME	DATE
DRAWN	GTL	2/1/17

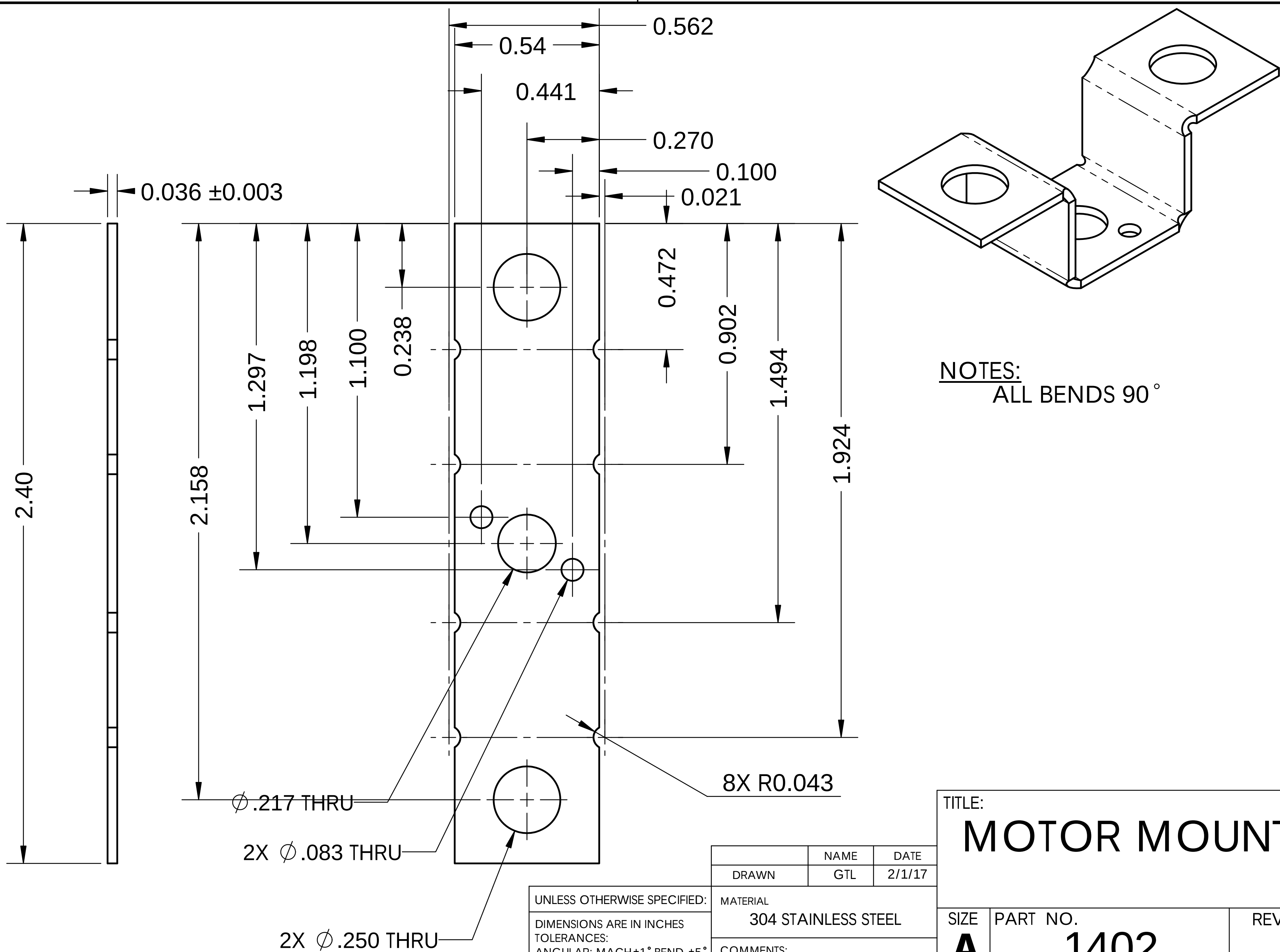
MATERIAL: VARIES

COMMENTS: DO NOT SCALE DRAWING

TITLE: MOTOR ASSEMBLY

SIZE: A | PART NO. 1311 | REV

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



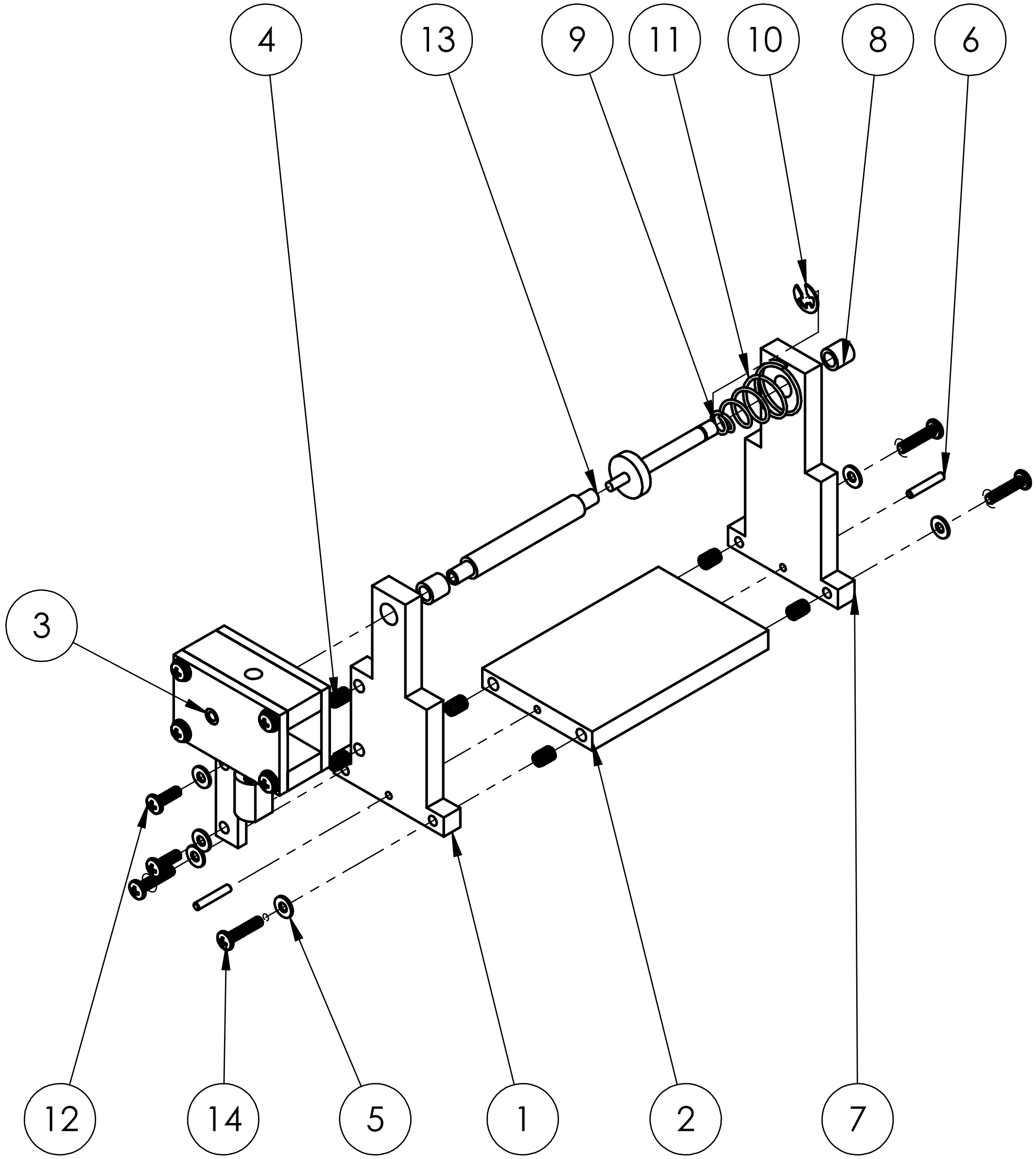
NOTES:
ALL BENDS 90°

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DRAWN	GTL	2/1/17
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	MATERIAL 304 STAINLESS STEEL COMMENTS: DO NOT SCALE DRAWING		

TITLE:
MOTOR MOUNT

SIZE	PART NO.	REV
A	1402	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	2101	GEAR BOX MOUNT	1
2	2104	FOOT	1
3	1102	GEAR BOX	1
4	4301	8-32 THREADED INSERT	6
5	4201	#8 FLAT WASHER	6
6	1209	ALIGNMENT PIN	2
7	2102	COUNTER SUPPORT	1
8	2103	SLEEVE BEARING	2
9	2107	SPRING SHAFT	1
10	2105	1/4" SHAFT E-CLIP	1
11	2108	CONICAL SPRING	1
12	4102	#8-32 PHILLIPS SCREW, 1/2" LONG	2
13	2106	AUXILIARY ROLLER	1
14	4103	#8-32 PHILLIPS SCREW, 5/8" LONG	4

	NAME	DATE
DRAWN	GTL	2/5/17

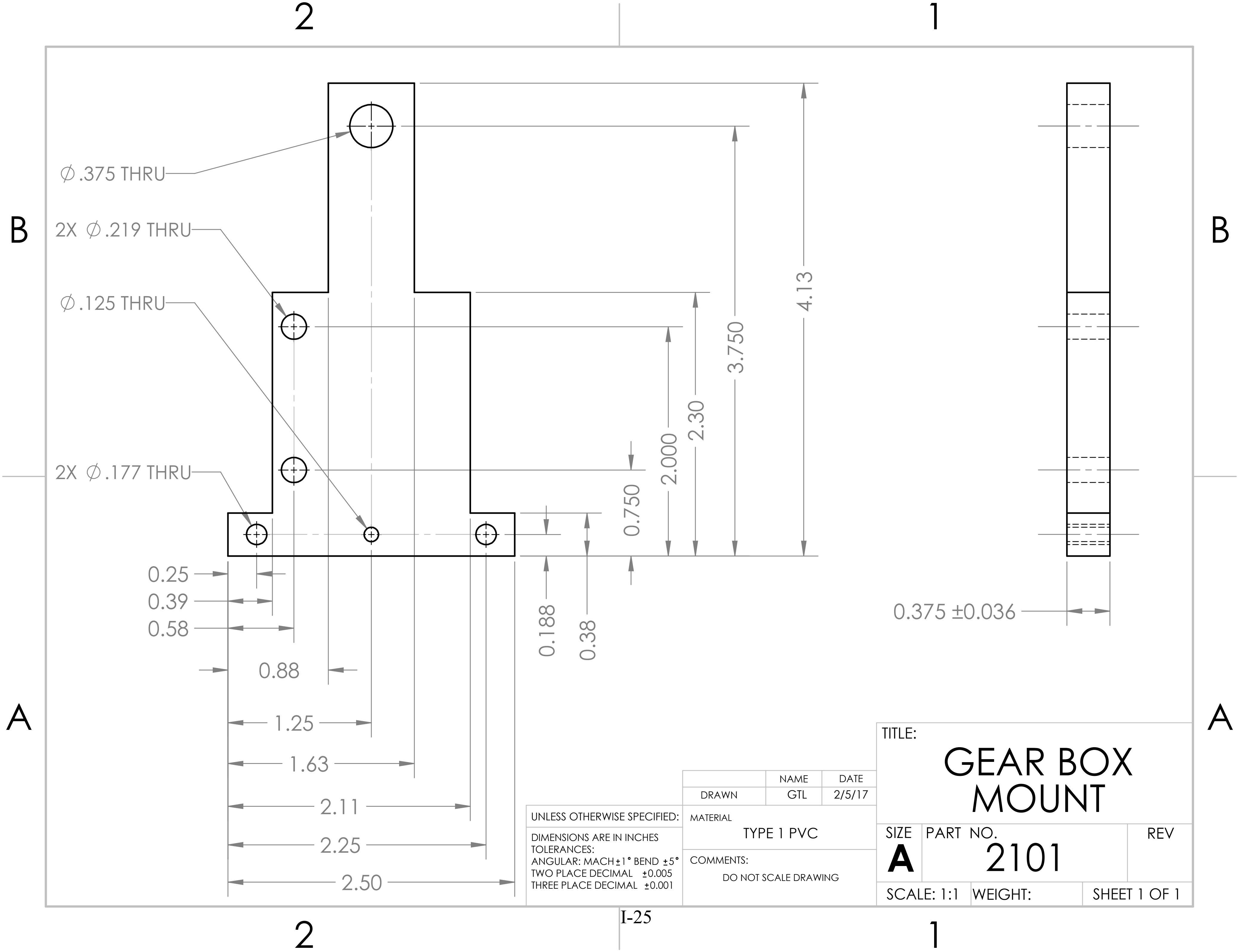
MATERIAL: VARIES

COMMENTS: DO NOT SCALE DRAWING

TITLE: ROLLER ASSEMBLY

SIZE: A | PART NO.: 2000 | REV:

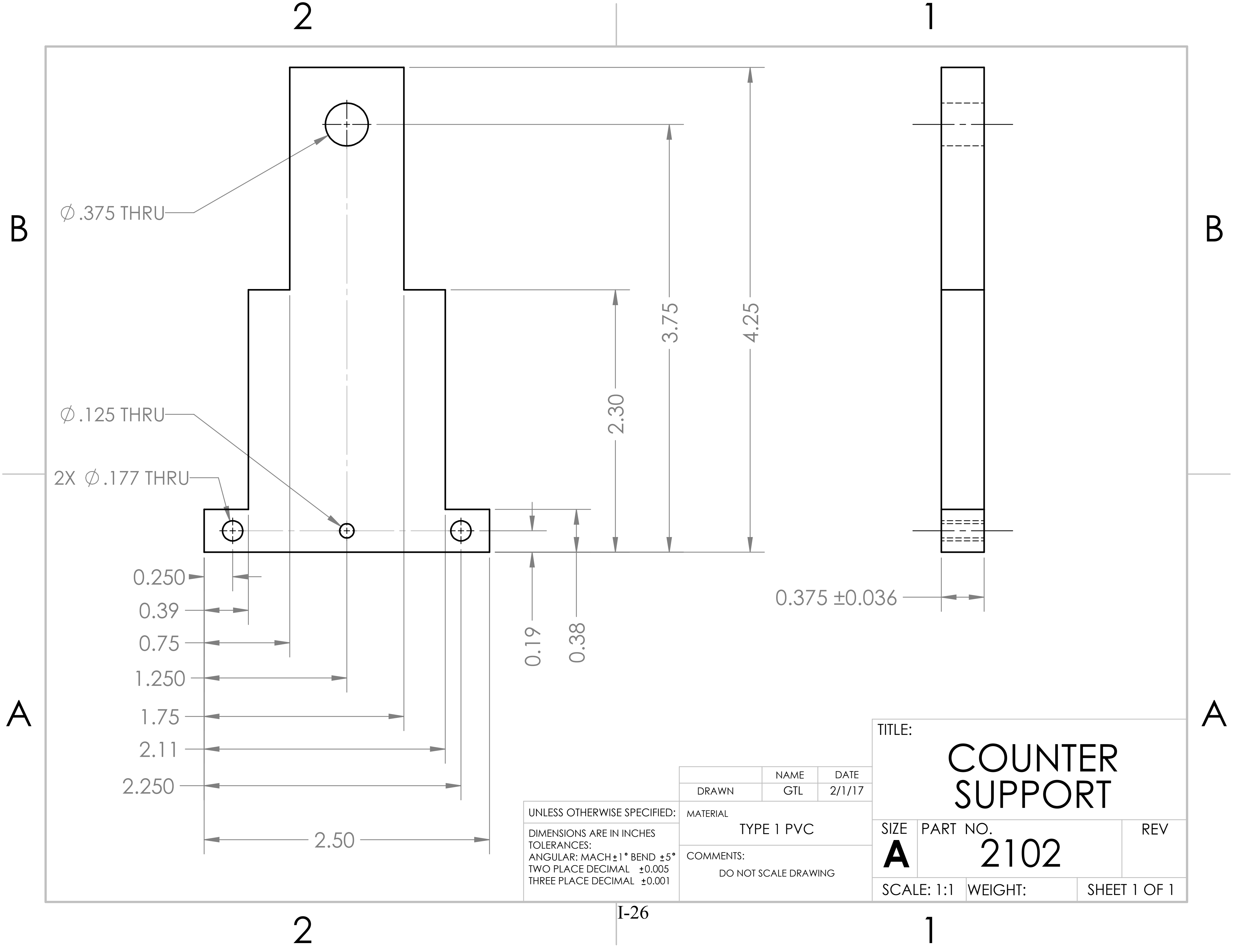
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1



TITLE: GEAR BOX MOUNT		
	NAME	DATE
DRAWN	GTL	2/5/17
MATERIAL	TYPE 1 PVC	
COMMENTS:	DO NOT SCALE DRAWING	
SIZE A	PART NO. 2101	REV
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

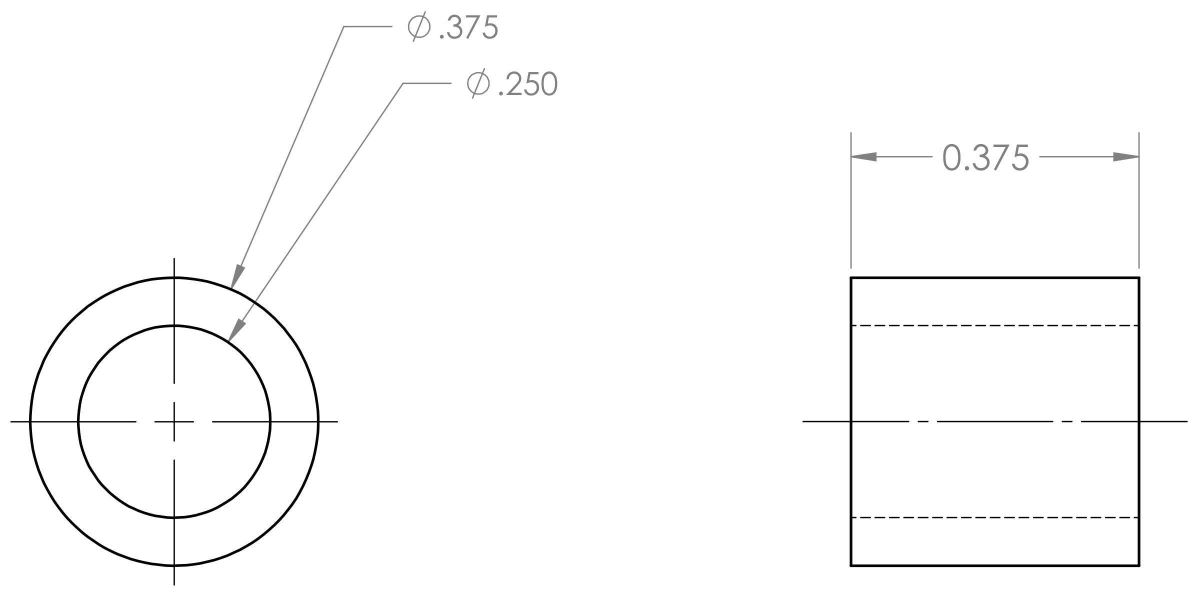


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DRAWN	GTL	2/1/17
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	MATERIAL TYPE 1 PVC COMMENTS: DO NOT SCALE DRAWING		

TITLE:

COUNTER SUPPORT

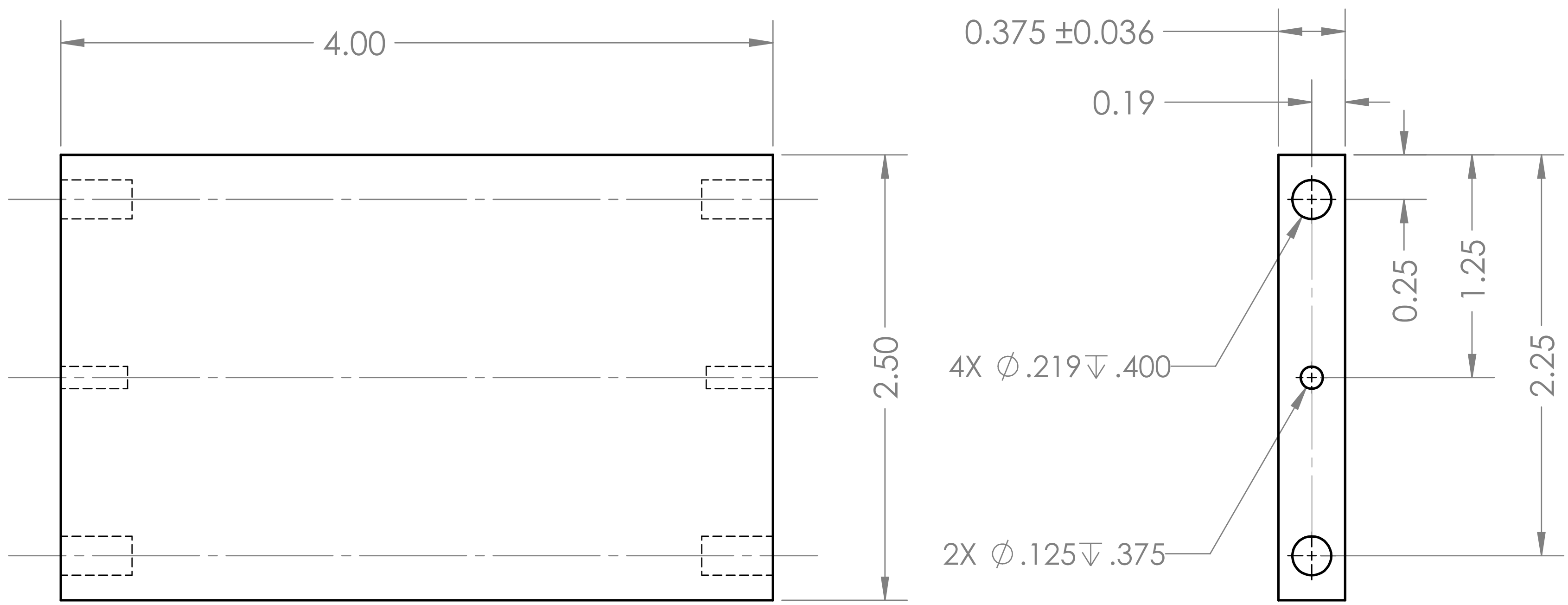
SIZE	PART NO.	REV
A	2102	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



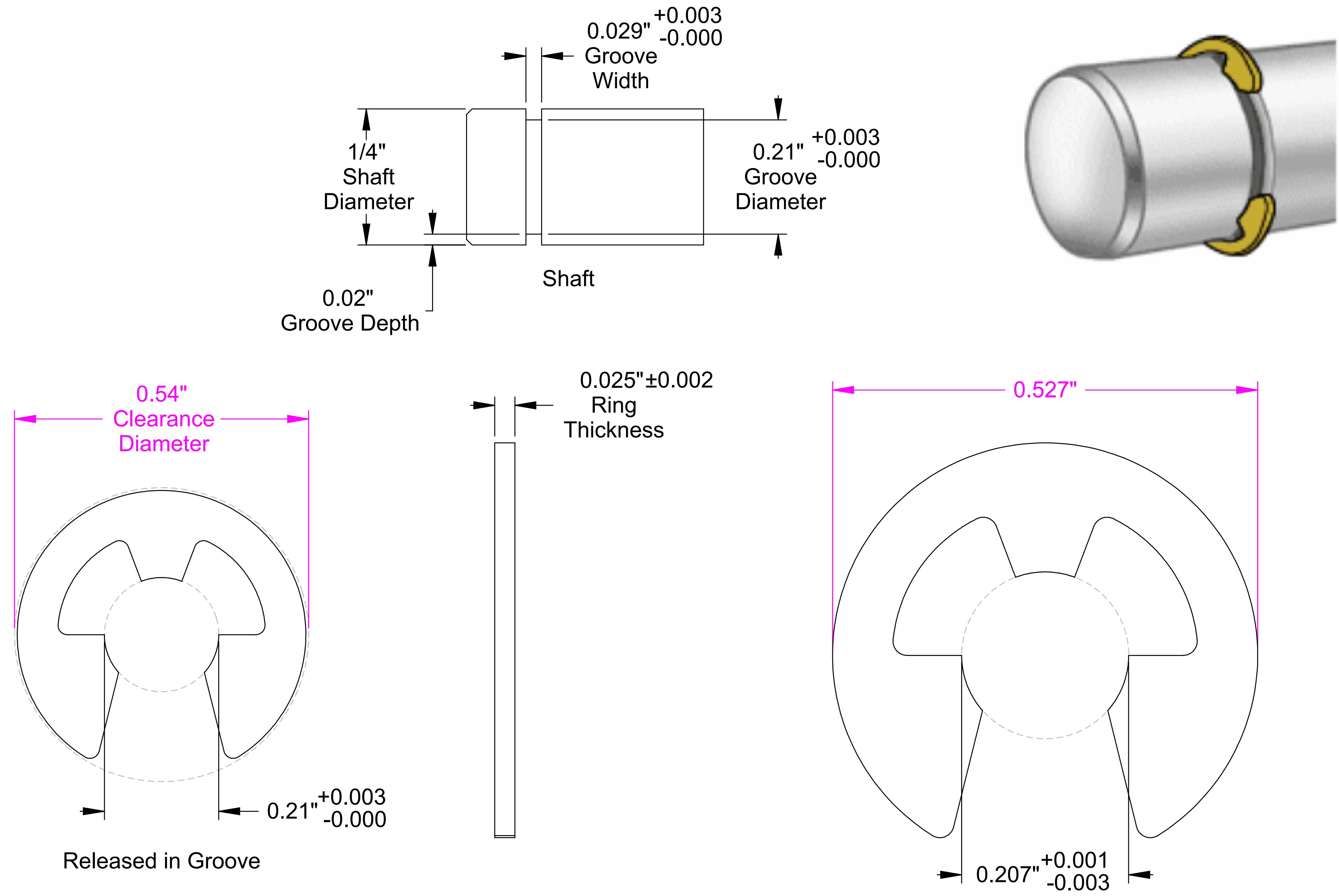
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DRAWN	GTL	2/5/17
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	MATERIAL TEFLON PTFE COMMENTS: DO NOT SCALE DRAWING		

TITLE: BEARING

SIZE	PART NO.	REV
A	2103	
SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



		NAME	DATE	TITLE: FOOT
	DRAWN	GTL	2/5/17	
UNLESS OTHERWISE SPECIFIED:	MATERIAL TYPE 1 PVC			SIZE A · PART NO. 2104 · REV
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	COMMENTS: DO NOT SCALE DRAWING			SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

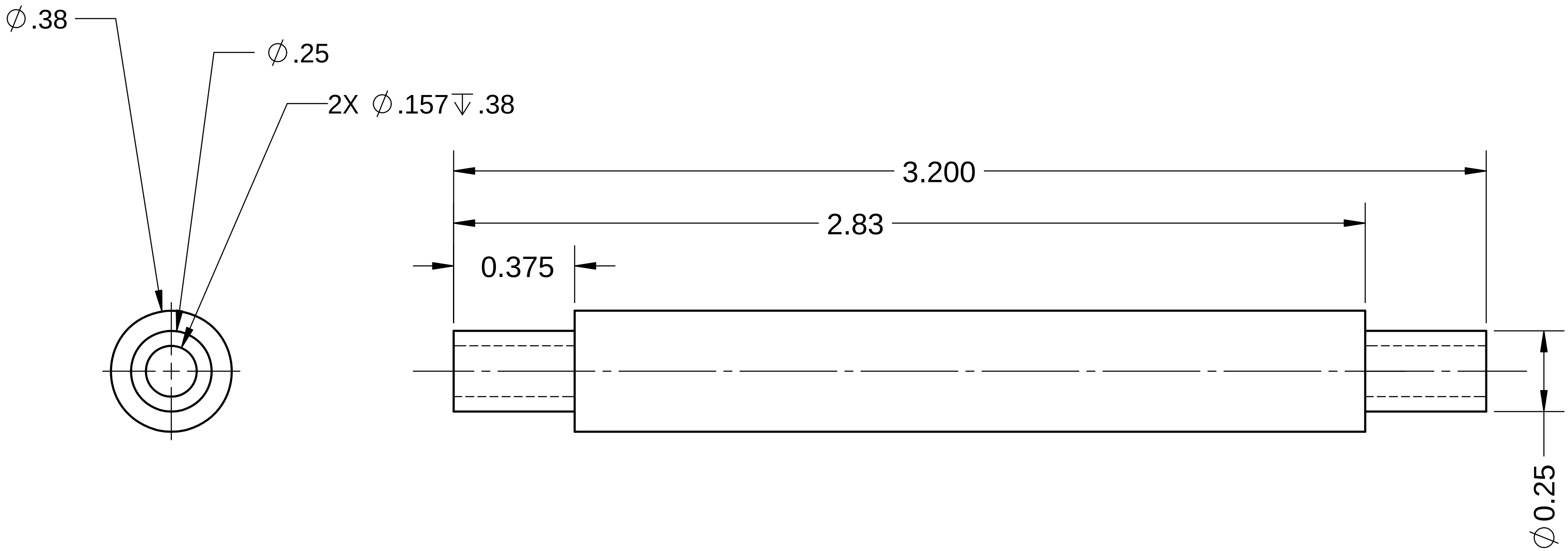


Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

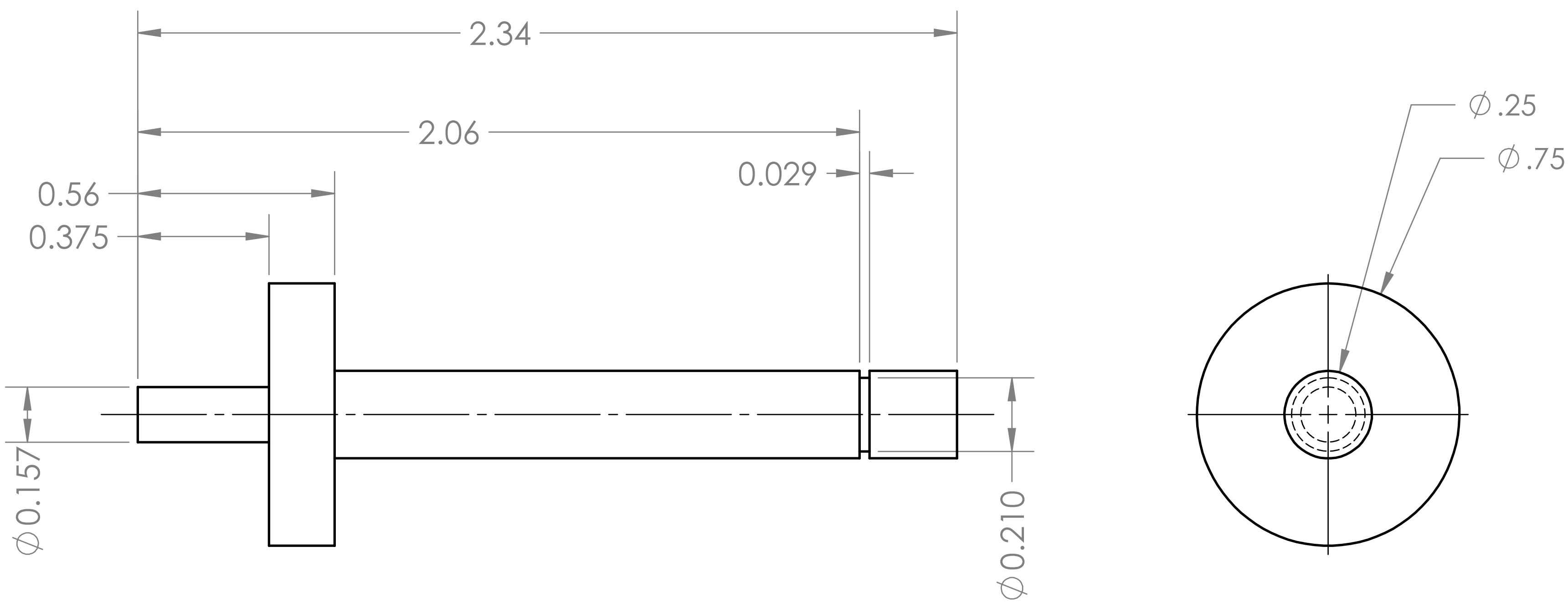
McMASTER-CARR® CAD

PART NUMBER **2105**

Black-Finish Steel Side-Mount External Retaining Ring



	NAME	DATE	TITLE: AUXILIARY ROLLER	
DRAWN	GTL	2/5/17		
UNLESS OTHERWISE SPECIFIED:	MATERIAL POLYPROPYLENE		SIZE A	PART NO. 2106 / REV
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	COMMENTS: DO NOT SCALE DRAWING		SCALE: 2:1	WEIGHT: / SHEET 1 OF 1



TITLE:

SPRING SHAFT

	NAME	DATE
DRAWN	GTL	2/5/17

UNLESS OTHERWISE SPECIFIED:

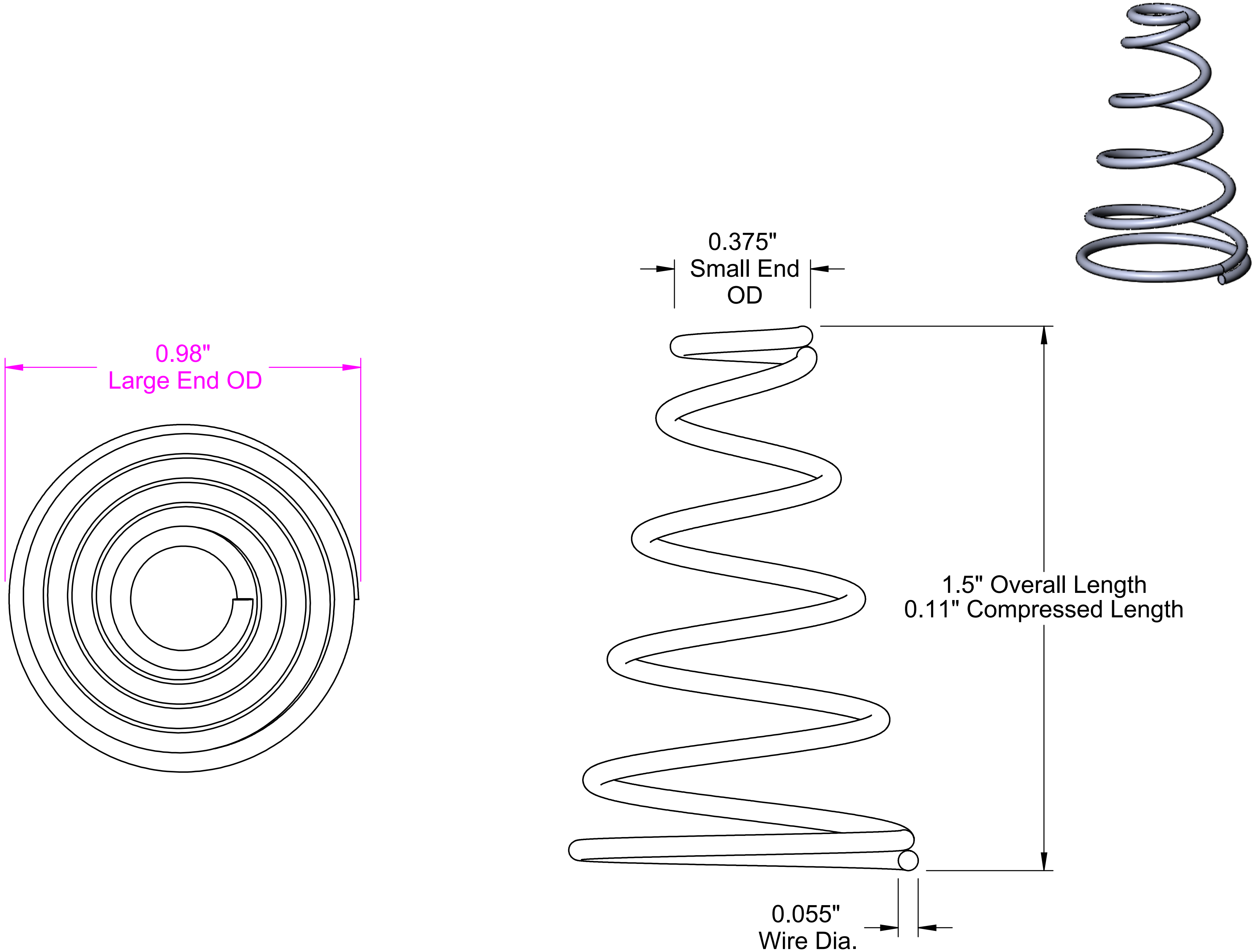
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL
POLYPROPYLENE

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	2107	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

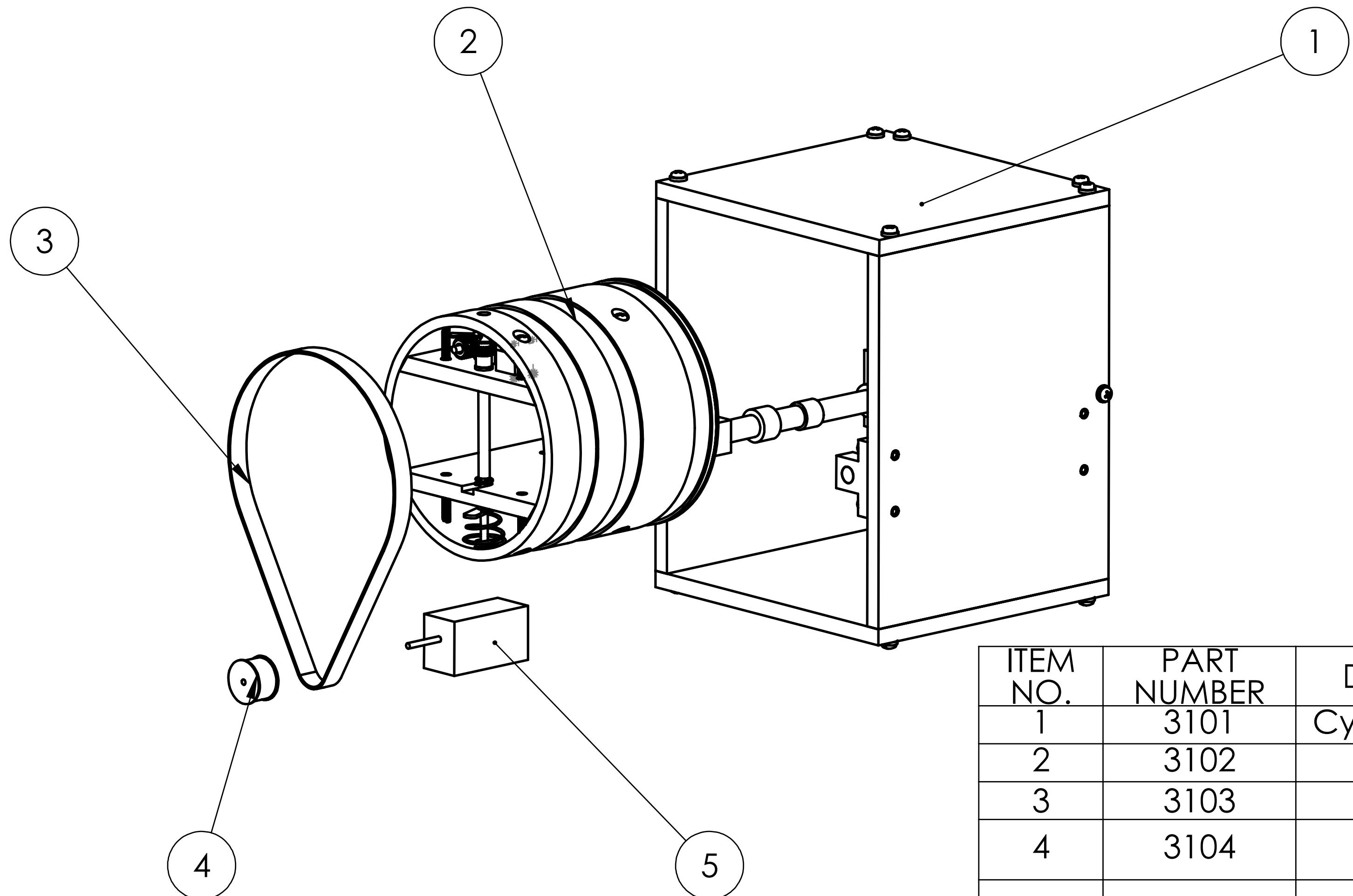


McMASTER-CARR® CAD

PART NUMBER **2108**

http://www.mcmaster.com

Confined-Space Conical Compression Spring



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3101	Cylinder Housing	1
2	3102	Cylinder	1
3	3103	Drive Belt	1
4	3104	Belt Pulley	1
5	3105	Motor	1

TITLE: E-Differental

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

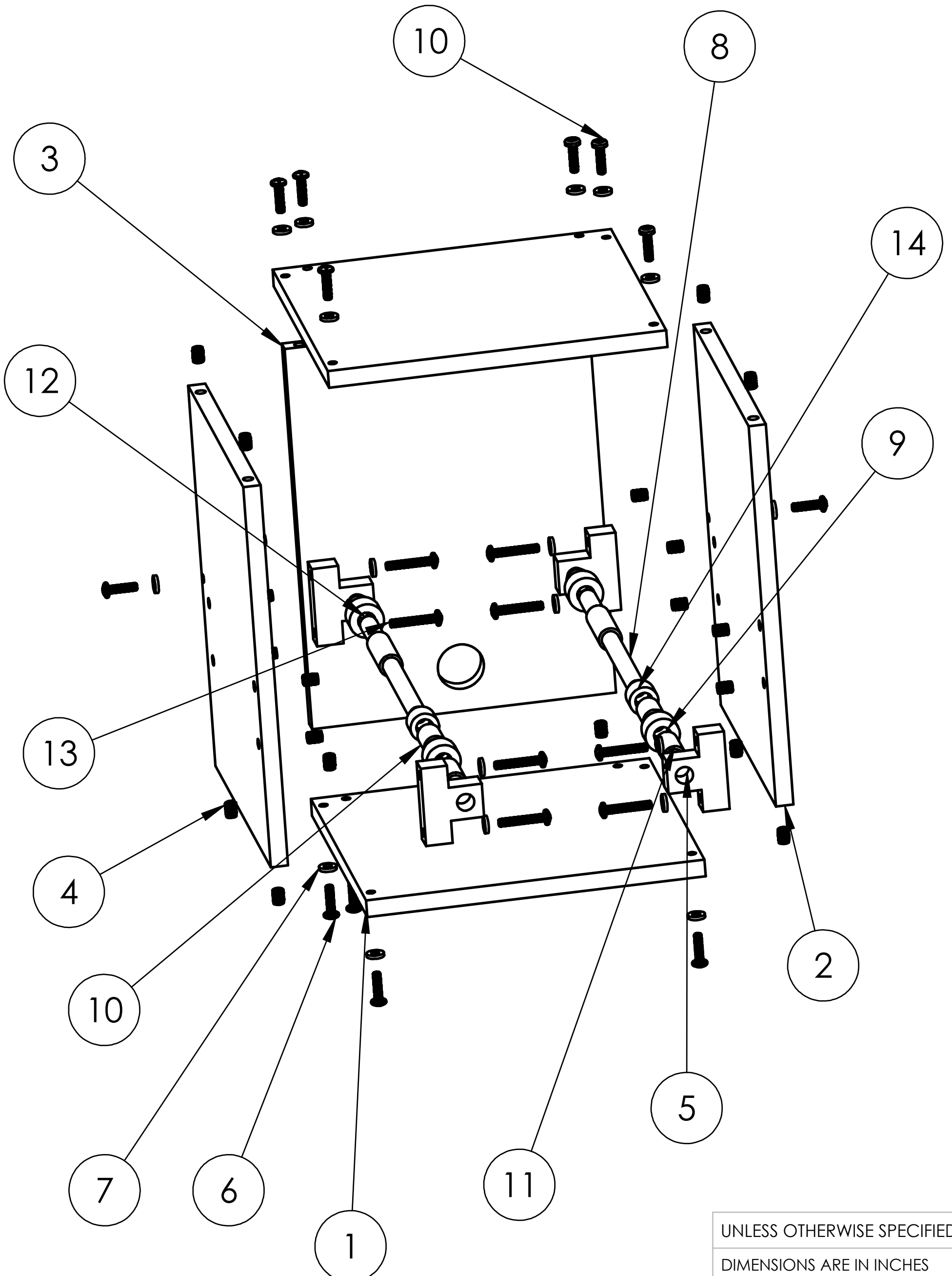
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

Various Materials

COMMENTS:
DO NOT SCALE DRAWING

SIZE A | PART NO. 3000 | REV

SCALE:1:4 | WEIGHT: 8.11 | SHEET 1 OF 1



ITEM NO.	PART NUMBER	NAME	QTY.
1	3201	COVER PLATE	2
2	3202	SIDE PLATE	2
3	3203	REAR PLATE	1
4	4302	8-32 THREADED INSERT	22
5	3204	ROD SUPPORT	4
6	4103	8-32PHILLIPS HEAD SCREW, 3/4"	14
7	4203	#8 FLAT WASHER NYLON	22
8	3205	STEP ROD	2
9	3206	CYLINDER ROLLER	4
10	3207	SPACER1	2
11	3208	SPACER2	2
12	3209	SPACER3	2
13	4106	8-32PHILLIPS HEAD SCREW,1"	8
14	3210	BELT ROLLER	2

TITLE: CYLINDER HOUSING EXPLODED ASSEMBLY

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

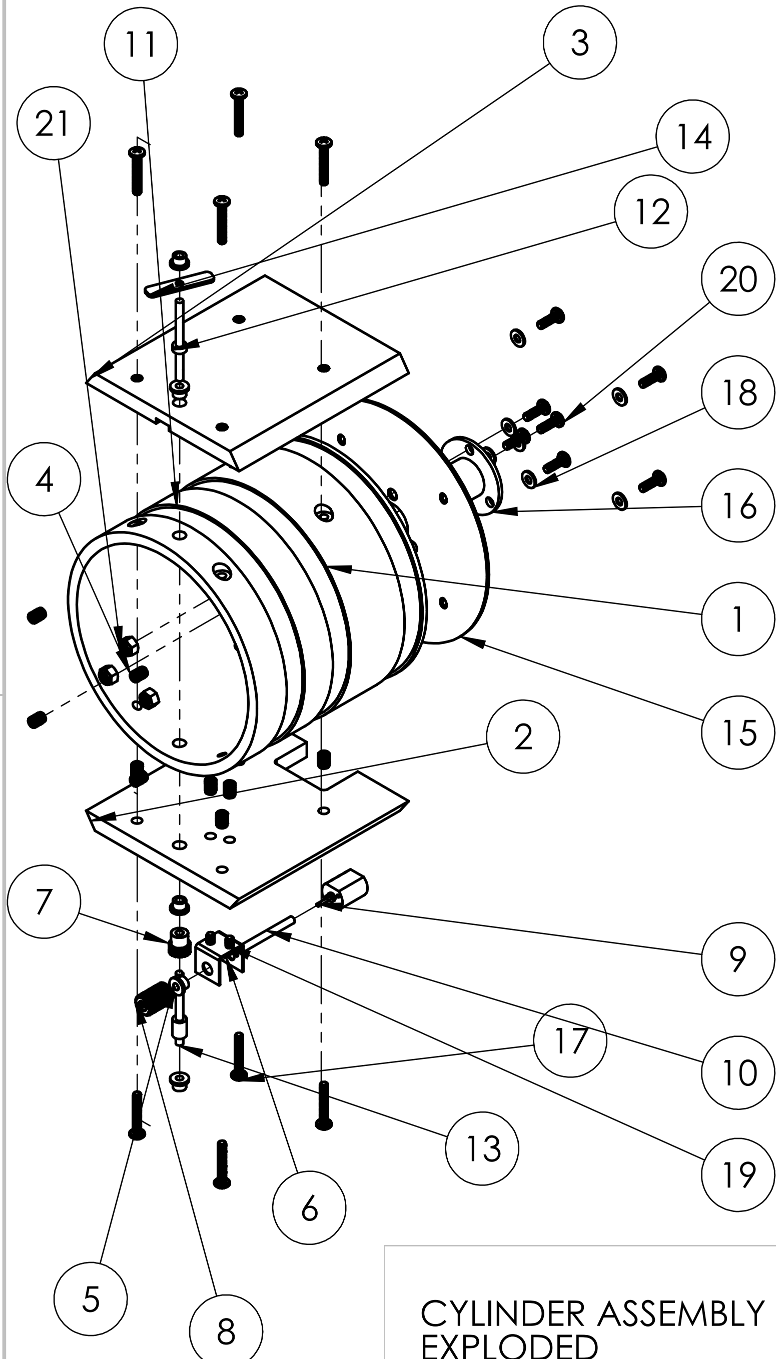
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PVC, PTFE, Polypropylene

COMMENTS:
DO NOT SCALE DRAWING

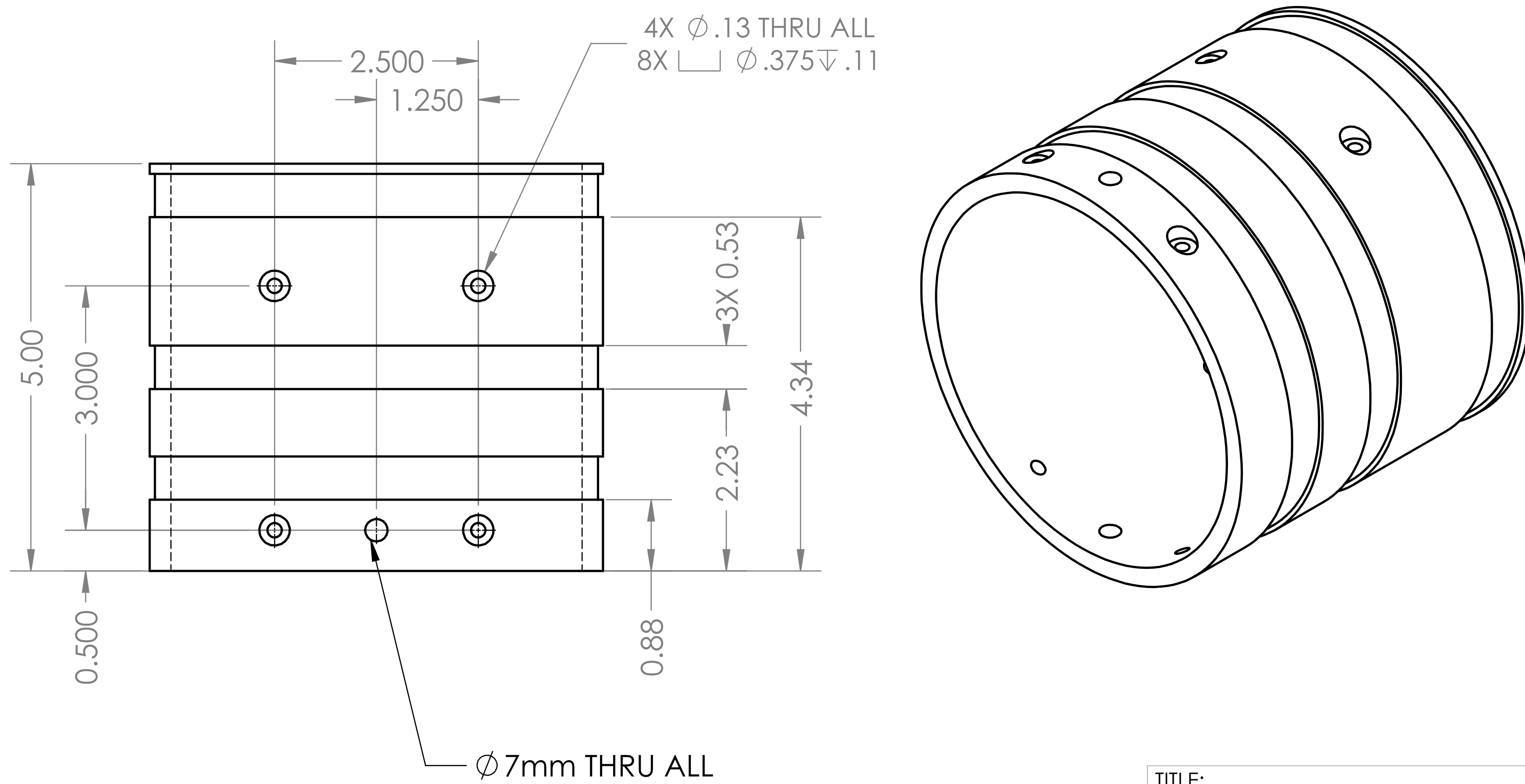
SIZE A | PART NO. 3101 | REV

SCALE: 1:8 | WEIGHT:4.47LBS | SHEET 1 OF 1

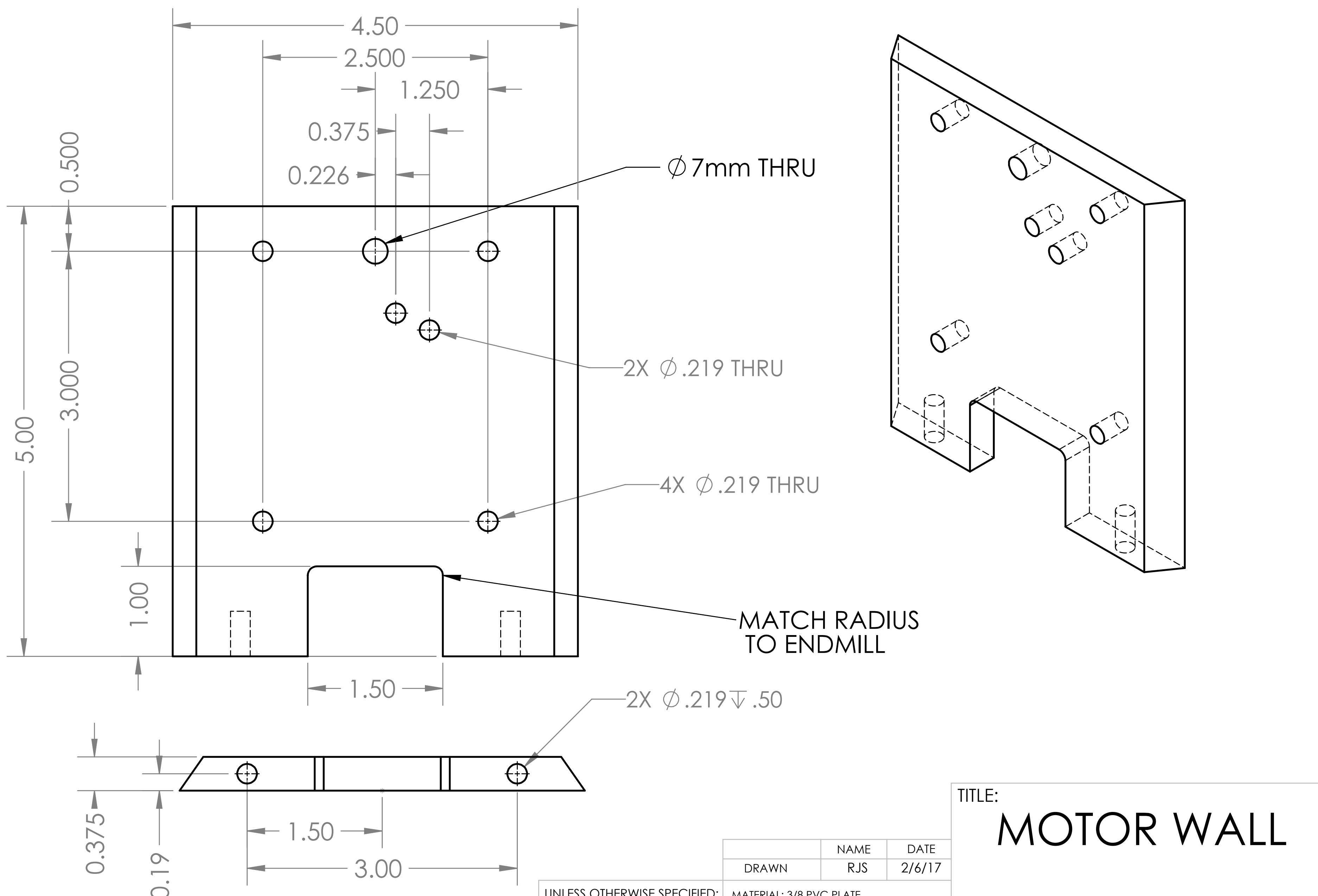


ITEM NO.	DESCRIPTION	PART NO.	Expolded View/QTY.
1	Cylinder	3129	1
2	Motor Wall	3130	1
3	Spring Wall	3138	1
4	Brass Threaded Insert	4302	14
5	FlangeBearing	1310	5
6	Cylinder Motor Mount	3131	1
7	Spur Gear	1309	1
8	Worm Gear	1308	1
9	Motor	1401	1
10	Worm Shaft	1305	1
11	Spool	3134	1
12	Spring Shaft	3139	1
13	Gear Shaft	3132	1
14	Spool Lever	3135	1
15	Cylinder Backing Plate	3136	1
16	Slip Ring	3137	1
17	1 in. #8-32 ZPS	4106	8
18	#8 Flat Washer	4202	7
19	1/4 in. #8-32 ZPS	4102	2
20	1/2 in. #8-32 ZPS	4103	7
21	Nylon-Insert Locknut	4303	3

	DRAWN	RJS	2/6/17
CYLINDER ASSEMBLY EXPLODED	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	MATERIAL VARIOUS COMMENTS: DO NOT SCALE DRAWING	SIZE A	PART NO 3102	REV SCALE: 1:8	WEIGHT:	SHEET 1 OF 1



	NAME	DATE	TITLE: CYLINDER
DRAWN	RJS	2/6/17	
UNLESS OTHERWISE SPECIFIED:	MATERIAL: ALUMINUM		SIZE A
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	COMMENTS: DO NOT SCALE DRAWING		PART NO. 3129	REV
			SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



TITLE: MOTOR WALL

	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

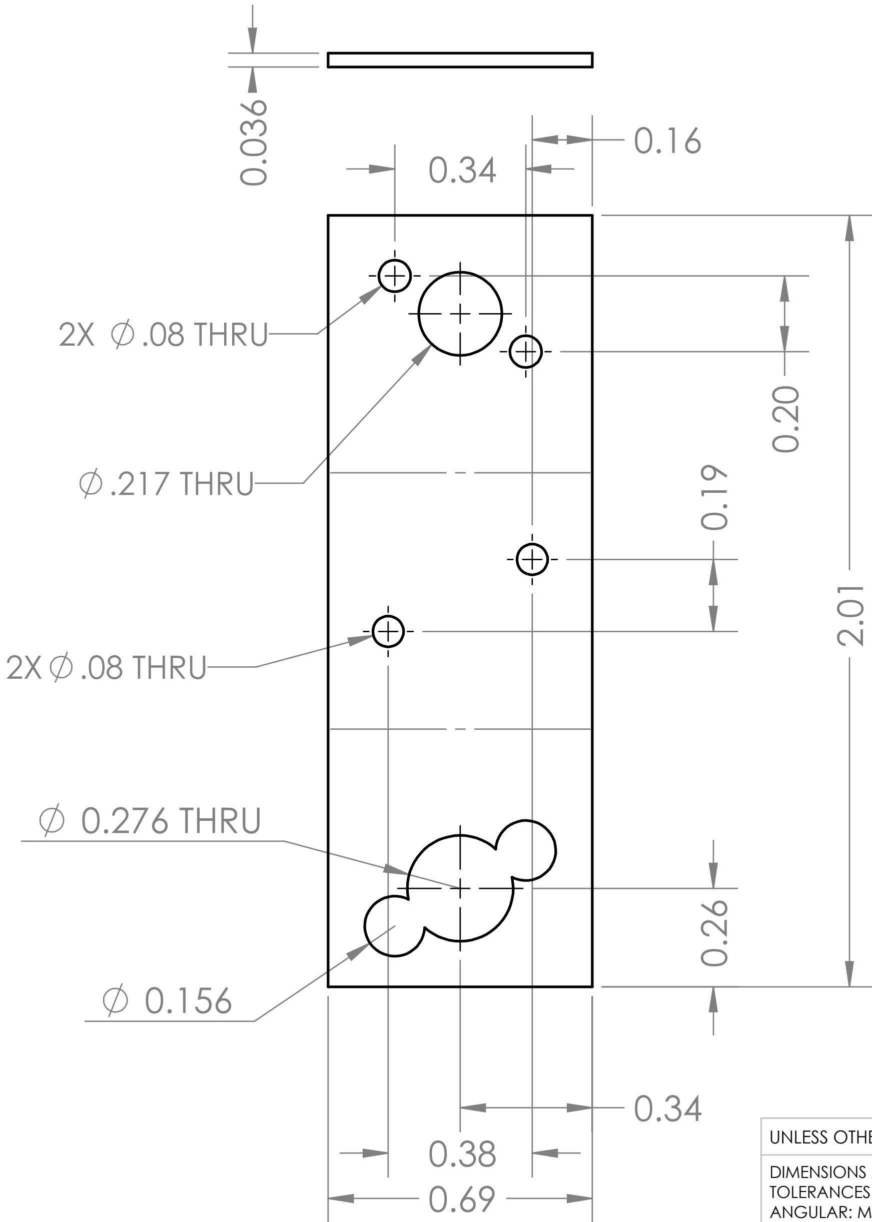
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

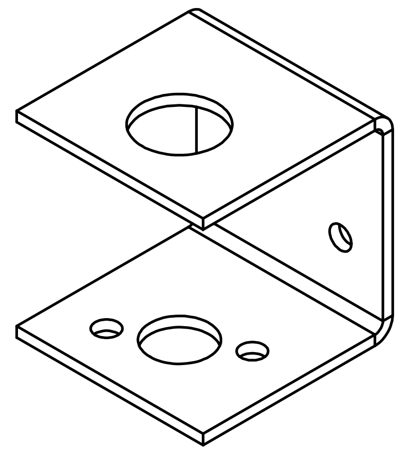
MATERIAL: 3/8 PVC PLATE

COMMENTS:
DO NOT SCALE DRAWING

SIZE A | PART NO. 3130 | REV

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





	NAME	DATE
DRAWN	RJS	2/1/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL: STEEL

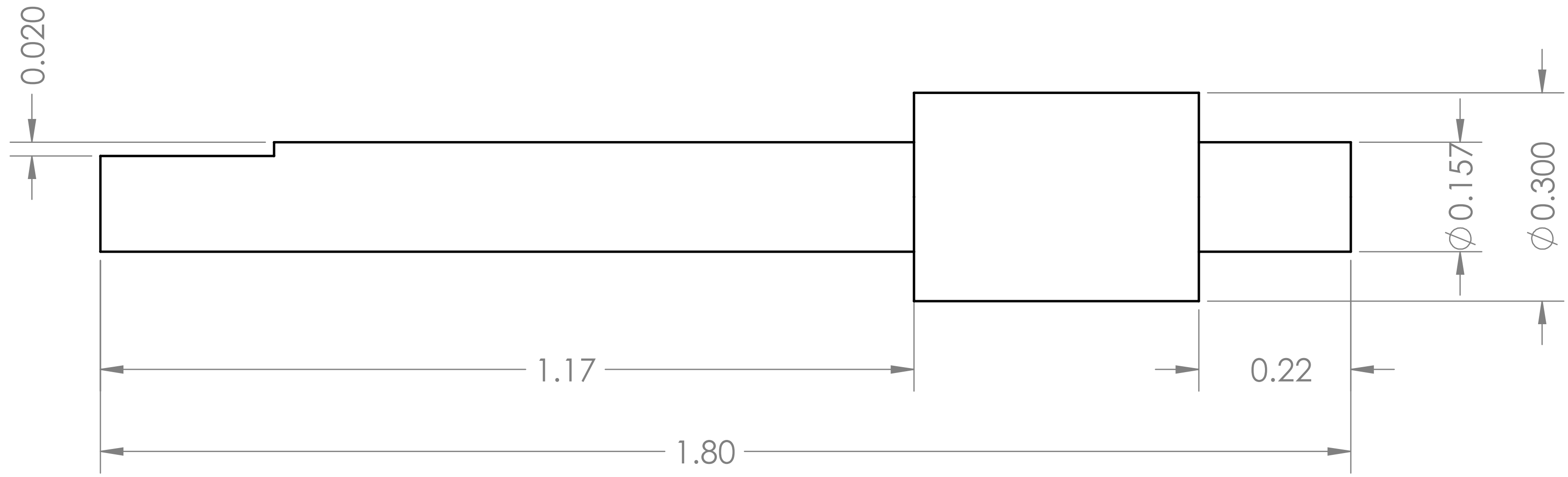
COMMENTS:
DO NOT SCALE DRAWING

TITLE:

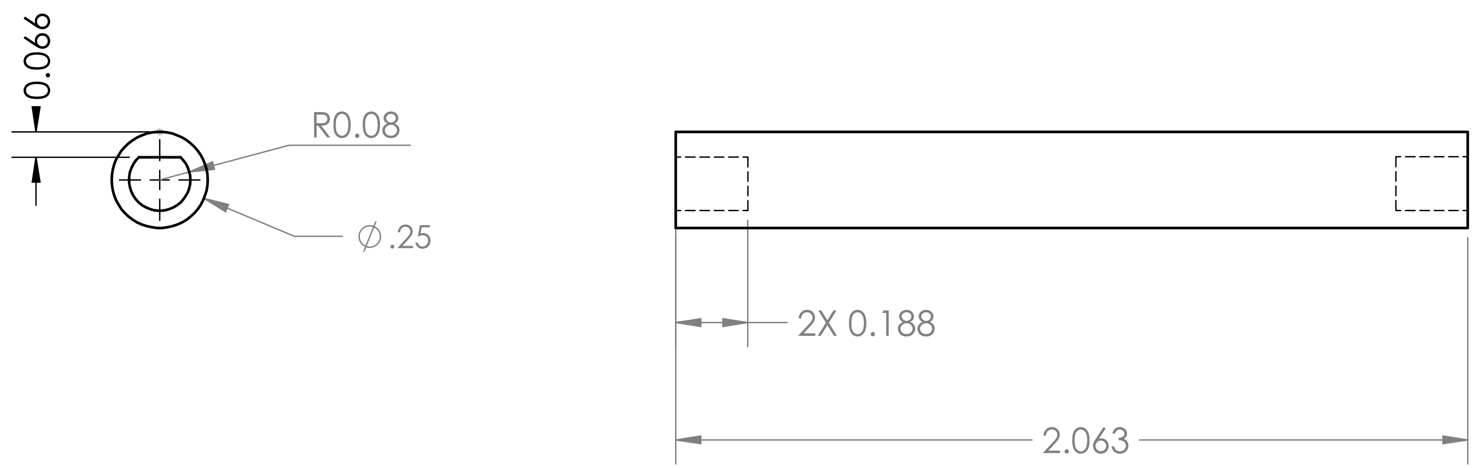
CYLINDER MOTOR MOUNT

SIZE **A** | PART NO. 3131 | REV

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



TITLE: GEAR SHAFT		
	NAME	DATE
DRAWN	RJS	2/6/17
UNLESS OTHERWISE SPECIFIED:	MATERIAL: POLYPROPOLENE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	COMMENTS: DO NOT SCALE DRAWING	
SIZE A	PART NO. 3132	REV
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

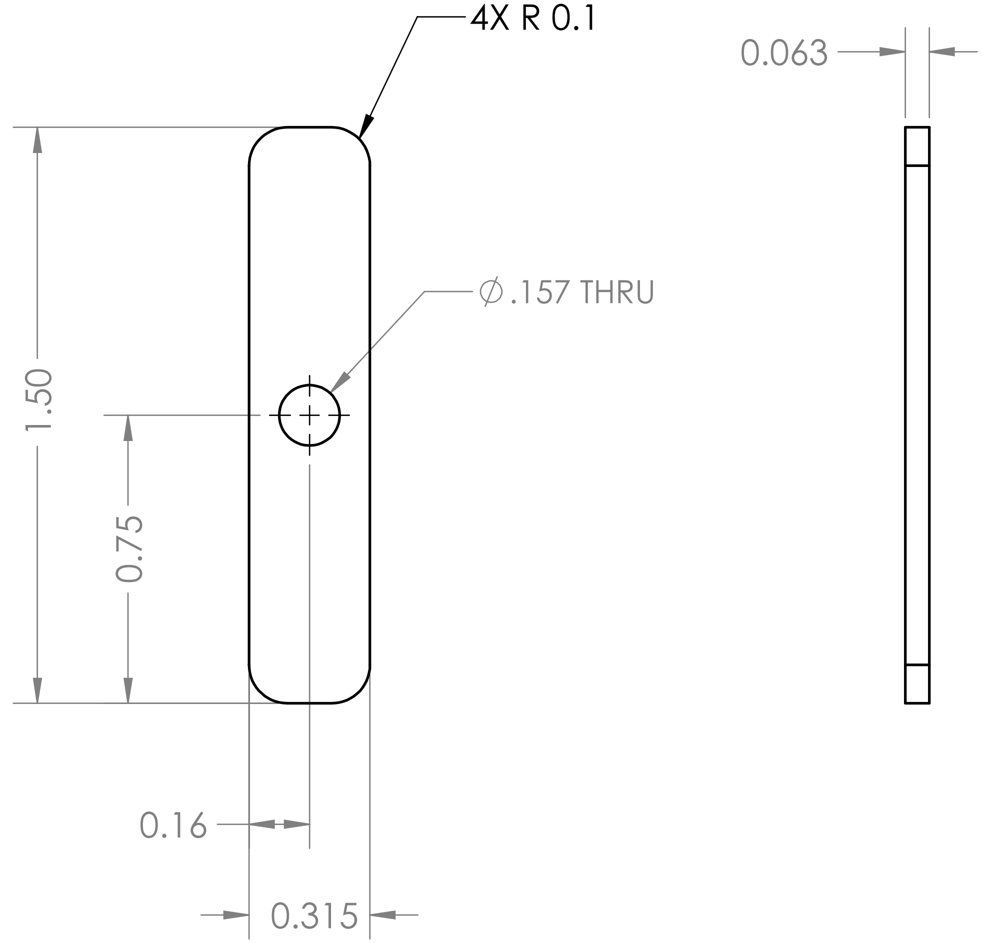
MATERIAL: ABS

COMMENTS:
DO NOT SCALE DRAWING

TITLE: SPOOL

SIZE	PART NO.	REV
A	3134	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

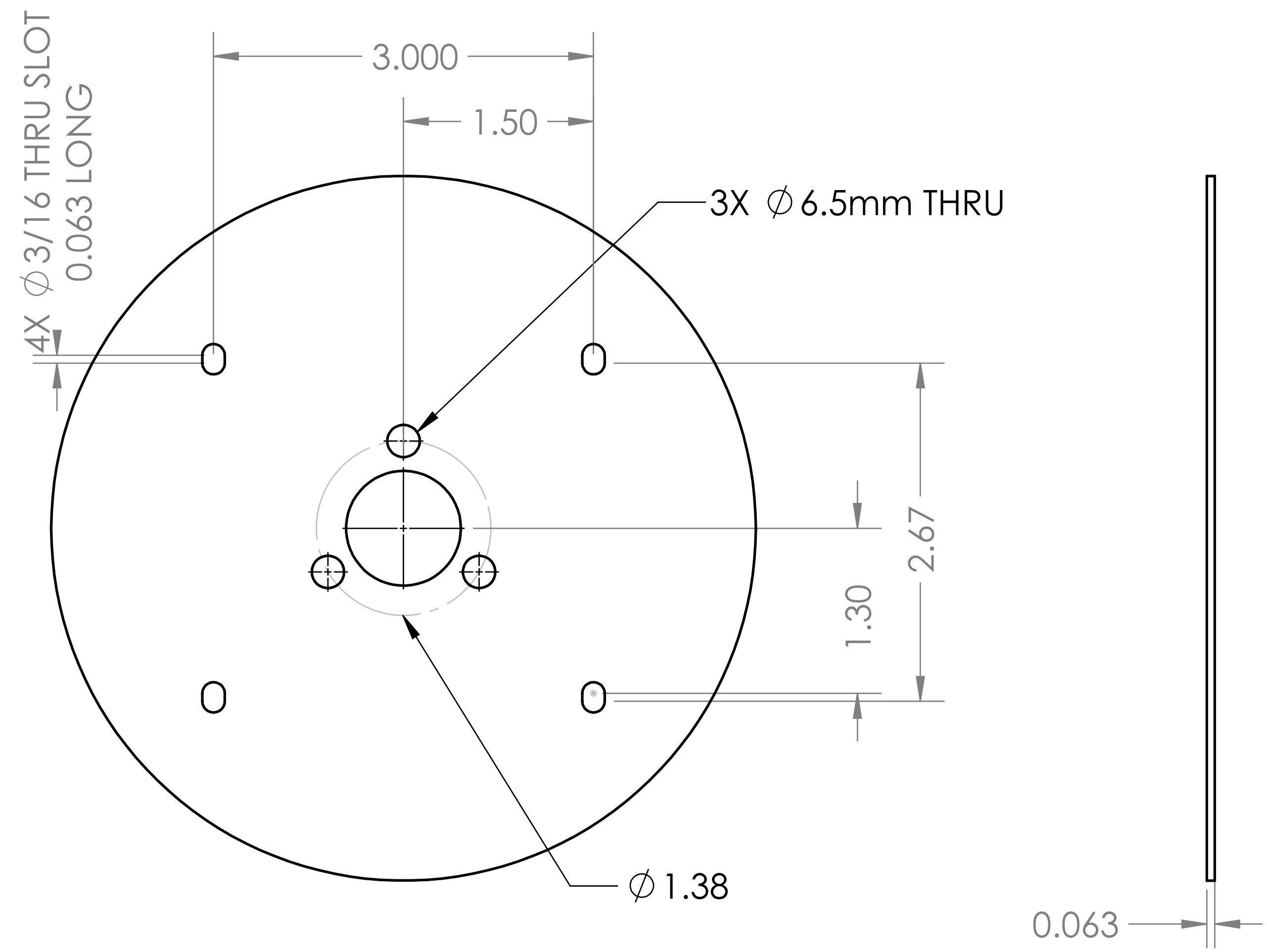
MATERIAL: ALUMINUM

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
SPRING LEVER

SIZE	PART NO.	REV
A	3135	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



TITLE:

CYLINDER BACKING PLATE

	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

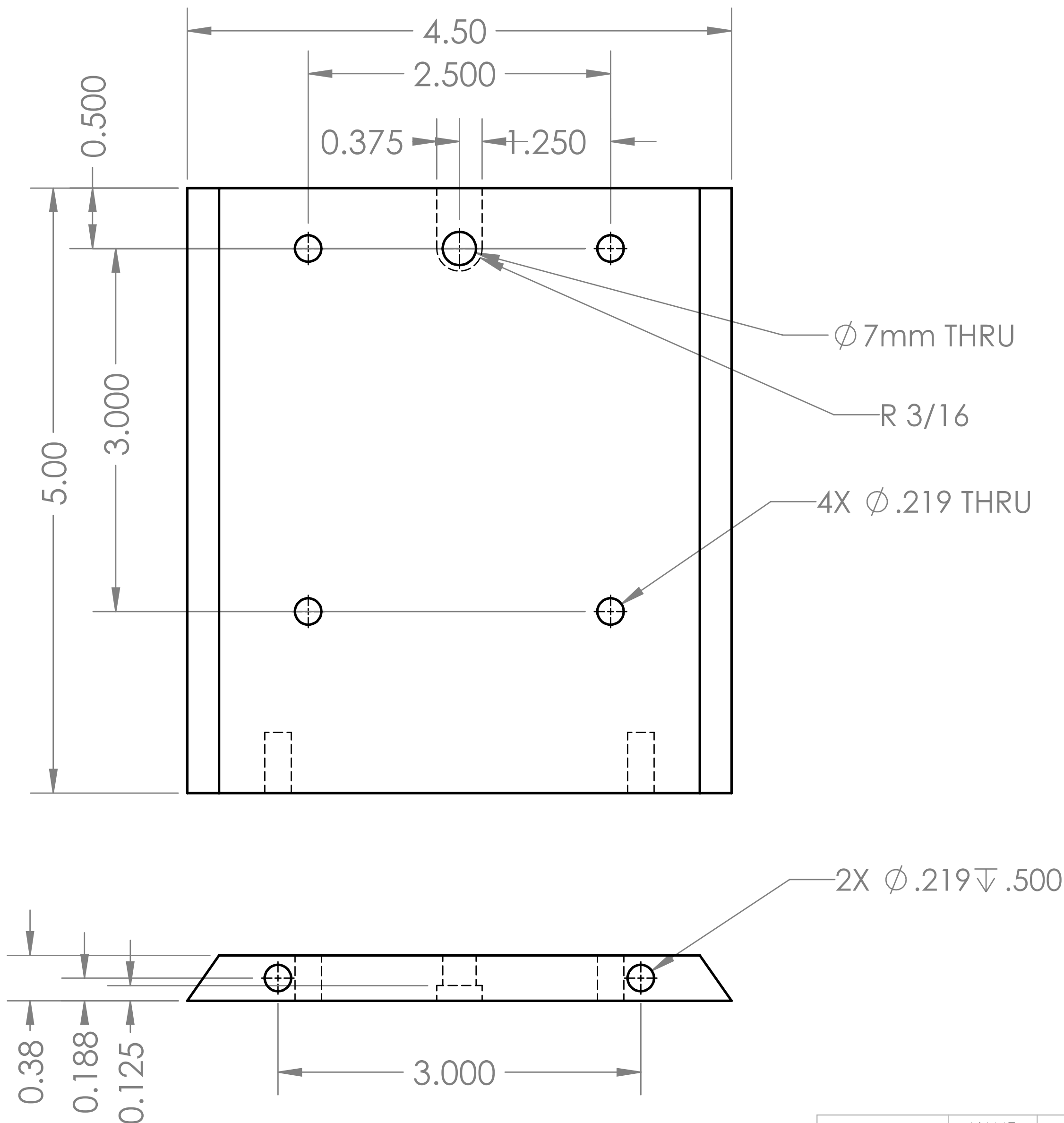
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

MATERIAL: ALUMINUM

COMMENTS:
DO NOT SCALE DRAWING

SIZE: A | PART NO. 3136 | REV

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



	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

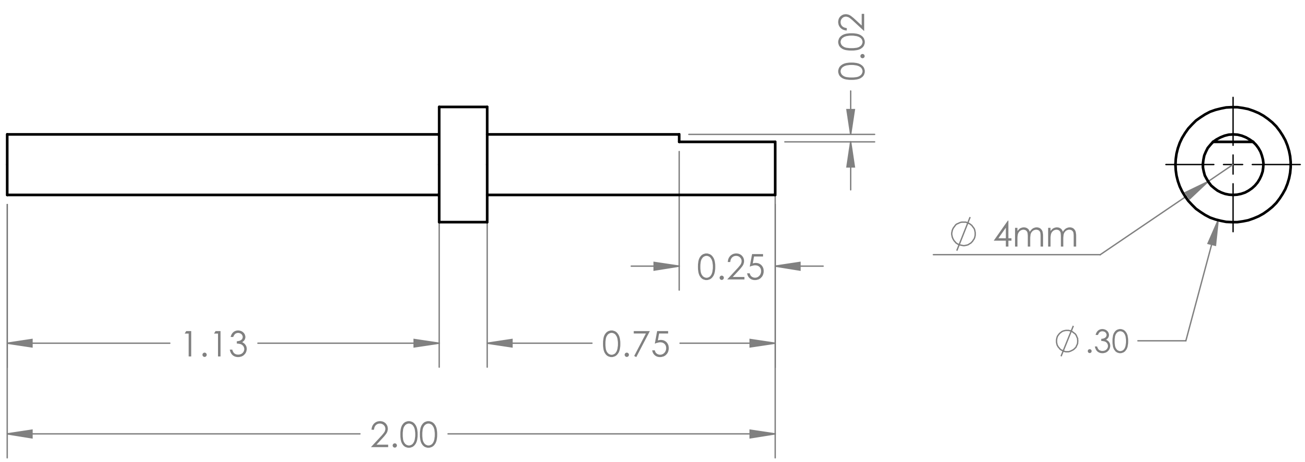
MATERIAL: PVC

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
SPRING WALL

SIZE A | PART NO. 3138 | REV

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



	NAME	DATE
DRAWN	RJS	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

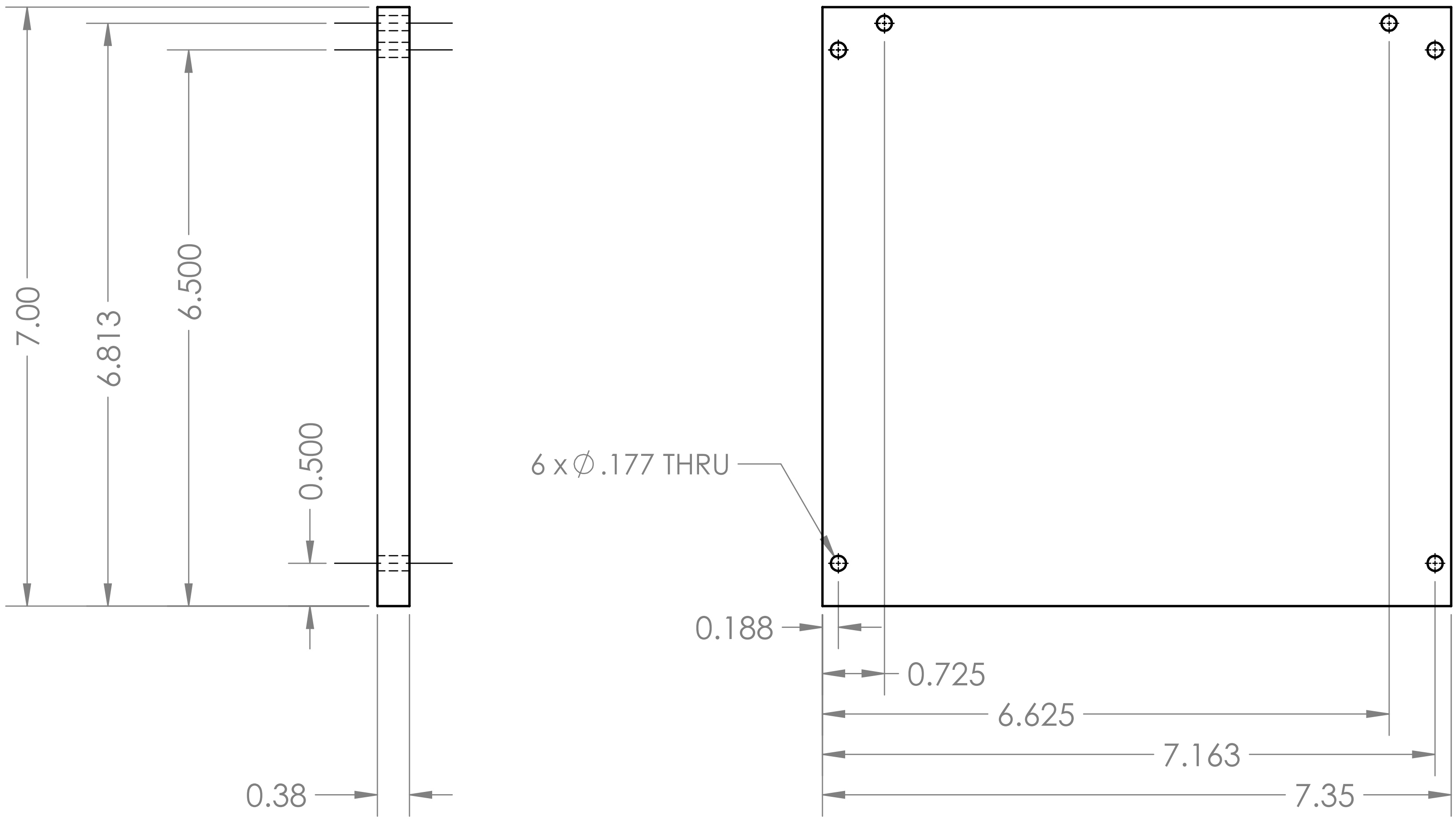
MATERIAL: POLYPROPOLENE

COMMENTS:
DO NOT SCALE DRAWING

TITLE:
SPRING SHAFT

SIZE **A** PART NO. 3139 REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



TITLE: COVER PLATE

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

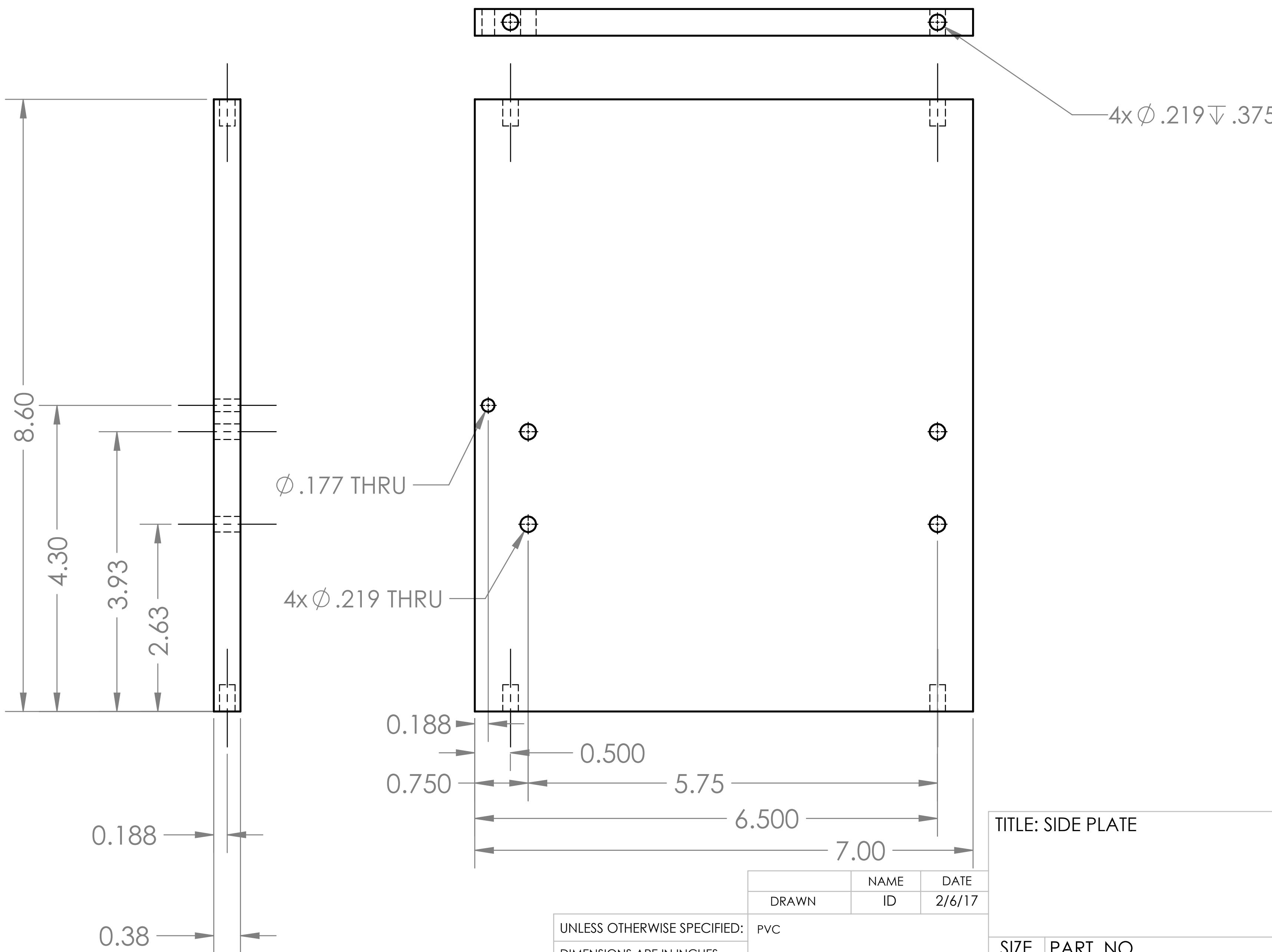
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PVC

COMMENTS:
DO NOT SCALE DRAWING

SIZE: A | PART NO. 3201 | REV

SCALE: 1:2 | WEIGHT: 0.6 LBS | SHEET 1 OF 1



TITLE: SIDE PLATE

	NAME	DATE
DRAWN	ID	2/6/17

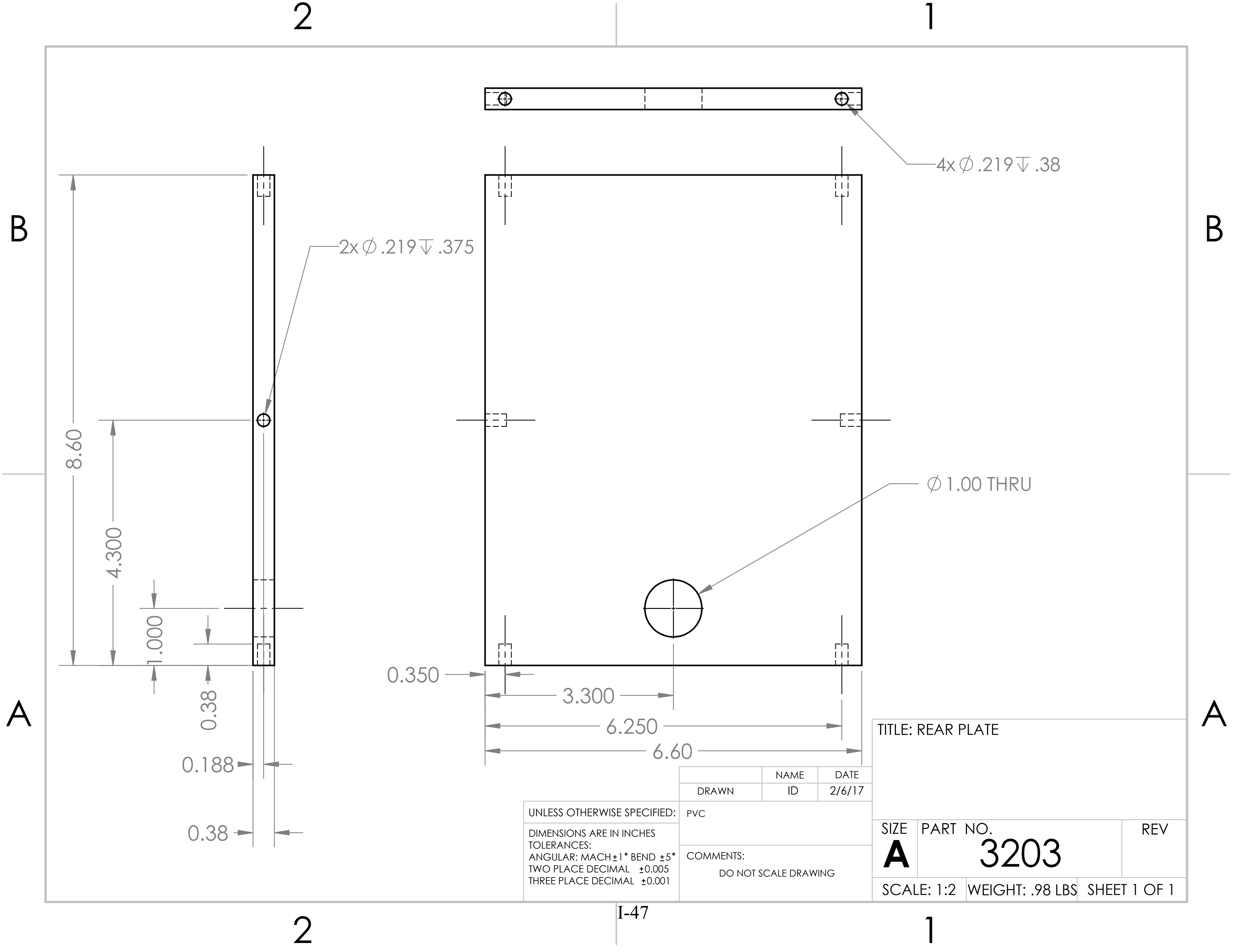
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PVC

COMMENTS:
DO NOT SCALE DRAWING

SIZE A | PART NO. 3202 | REV

SCALE: 1:2 | WEIGHT:1.05LBS | SHEET 1 OF 1



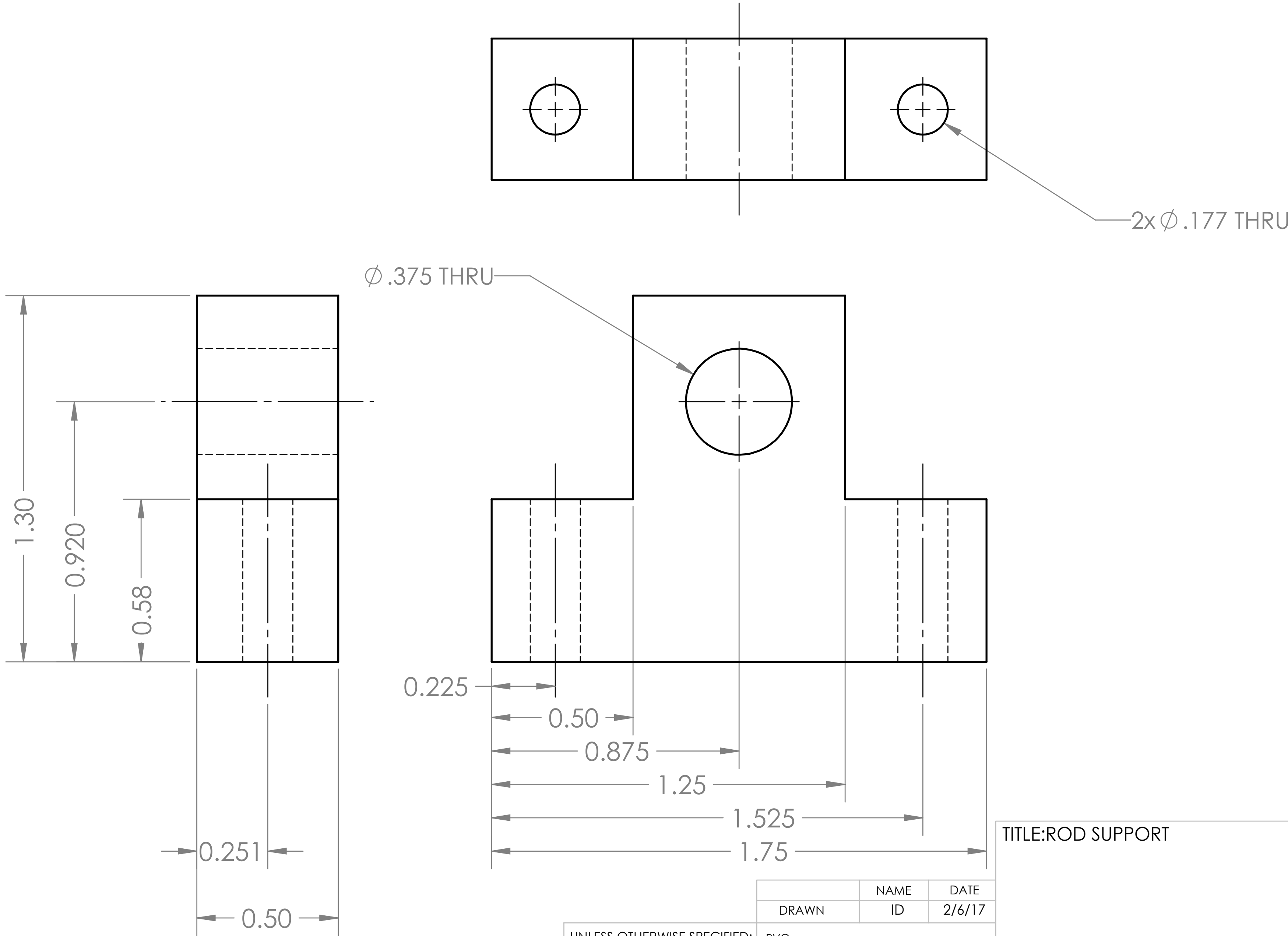
TITLE: REAR PLATE

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:	PVC
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±1° BEND ±5° TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.001	COMMENTS: DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	3203	

SCALE: 1:2 | WEIGHT: .98 LBS | SHEET 1 OF 1



TITLE:ROD SUPPORT

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

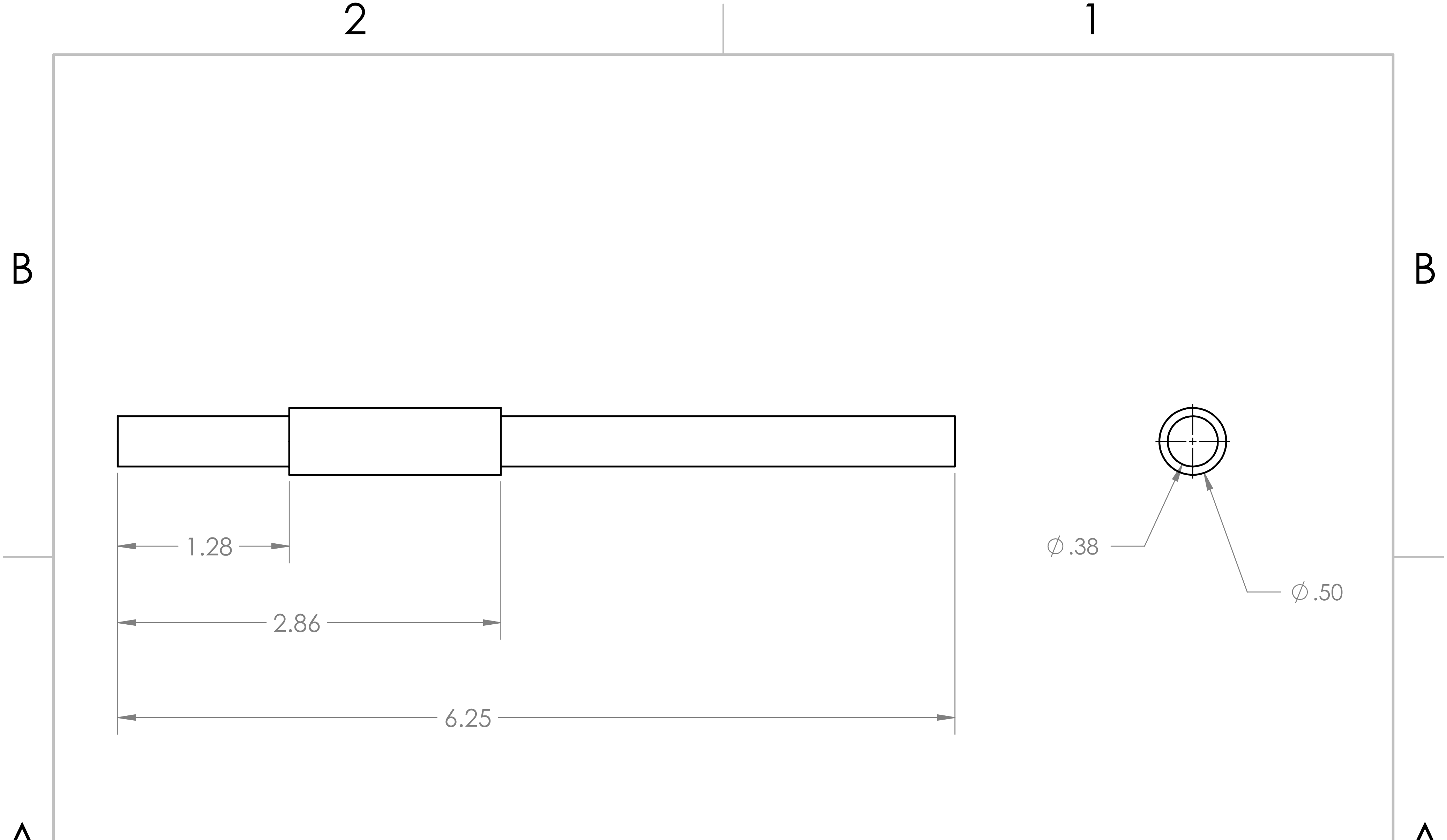
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PVC

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	3204	

SCALE: 2:1 | WEIGHT: .04LBS | SHEET 1 OF 1



	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

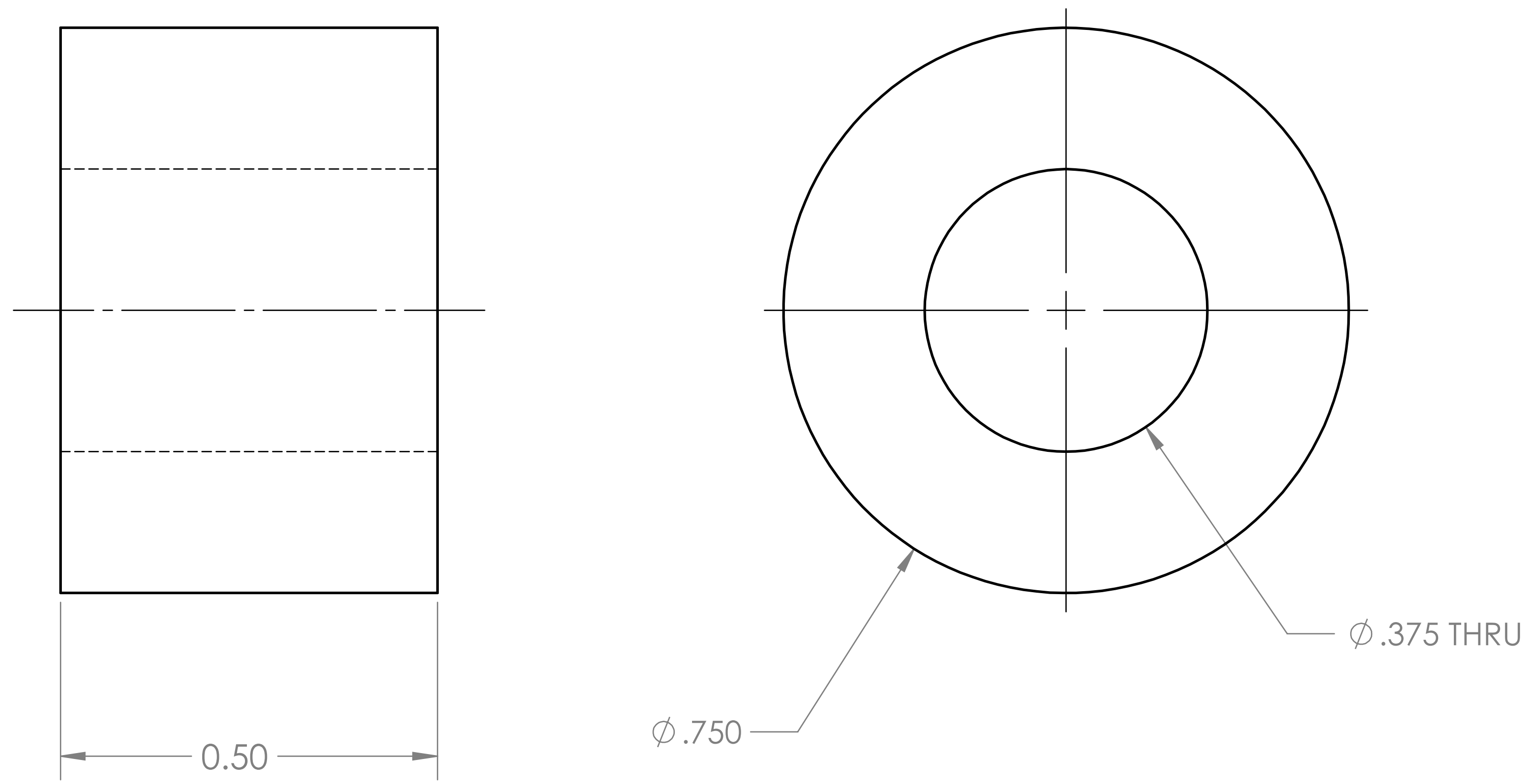
Polypropylene

COMMENTS:
DO NOT SCALE DRAWING

TITLE: STEP ROD

SIZE	PART NO.	REV
A	3205	

SCALE: 1:2	WEIGHT: .03	SHEET 1 OF 1



	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

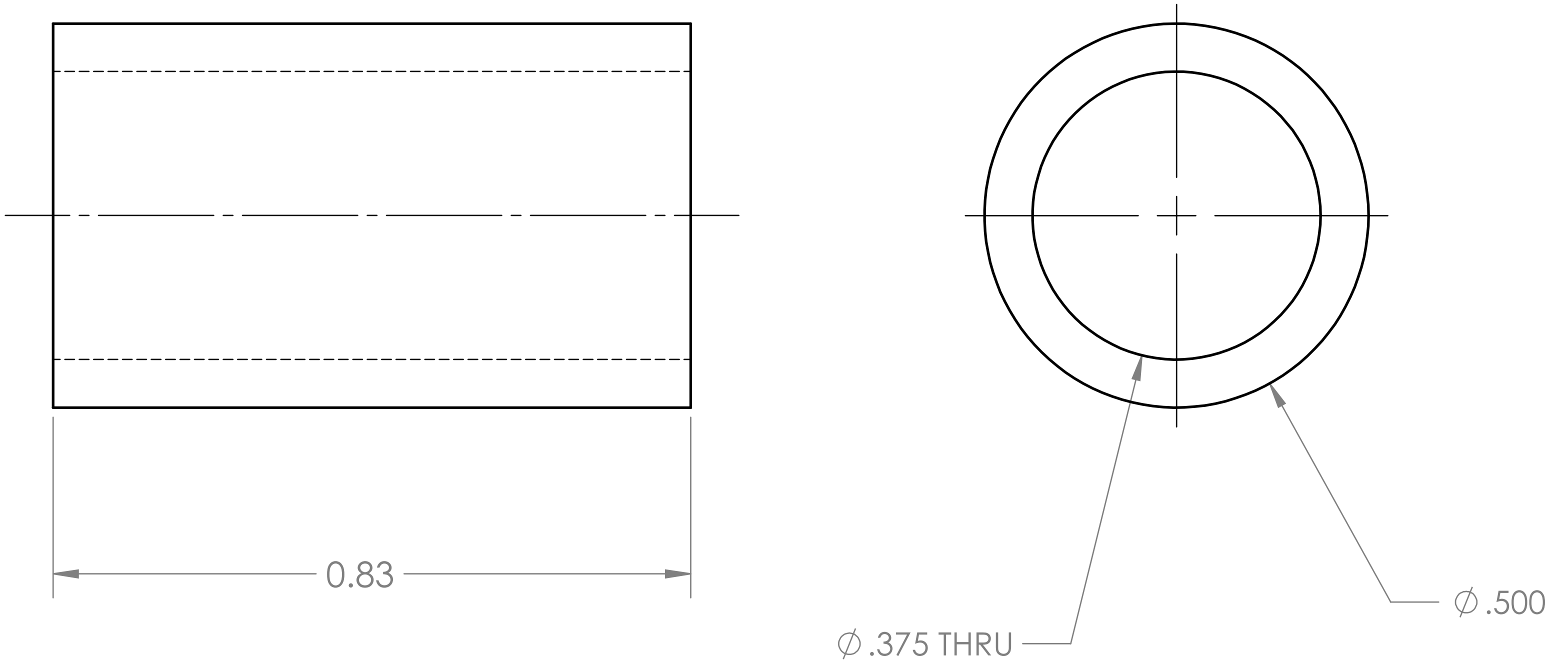
PTFE

COMMENTS:
DO NOT SCALE DRAWING

TITLE: CYLINDER ROLLER

SIZE	PART NO.	REV
A	3206	

SCALE: 4:1 | WEIGHT: .01LBS | SHEET 1 OF 1



TITLE: SPACER #1

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

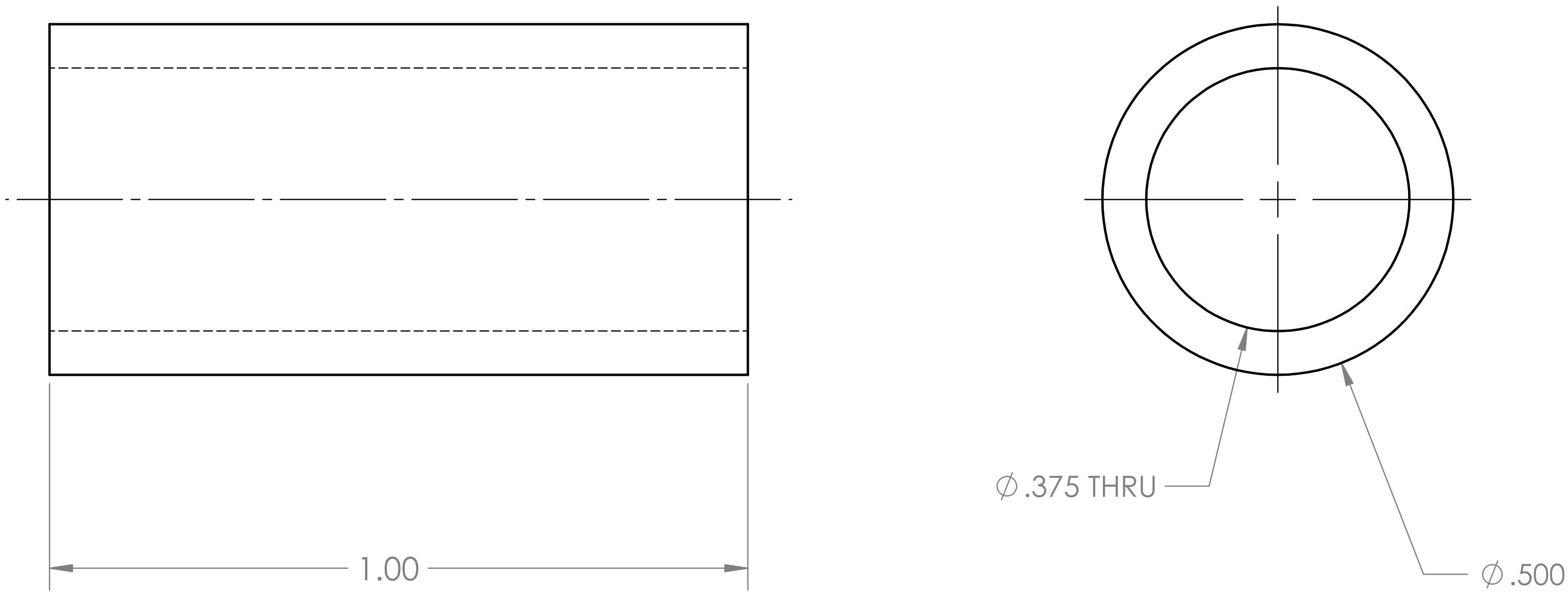
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PTFE

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	3207	

SCALE: 4:1 | WEIGHT: .01LBS | SHEET 1 OF 1



TITLE: SPACER #2

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

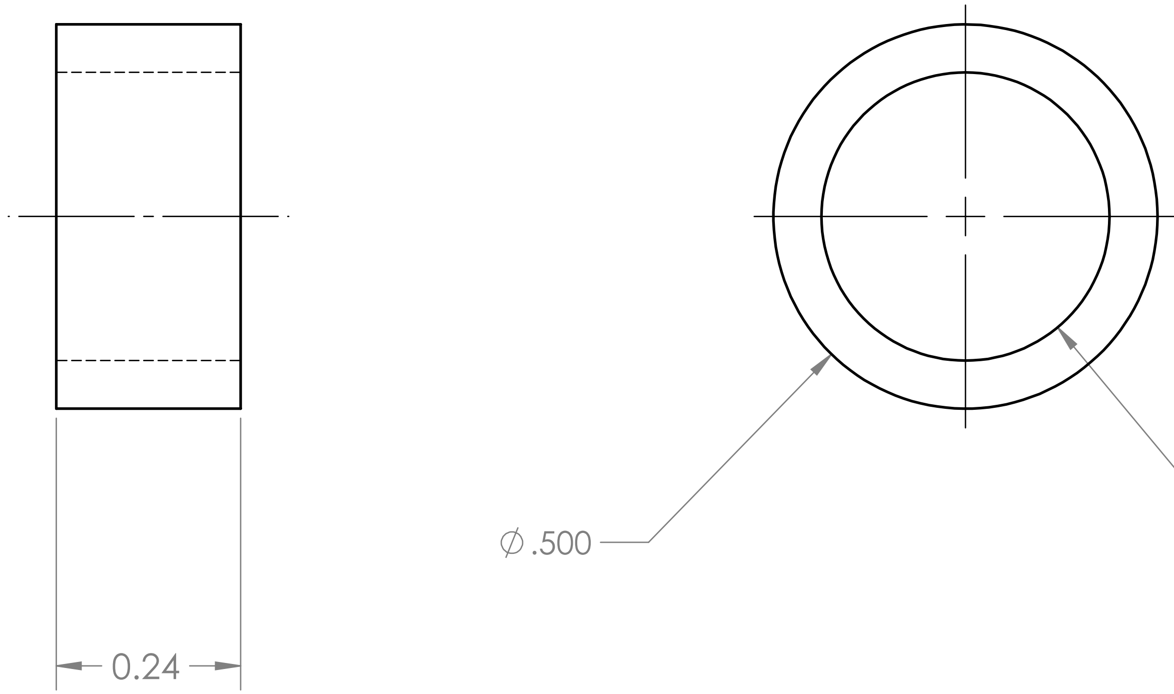
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

PTFE

COMMENTS:
DO NOT SCALE DRAWING

SIZE	PART NO.	REV
A	3208	

SCALE: 4:1 | WEIGHT: .01LBS | SHEET 1 OF 1



	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

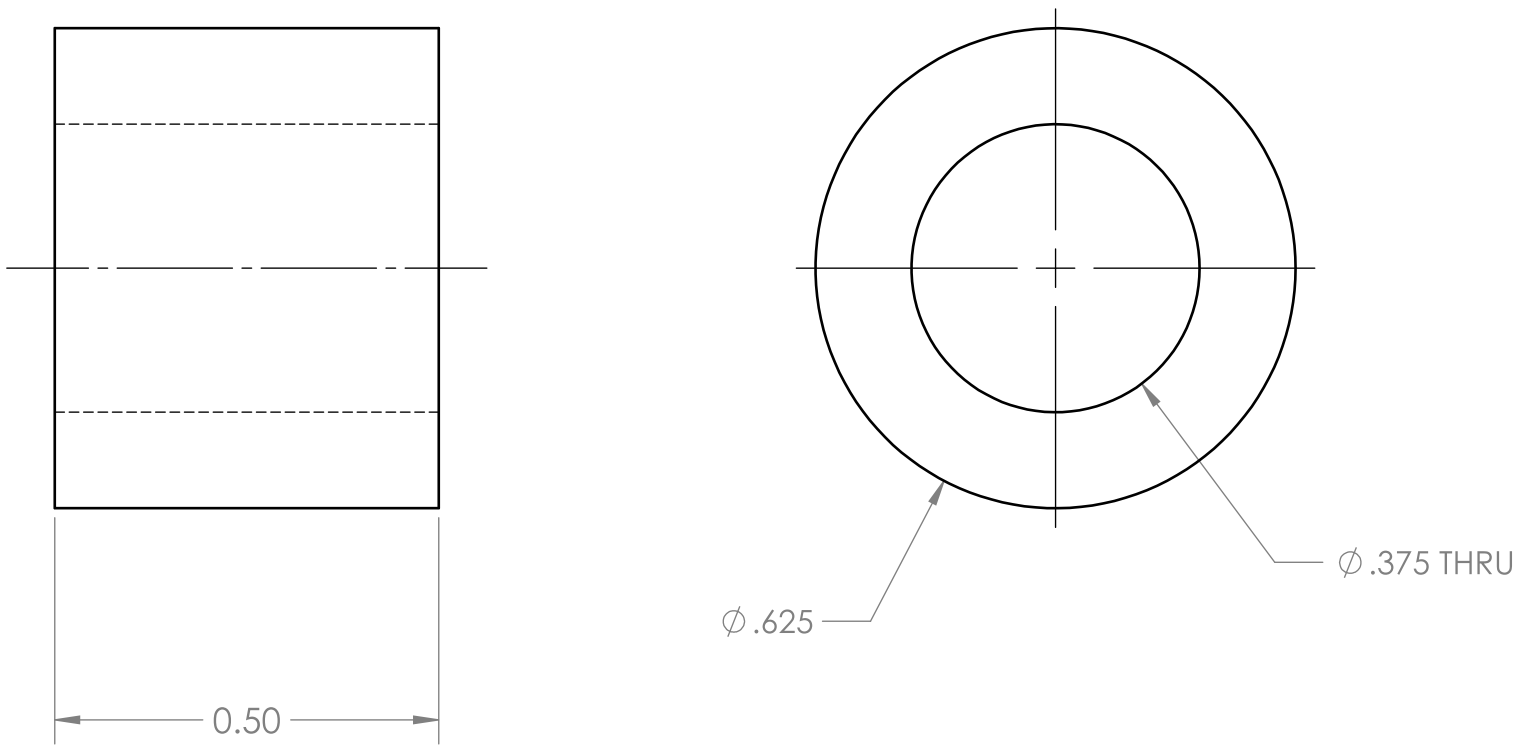
PTFE

COMMENTS:
DO NOT SCALE DRAWING

TITLE: SPACER #3

SIZE	PART NO.	REV
A	3209	

SCALE: 4:1	WEIGHT: .00LBS	SHEET 1 OF 1



TITLE: BELT ROLLER

	NAME	DATE
DRAWN	ID	2/6/17

UNLESS OTHERWISE SPECIFIED:

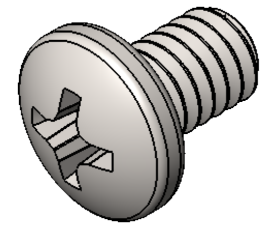
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±1° BEND ±5°
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001

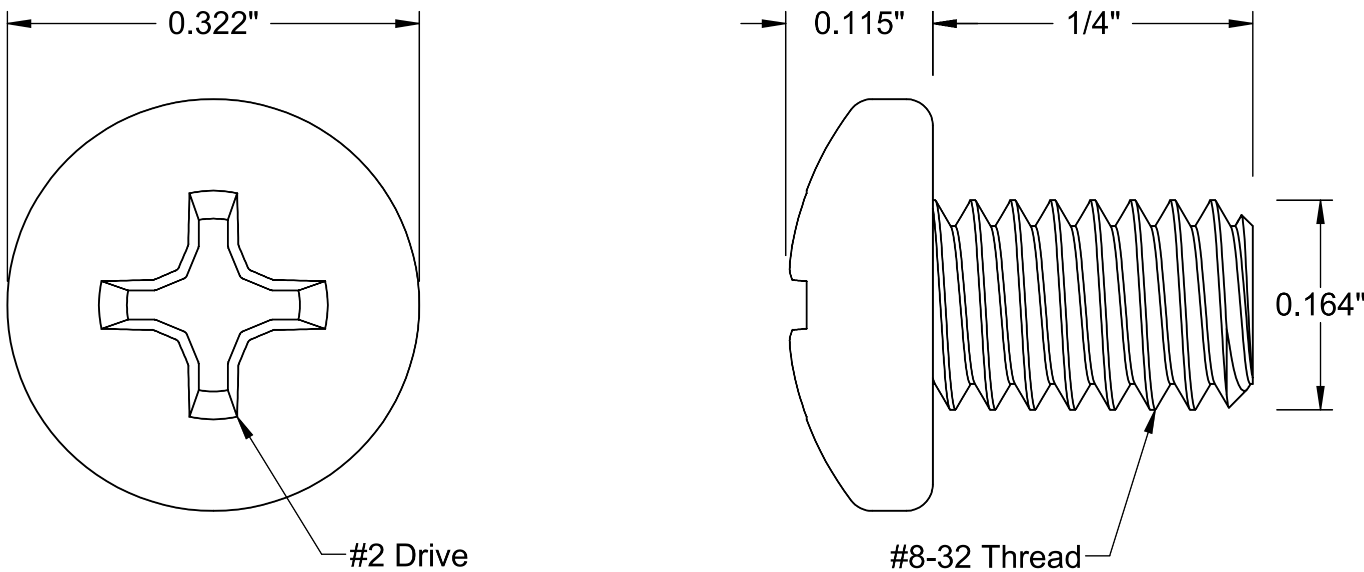
PTFE

COMMENTS:
DO NOT SCALE DRAWING

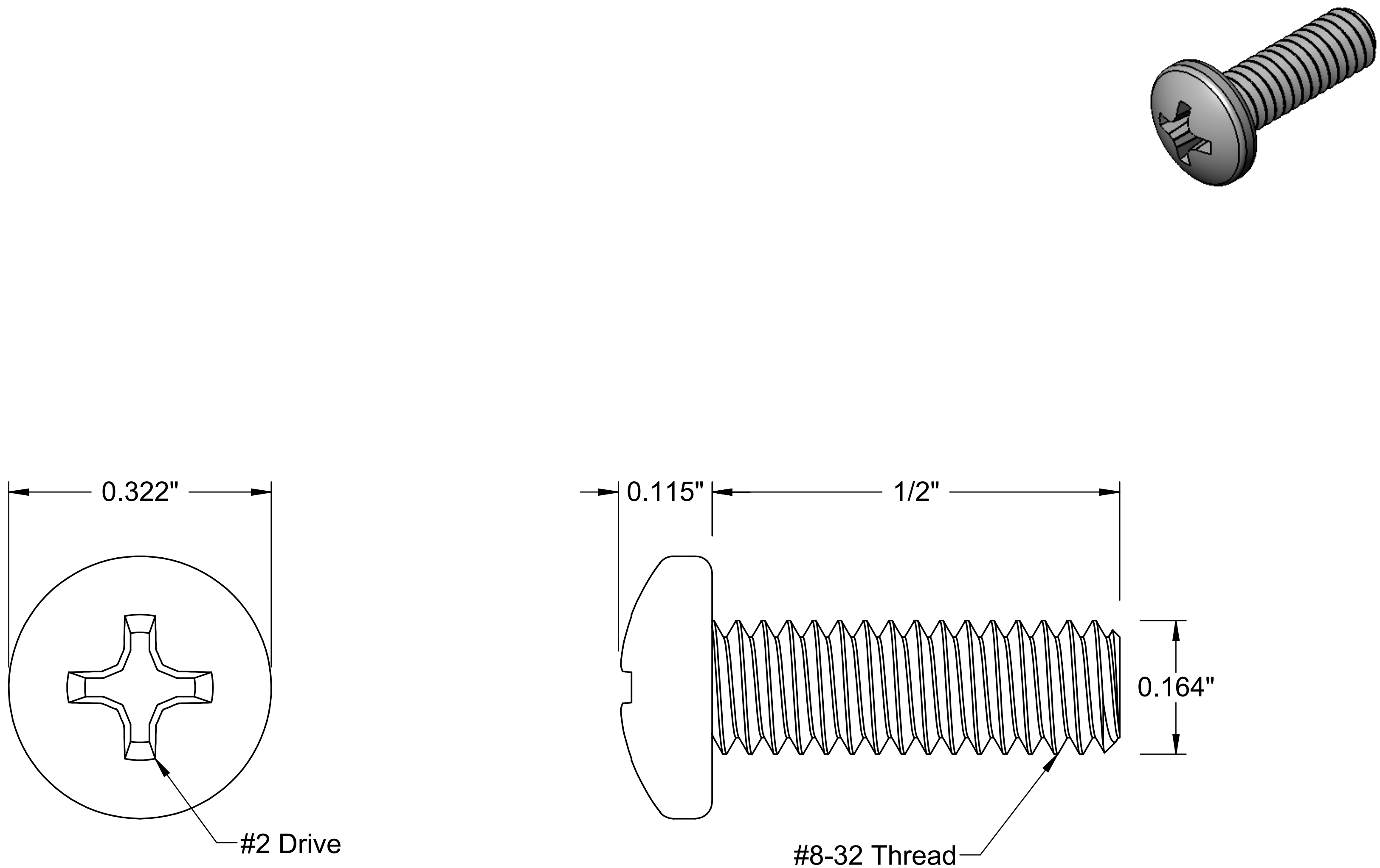
SIZE A | PART NO. 3210 | REV

SCALE: 4:1 | WEIGHT: .01LBS | SHEET 1 OF 1

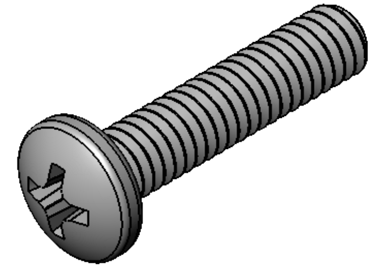


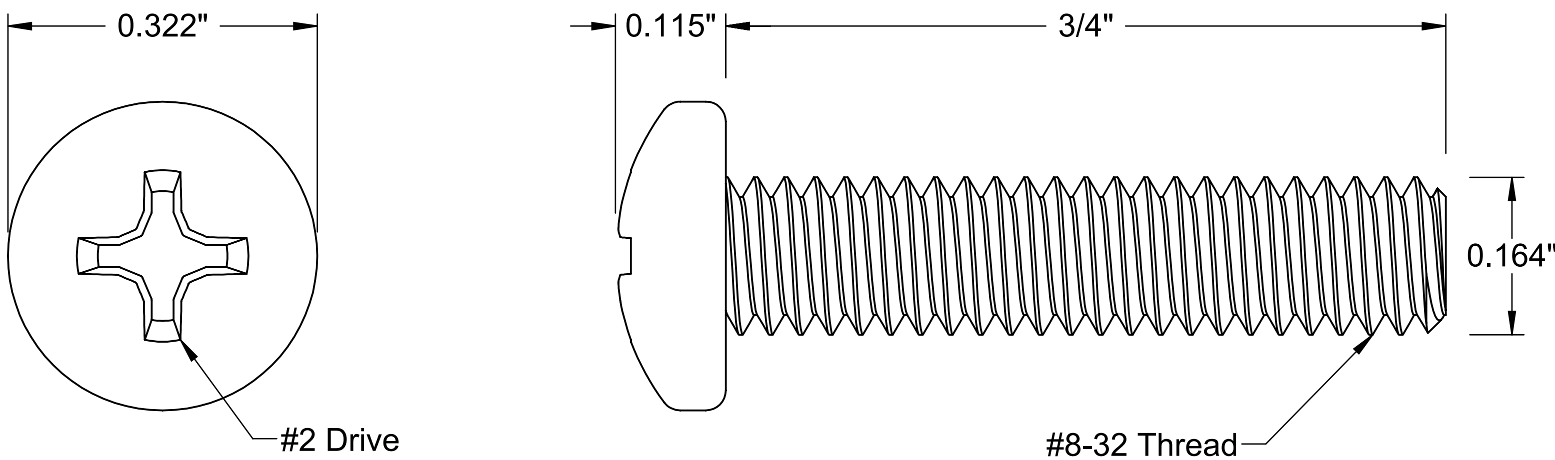


McMASTER-CARR® CAD	PART NUMBER	4101
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	

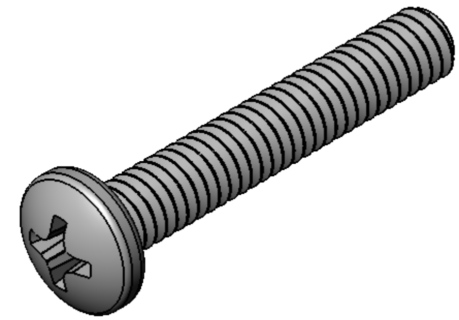


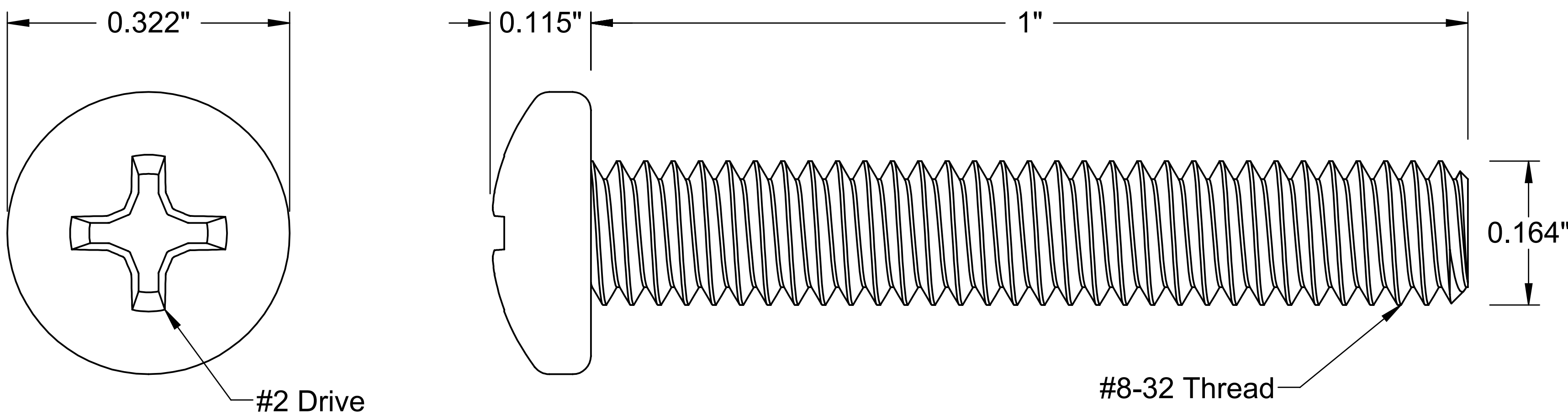
McMASTER-CARR® CAD	PART NUMBER	4102
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	





McMASTER-CARR® CAD	PART NUMBER	4103
http://www.mcmaster.com Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	



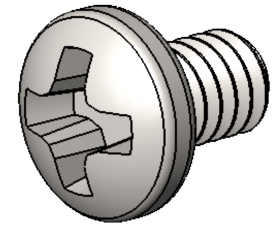


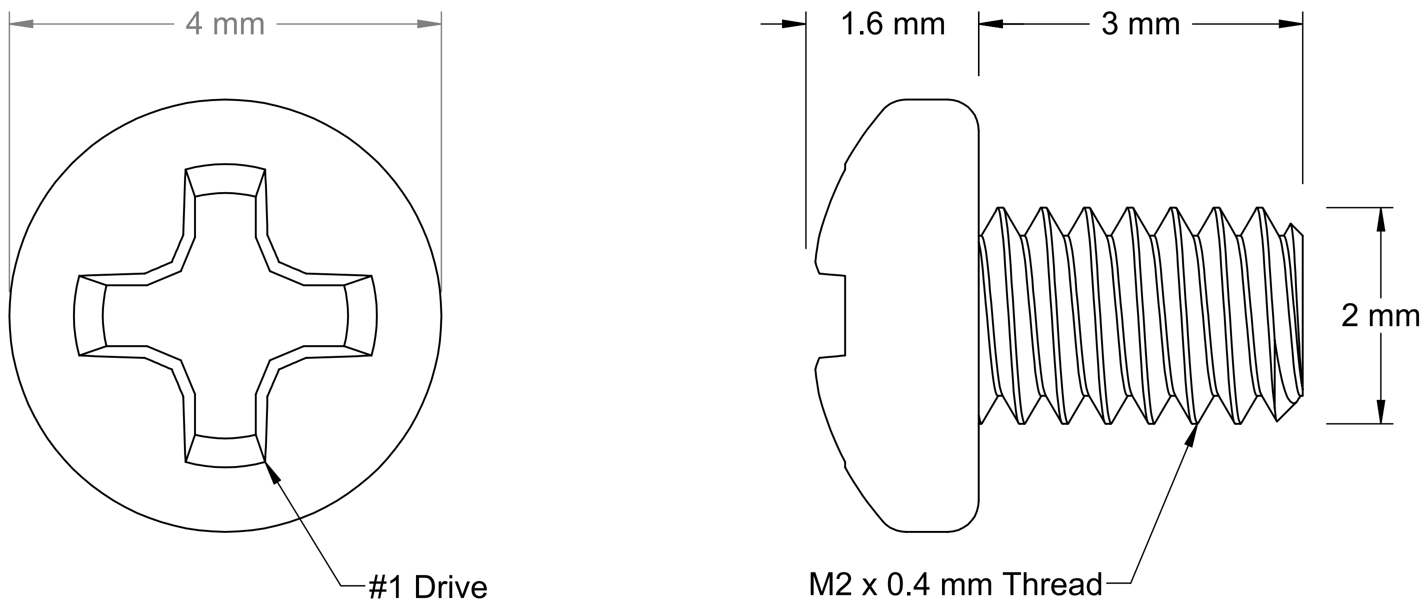
McMASTER-CARR® CAD

http://www.mcmaster.com

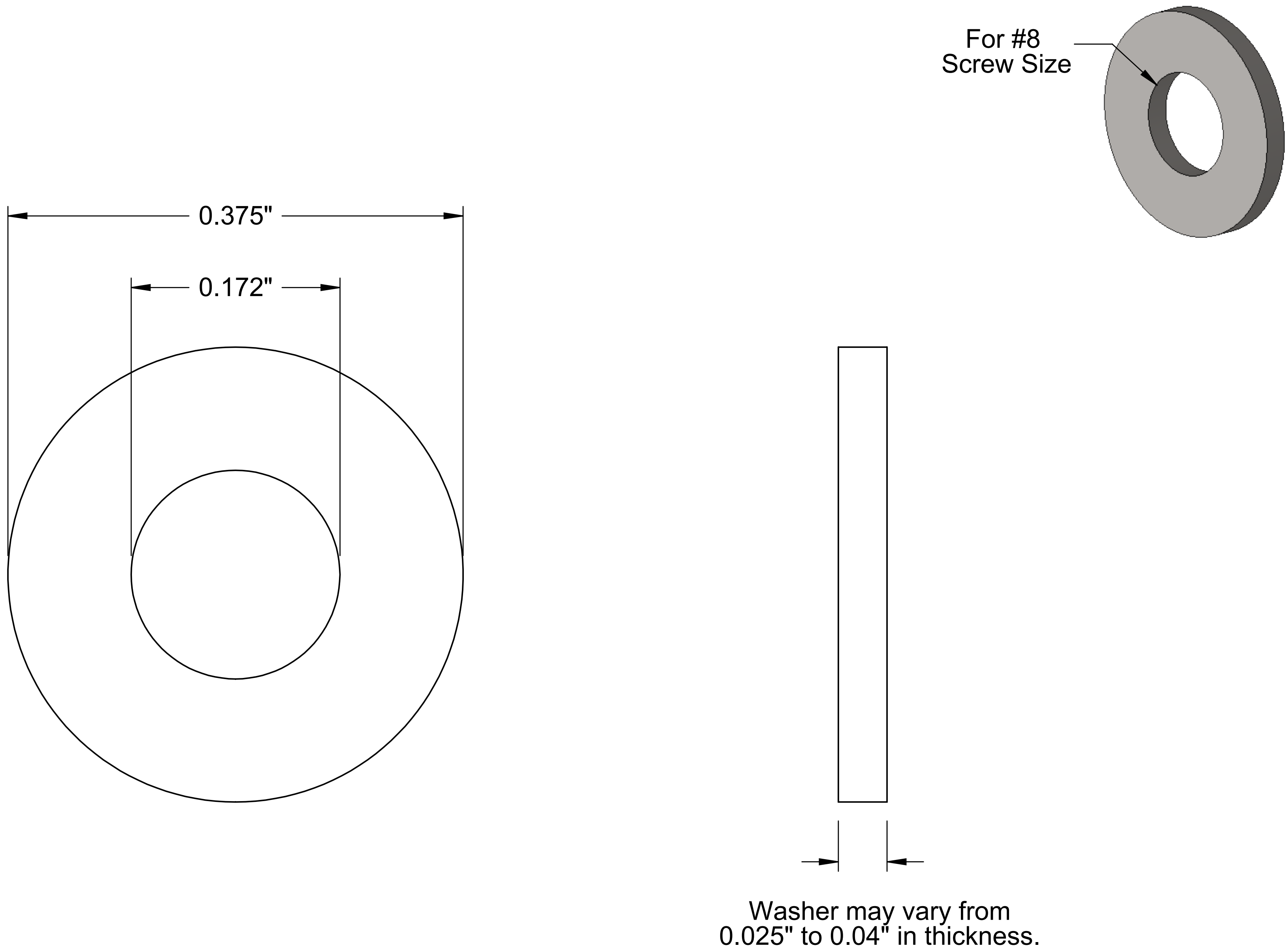
PART NUMBER **4104**

Pan Head Phillips Machine Screw

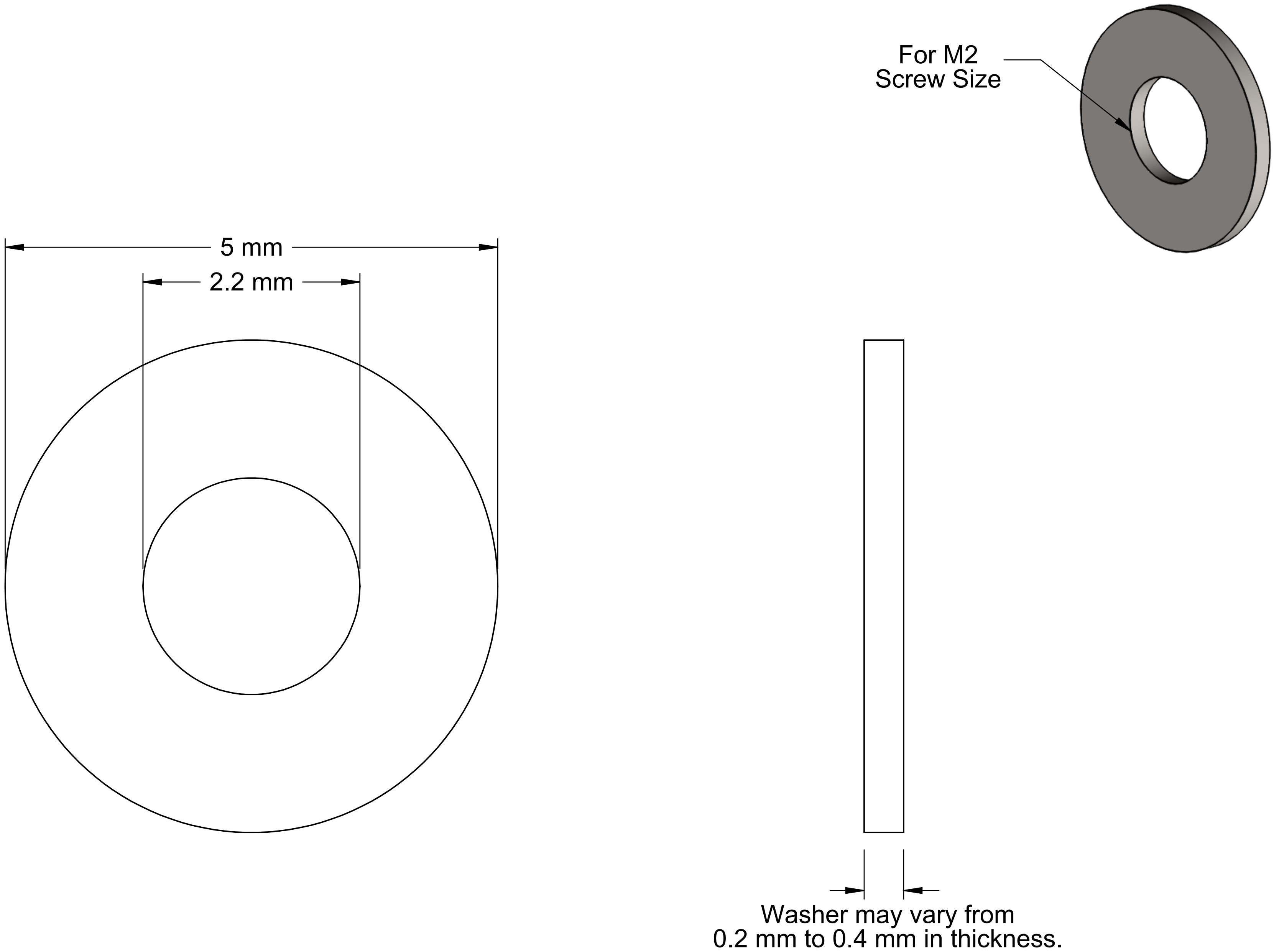




McMASTER-CARR® CAD	PART NUMBER	4105
http://www.mcmaster.com Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	



McMASTER-CARR® CAD	PART NUMBER	4201
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	General Purpose Washer	

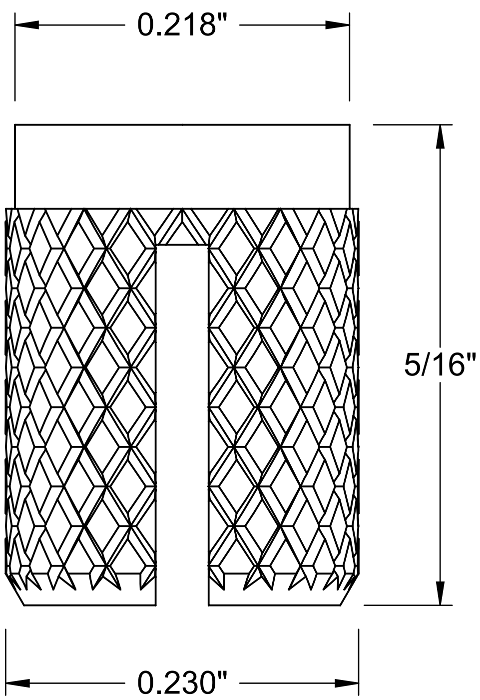


McMASTER-CARR® CAD

PART NUMBER **4202**

http://www.mcmaster.com

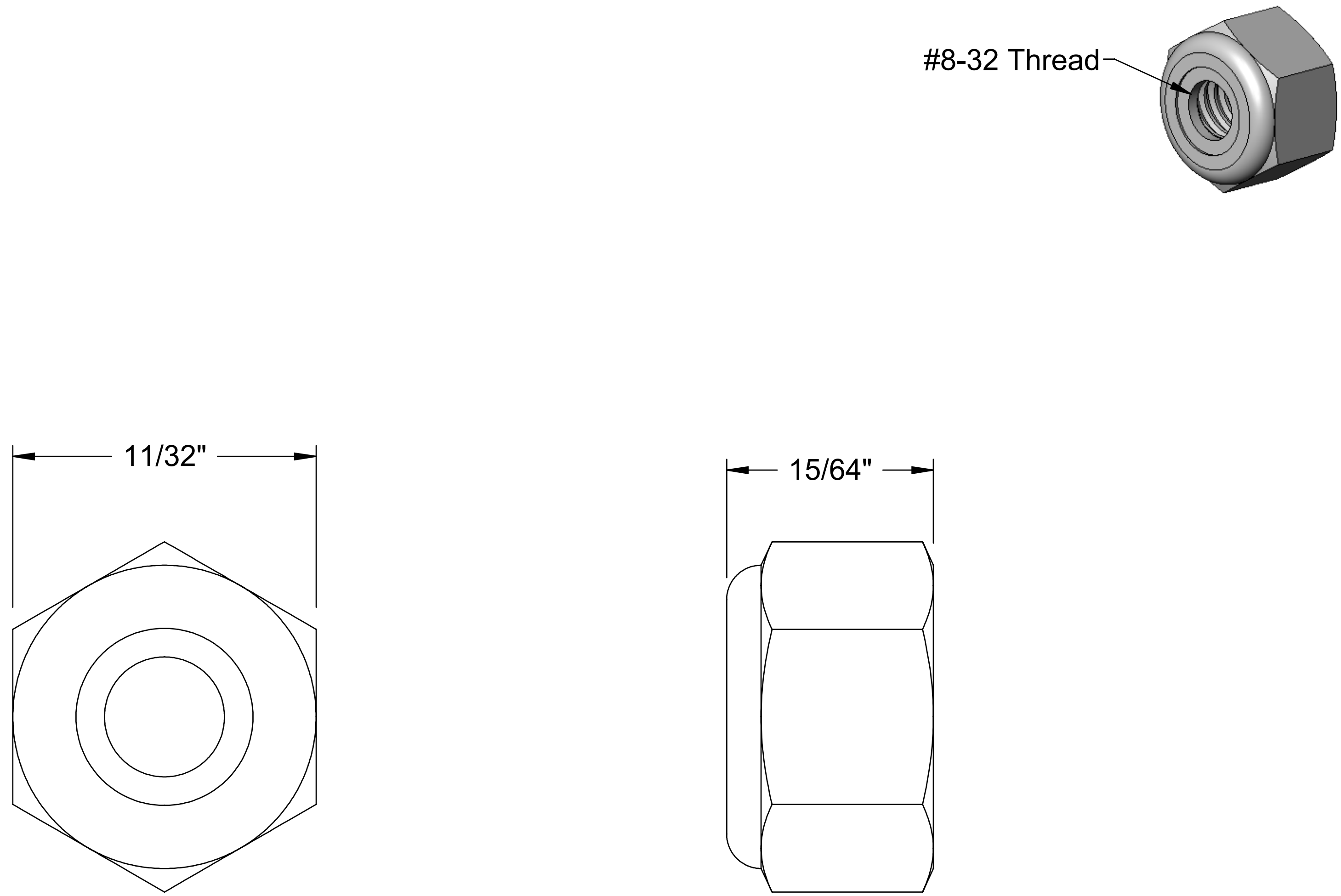
Metric General Purpose Washer



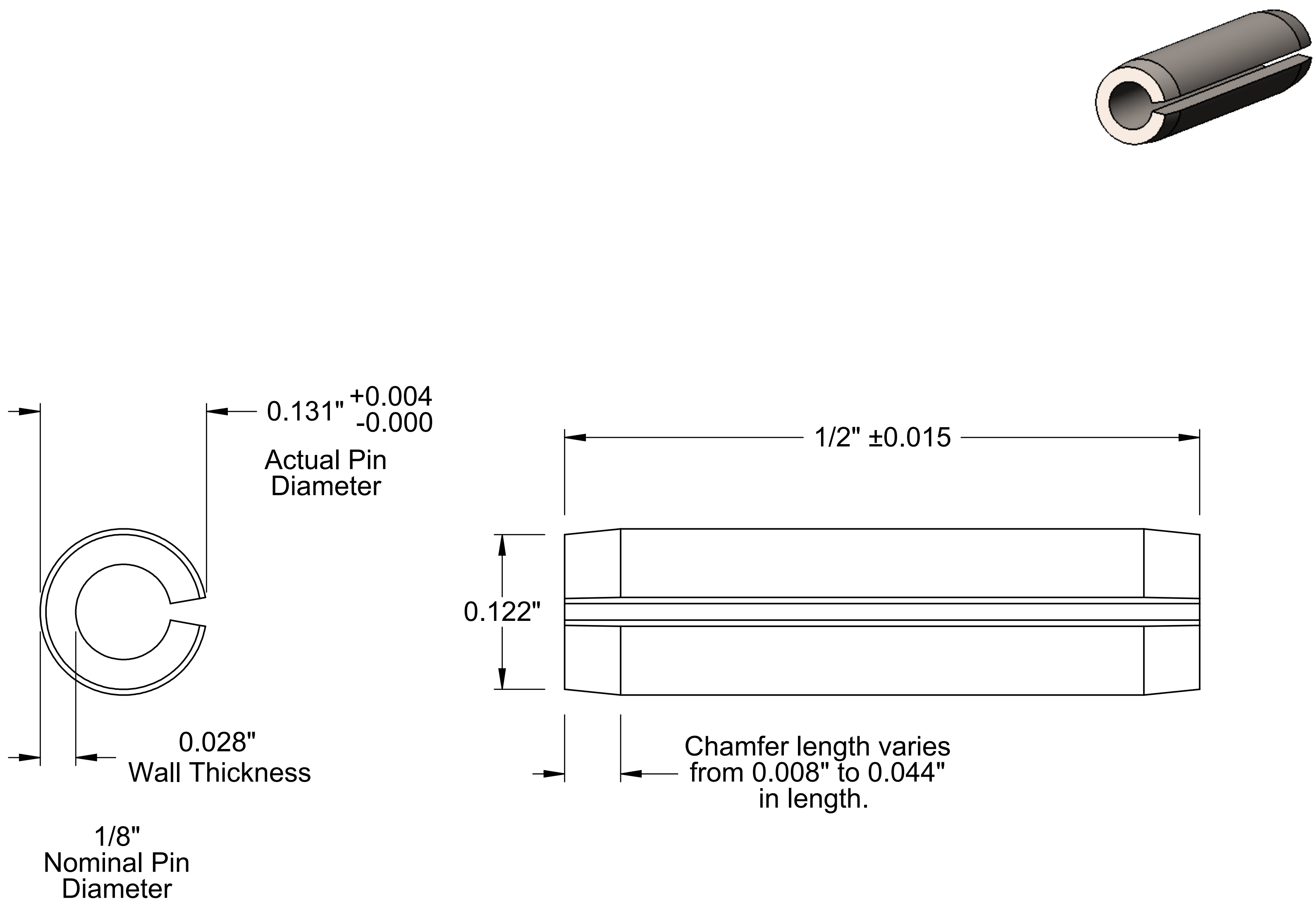
Suggested Drill Bit Size 7/32"

PART NUMBER 4301

Press-Fit Expansion Insert for Plastic



McMASTER-CARR® CAD	PART NUMBER	4302
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Nylon-Insert Locknut	

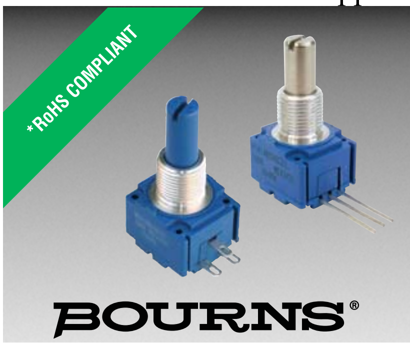


Recommended 0.125" to 0.129" Diameter Hole Size

McMASTER-CARR CAD	PART NUMBER 4401
http://www.mcmaster.com © 2011 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	18-8 Stainless Steel Slotted Spring Pin

Appendix J

Graphene Twisters Spec Sheets For Off-The-Shelf Components



Features

- Available in a variety of pin-out configurations
- Virtually infinite electrical circuit isolation
- Metal or plastic shaft options
- RoHS compliant*

Model 91, 92, 93, 94 & 95 - 5/8 " Square Single-Turn Panel Control

Initial Electrical Characteristics[1]	Conductive Plastic Element	Cermet Element
Standard Resistance Range		
Linear Tapers (A, B, E, & H)	(B & E) 1 K ohms to 1 megohm	(A & H) 100 ohms to 1 megohm
Audio Tapers (C, D, F, G, S, & T)	(D,G,S, & T) 1 K ohms to 1 megohm	(C & F) 1 K ohms to 1 megohm
Total Resistance Tolerance	10 % or 20 %	5% or 10%
Independent Linearity	±5 %	±5 %
Absolute Minimum Resistance	2 ohms maximum	2 ohms maximum
Effective Electrical Angle	(Linear tapers) 240 ° ± 5 °	(Linear tapers) 240 ° ± 6 °
	(Audio tapers) 225 ° ± 5 °	(Audio tapers) 225 ° ± 6 °
Contact Resistance Variation	±1 %	±1 % or 3 ohms (whichever is greater)
Dielectric Withstanding Voltage (MIL-STD-202, Method 301)		
Sea Level	1,500 VAC minimum	1,500 VAC minimum
70,000 Feet	500 VAC minimum	500 VAC minimum
Insulation Resistance (500 VDC)	1,000 megohms minimum	1,000 megohms minimum
Power Rating (Voltage Limited By Power Dissipation or 350 VAC, Whichever Is Less)		
+70 °C Single Section Assembly	(Linear tapers) 1 watt	(Linear tapers) 2 watts
	(Audio tapers) 0.5 watt	(Audio tapers) 1 watt
+70 °C Multiple Section Assembly	(Linear tapers) 0.5 watt/section	(Linear tapers) 1 watt/section
	(Audio tapers) 0.25 watt/section	(Audio tapers) 0.5 watt/section
+125 °C	0 watt	0 watt
Theoretical Resolution	Essentially infinite	Essentially infinite

Environmental Characteristics[1]		
Operating Temperature Range	-40 °C to +125 °C	-40 °C to +125 °C
Storage Temperature Range	-55 °C to +125 °C	-55 °C to +125 °C
Temperature Coefficient Over Storage Temperature Range	±1,000 ppm/°C	±150 ppm/°C
Vibration (Single Section)	15 G	15 G
Total Resistance Shift	±2 % maximum	±2 % maximum
Voltage Ratio Shift	±5 % maximum	±5 % maximum
Shock (Single Section)	30 G	30 G
Total Resistance Shift	±2 % maximum	±2 % maximum
Voltage Ratio Shift	±5 % maximum	±5 % maximum
Load Life	1,000 hours	1,000 hours
Total Resistance Shift	±10 % maximum	±5 % maximum
Rotational Life (No Load)	100,000 cycles	100,000 cycles
Total Resistance Shift	(Linear tapers) 10 ohms or ±15 % TRS max. (whichever is greater) (Audio tapers) ±20 % maximum	(All tapers) ±5 % TRS max.
Contact Resistance Variation @ 50,000 cycles	(Linear tapers) ±2 %	±2 %
	(Audio tapers) ±3 %	±3 %
Moisture Resistance (MIL-STD-202, Method 103, Condition B)		
Total Resistance Shift	(Linear tapers) ±10 % TRS maximum (Audio tapers) ±20 % TRS maximum	(All tapers) ±5 % TRS maximum
Insulation Resistance (500 VDC)	100 megohms minimum	100 megohms minimum
IP Rating	IP 40	IP 40

*RoHS Directive 2002/95/EC Jan. 27, 2003 including annex and RoHS Recast 2011/65/EU June 8, 2011.
Specifications are subject to change without notice.
The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.
Users should verify actual device performance in their specific applications.

Model 91, 92, 93, 94 & 95 - 5/8 " Square Single-Turn Panel Control BOURNS®

Mechanical Characteristics[1]

Stop Strength (1/4 " D shaft) ....45.19 N-cm (4 lb.-in.)
(1/8 " D shaft) ....33.89 N-cm (3 lb.-in.)
Mechanical Angle..300 ° ±5 °
Torque
Starting ....0.3 max. above average running torque
Running Torque
Single or Dual Section (A & R Bushings) ....0.21 to 1.06 N-cm (0.3 to 1.5 oz.-in.)
Single or Dual Section (C & U Bushings) ....0.14 to 1.06 N-cm (0.2 to 1.5 oz.-in.)
Mounting ....1.7-2.0 N-m (15-18 lb.-in.) maximum
Variation..0.35 N-cm (0.5 oz.-in.) maximum in 45 ° shaft travel
Weight (Single Section, Metal Bushing)..12.7 grams nominal
(Each Additional Section) ....4 grams nominal
Terminals ....Printed circuit terminals, J-Hooks or solder lugs
Soldering Condition ....Recommended hand soldering using Sn95/Ag5 no clean solder, 0.025 " wire diameter.
Maximum temperature 399 °C (750 °F) for 3 seconds. No wash process to be used with no clean flux.
Marking ....Manufacturer's trademark, date code, resistance, manufacturer's part number
Ganging (Multiple Section Potentiometers)..2 cups maximum
Hardware..................One lockwasher and one mounting nut is shipped with each potentiometer, except where noted in the part number.

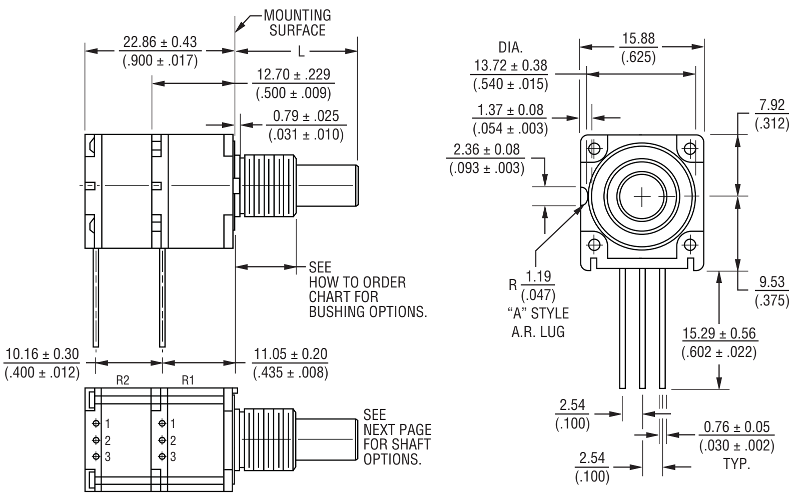
NOTE: Performance specifications do not apply to units subjected to printed circuit board cleaning procedures.

[1]At room ambient: +25 °C nominal and 50 % relative humidity nominal, except as noted.

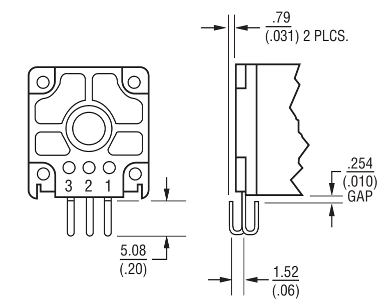
Model 91, 92, 93, 94 & 95 - 5/8 ” Square Single-Turn Panel Control BOURNS®

Product Dimensions

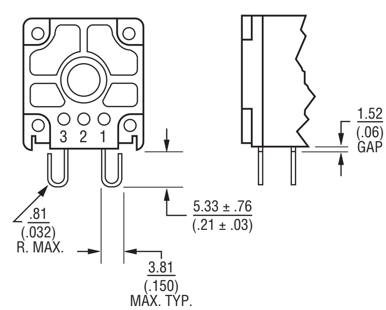
Model 91 PC Pin Terminals, In-Line



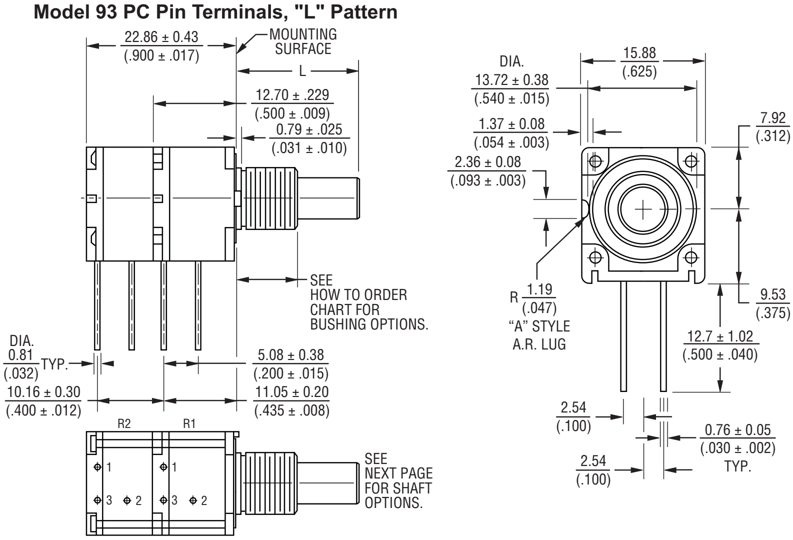
Model 92 J-Hooked Terminals, In-Line



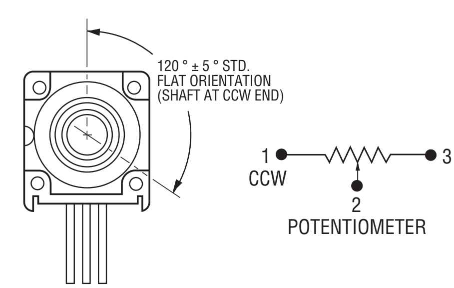
Model 94 J-Hooked Terminals, "L" Pattern



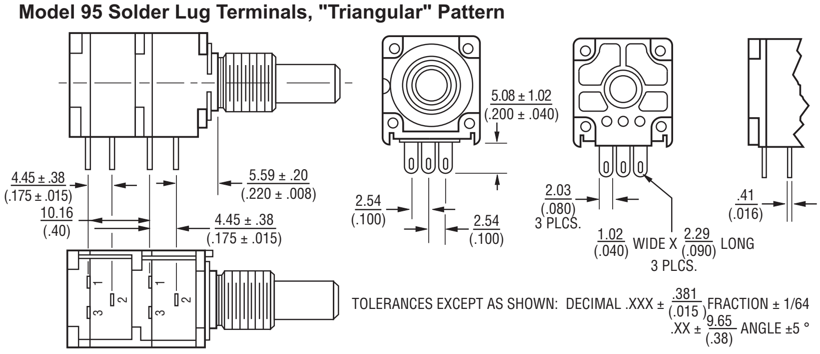
Model 93 PC Pin Terminals, "L" Pattern



Shaft Flat Orientation



Model 95 Solder Lug Terminals, "Triangular" Pattern



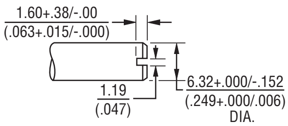
Specifications are subject to change without notice.
The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.
Users should verify actual device performance in their specific applications.

Model 91, 92, 93, 94 & 95 - 5/8 " Square Single-Turn Panel Control BOURNS®

Product Dimensions

Plastic Shaft Styles

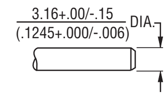
SHAFT TYPE "B" (USES BUSHING A)



STD. LENGTHS:

12.70 (.500)	15.88 (.625)	19.05 (.750)	22.23 (.875)

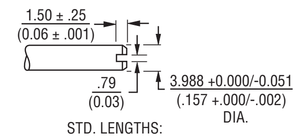
SHAFT TYPE "D" (USES BUSHING C)



STD. LENGTHS:

12.70 (.500)	15.88 (.625)	19.05 (.750)

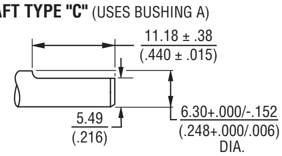
SHAFT TYPE "T" (USES BUSHING U)



STD. LENGTHS:

16.0 (.630)	22.0 (.866)

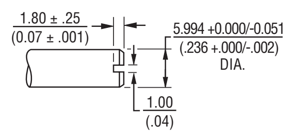
SHAFT TYPE "C" (USES BUSHING A)



STD. LENGTHS:

19.05 (.750)	22.23 (.875)

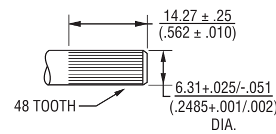
SHAFT TYPE "R" (USES BUSHING R)



STD. LENGTHS:

16.0 (.630)	22.0 (.866)

SHAFT TYPE "W" (USES BUSHING A)

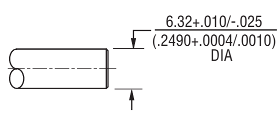


STD. LENGTHS:

25.40 (1.00)

Metal Shaft Styles

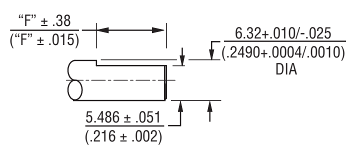
SHAFT TYPE "A" (USES BUSHING A)



STD. LENGTHS:

12.70 (.500)	15.88 (.625)	19.05 (.750)	22.23 (.875)	25.4 (1.000)

SHAFT TYPE "H" (USES BUSHING A)



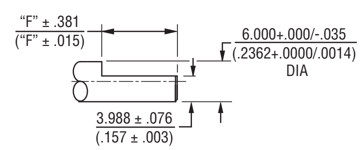
STD. LENGTHS:

19.05 (.750)	22.23 (.875)

FLAT LENGTH "F":

7.95 (.313)	11.13 (.438)

SHAFT TYPE "S" (USES BUSHING R)



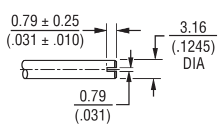
STD. LENGTHS:

16.0 (.630)	22.0 (.866)

FLAT LENGTH "F":

6.99 (.275)	12.98 (.511)

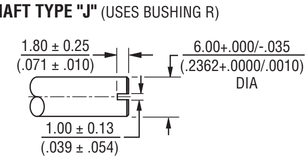
SHAFT TYPE "E" (USES BUSHING C)



STD. LENGTHS:

12.0 (.500)	16.0 (.625)	19.0 (.750)

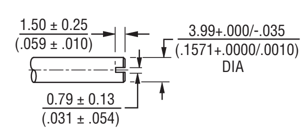
SHAFT TYPE "J" (USES BUSHING R)



STD. LENGTHS:

16.0 (.630)	22.0 (.866)

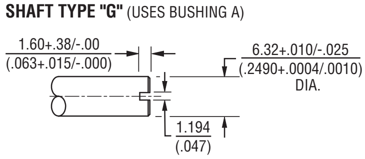
SHAFT TYPE "V" (USES BUSHING U)



STD. LENGTHS:

16.0 (.630)	22.0 (.866)

SHAFT TYPE "G" (USES BUSHING A)



STD. LENGTHS:

12.70 (.500)	15.88 (.625)	19.05 (.750)	22.23 (.875)

TOLERANCES EXCEPT AS SHOWN: .XX = ± .02 / (.050)

.XXX = ± .005 / (.127)

.XXXX = ± .0005 / (.0127)

DIMENSIONS: MM / (INCHES)

How to Order Model 91, 92, 93, 94 & 95 Panel Controls

BOURNS®

91	A	2	A	-	A	28	-	A	15	/	A15	L

Part number for multiple section potentiometers must have a taper and resistance value for each section.

MODEL

91	**Single-Turn, In-Line PC Pins**
92	Single-Turn, In-Line J-Hooks
93	Single-Turn, L-Pattern PC Pins
94	Single-Turn, L-Pattern J-Hooks
95	Single-Turn, Triangle-Pattern Solder Lugs

BUSHING

A	**Metal Plain 3/8 " (9.53 mm) D x 3/8 " (9.53 mm) L**
C	Metal Plain 1/4 " (6.35 mm) D x 1/4 " (6.35 mm) L
R	**Metal Plain 10 mm D x 9 mm L**
U	Metal Plain 7 mm D x 9 mm L

 # SECTIONS

1	**Single**
2	Dual

ANTI-ROTATION LUG

A	**Single .305 " (7.8 mm) R, 90 °CW**
D	**No Lug**

SHAFT TYPE		AVAILABLE ONLY IN LENGTHS (CODE)	AVAILABLE ONLY IN BUSHINGS (CODE)
B	**Plastic Single Slotted 1/4 " (6.35 mm) D**	16, 20, 24, 28	**A**
C	**Plastic Single Flatted 1/4" (6.35 mm) D**	24, 28	**A**
D	Plastic Single Plain 1/8" (3.18 mm) D	16, 20, 24	C
R	**Plastic Single Slotted 6 mm D**	Metric 16, 22	R
T	**Plastic Single Slotted 4 mm D**	Metric 16, 22	U
W	Plastic Single Knurled 1/4" (6.35 mm) D	32	**A**
A	**Metal Single Plain 1/4" (6.35 mm) D**	16, 20, 24	**A**
E	**Metal Single Slotted 1/8" (3.18 mm) D**	16, 20, 24	**C**
G	**Metal Single Slotted 1/4" (6.35 mm) D**	16, 20, 24, 28	**A**
H	**Metal Single Flatted 1/4" (6.35 mm) D**	24, 28	**A**
J	**Metal Single Slotted 6 mm D**	Metric 16, 22	R
S	**Metal Single Flatted 6 mm D**	Metric 16, 22	R
V	**Metal Single Slotted 4 mm D**	Metric 16, 22	U

SHAFT LENGTH (FMS) Code	Description	AVAILABLE ONLY IN BUSHING Code
16	1/2 "L	A, C
20	5/8 "L	A, C
24	**3/4 "L**	A, C
28	**7/8 "L**	**A**
32	1 "L	A
METRIC		
16	16 mmL	R, U
22	**22 mmL**	R, U

RoHS IDENTIFIER

L	**Compliant**

ELEMENT TAPER TYPE/TOLERANCE		RESISTANCE CODE VALUE IN OHMS	
(A)	**Linear Cermet ±10 %**	(05) - 100	(30) - 15 K
(H)	Linear Cermet ±5 %	(28) - 150	(16) - 20 K
		(06) - 200	(17) - 25 K
		(07) - 250	**(18) - 50 K**
		(08) - 500	**(20) - 100 K**
		(10) - 1 K	(21) - 200 K
		(11) - 2 K	(22) - 250 K
		(12) - 2.5 K	(23) - 500 K
		(13) - 5 K	(25) - 1 M
		(15) - 10 K	
(B)	**Linear C-P ±20 %**	**(10) - 1 K**	**(18) - 50 K**
(E)	Linear C-P ±10 %	(12) - 2.5 K	**(20) - 100 K**
		(13) - 5 K	(22) - 250 K
		(15) - 10 K	(23) - 500 K
		(16) - 20 K	(25) - 1 M
		(17) - 25 K	
(C)	CW Audio Cermet ±10 %	(10) - 1 K	(18) - 50 K
(D)	CW Audio C-P ±20 %	(12) - 2.5 K	(20) - 100 K
(F)	CCW Audio Cermet ±10 %	(13) - 5 K	(22) - 250 K
(G)	CCW Audio C-P ±20 %	(15) - 10 K	(23) - 500 K
(S)	CW Audio C-P ±10 %	(17) - 25 K	(25) - 1 M
(T)	CCW Audio C-P ± 10 %		

Boldface features are Bourns standard options. All others are available with higher minimum order quantities.

REV. 05/13

DIODES INCORPORATED

Green

APT13005S

450V NPN HIGH VOLTAGE POWER TRANSISTOR

Features

- BV_{CEO} > 450V
- BV_{CES} > 700V
- BV_{EBO} > 9V
- I_C = 3.2A High Continuous Collector Current
- **Lead-Free Finish; RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**

Mechanical Data

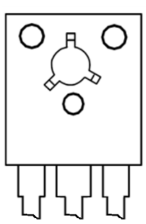
- Case: TO126, TO251 or ITO220AB
- Case Material: Molded Plastic, "Green" Molding Compound; UL Flammability Classification Rating 94V-0
- Terminals: Matte Tin Finish; Solderable per MIL-STD-202, Method 208 e3
- Weight: TO126: 400mg (Approximate)
  TO251: 340mg (Approximate)
  ITO220AB: 1500mg (Approximate)

Applications

Low Power AC-DC SMPS for:

- Battery Chargers for Mobile Phone / Tablets / Smartphones
- Power Supply for DVD / STB
- LED Lighting

TO126

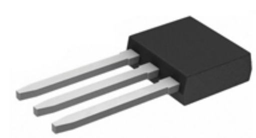


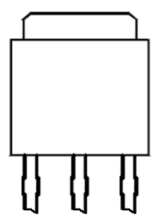
B C E

Front Face View

Pin-Out

TO251



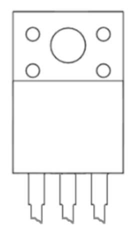


B C E

Front Face View

Pin-Out

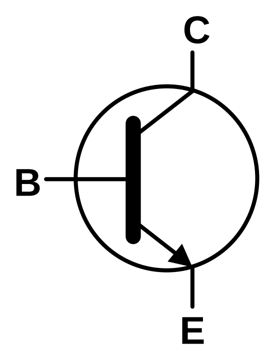
ITO220AB Isolated



B C E

Front Face View

Pin-Out



Device Schematic

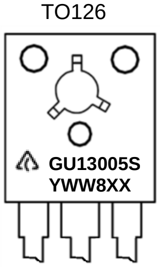
Ordering Information (Note 4)

Product	Package	Marking	Quantity
APT13005SU-G1	TO126	GU13005S	4,000 Bulk, Loose per Box
APT13005SI-G1	TO251	APT13005SI-G1	3,600 per Box in Tubes
APT13005STF-G1	ITO220AB	APT13005STF-G1	1,000 per Box in Tubes

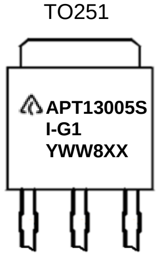
Notes:
1. EU Directive 2002/95/EC (RoHS) & 2011/65/EU (RoHS 2) compliant. All applicable RoHS exemptions applied.
2. See http://www.diodes.com/quality/lead_free.html for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
3. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.
4. For packaging details, go to our website at http://www.diodes.com/products/packages.html.

Marking Information

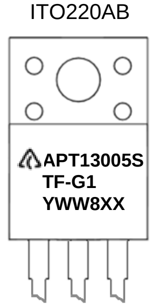
TO126



TO251



ITO220AB



= Manufacturers' Code Marking
For TO126: GU13005S = Product Type Marking ID
For TO251: APT13005SI-G1 = Product Type Marking ID
For ITO220AB: APT13005STF-G1 = Product Type Marking ID
YWW = Date Code Marking
e.g. 312 = Year 2013, Week 12.
8 = Assembly Site Code
XX = Batch Number

DIODES INCORPORATED

APT13005S

Absolute Maximum Ratings (@T_A = +25°C, unless otherwise specified.)

Characteristic	Symbol	Value	Unit
Collector-Emitter Voltage (V_{BE} = 0V)	V_{CES}	700	V
Collector-Emitter Voltage	V_{CEO}	450	V
Emitter-Base Voltage	V_{EBO}	9	V
Continuous Collector Current	I_C	3.2	A
Peak Pulse Collector Current	I_{CM}	6.4	A
Continuous Base Current	I_B	1.6	A
Peak Pulse Base Current	I_{BM}	3.2	A

Thermal Characteristics (@T_A = +25°C, unless otherwise specified.)

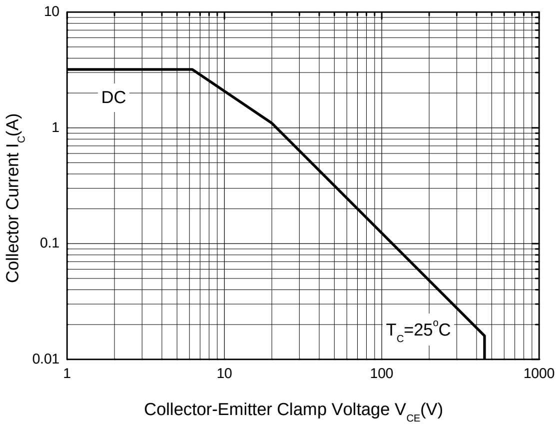
Characteristic		Symbol	Value	Unit
Power Dissipation	For TO126 @T_C = +25°C	P_D	20	W
	For TO251 @T_C = +25°C		25	
	For ITO220AB @T_C = +25°C		28	
Thermal Resistance, Junction to Case	For TO126	$R_{\theta JC}$	6.25	°C/W
	For TO251		5.0	
	For ITO220AB		4.5	
Operating and Storage Temperature Range		T_J, T_{STG}	-65 to +150	°C

ESD Ratings (Note 5)

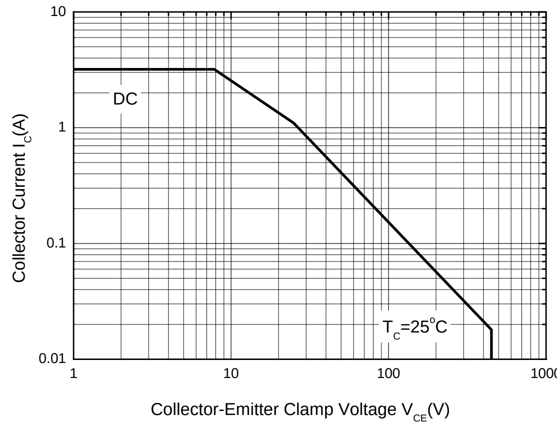
Characteristic	Symbol	Value	Unit	JEDEC Class
Electrostatic Discharge - Human Body Model	ESD HBM	8,000	V	3B
Electrostatic Discharge - Machine Model	ESD MM	400	V	C

Note: 5. Refer to JEDEC specification JESD22-A114 and JESD22-A115.

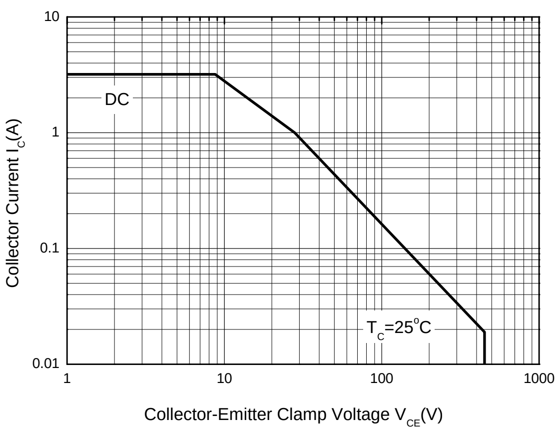
Safe Operating Areas (@T_A = +25°C, unless otherwise specified.)



Safe Operating Areas
(TO126 Package)



Safe Operating Areas
(TO251 Package)



Safe Operating Areas
(ITO220AB Package)

Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)

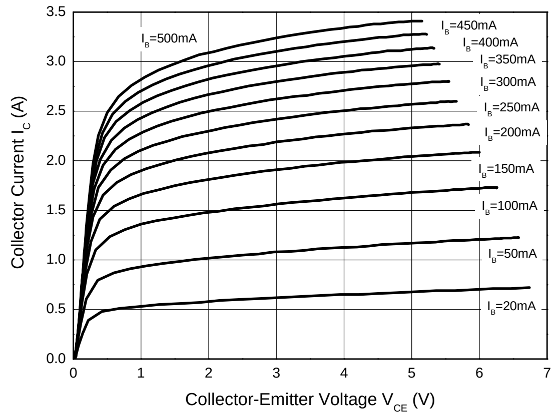
Characteristic	Symbol	Min	Typ	Max	Unit	Test Condition
Collector-Emitter Breakdown Voltage	BV_{CES}	700	—	—	V	I_C = 100µA, V_{BE} = 0V
Collector-Emitter Breakdown Voltage	BV_{CEO}	450	—	—	V	I_C = 100µA
Emitter-Base Breakdown Voltage	BV_{EBO}	9	—	—	V	I_E = 100µA
Collector Cutoff Current	I_{CEV}	—	—	10	µA	V_{CE} = 700V, V_{BE} = -1.5V
DC Current Transfer Static Ratio (Note 6)	h_{FE}	20 11	— —	35 35	—	I_C = 1A, V_{CE} = 5V I_C = 2A, V_{CE} = 5V
Collector-Emitter Saturation Voltage (Note 6)	$V_{CE(sat)}$	— — —	— — —	0.3 0.6 1.0	V	I_C = 1A, I_B = 0.2A I_C = 2A, I_B = 0.5A I_C = 3A, I_B = 0.75A
Base-Emitter Saturation Voltage (Note 6)	$V_{BE(sat)}$	— —	— —	1.2 1.4	V	I_C = 1A, I_B = 0.2A I_C = 2A, I_B = 0.5A
Output Capacitance	C_{OB}	—	35	—	pF	V_{CB} = 10V, f = 0.1MHz
Transition Frequency	f_T	4	—	—	MHz	I_C = 0.5A, V_{CE} = 10V
Turn-on Time with Resistive Load	t_{on}	—	—	0.7	µs	I_C = 2A, V_{CC} = 125V, I_{B1} = $-I_{B2}$ = 0.4A
Storage Time with Resistive Load	t_s	—	—	4.5		
Fall Time with Resistive Load	t_f	—	—	0.8		

Note: 6. Measured under pulsed conditions. Pulse width ≤ 300µs. Duty cycle ≤ 2%.

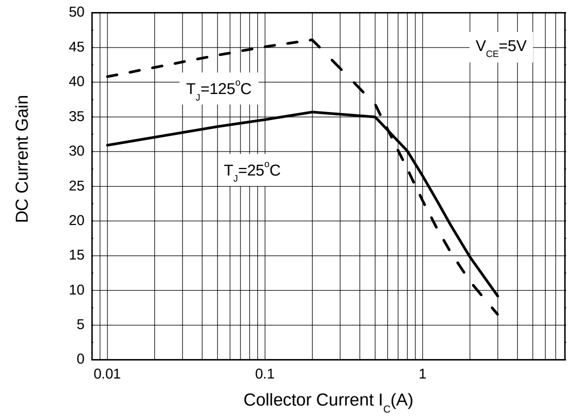
DIODES INCORPORATED

APT13005S

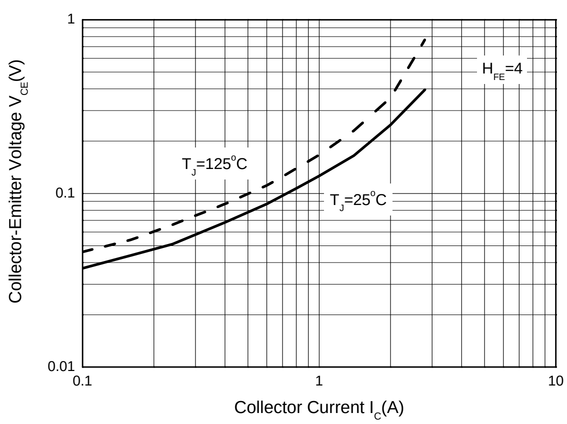
Typical Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)



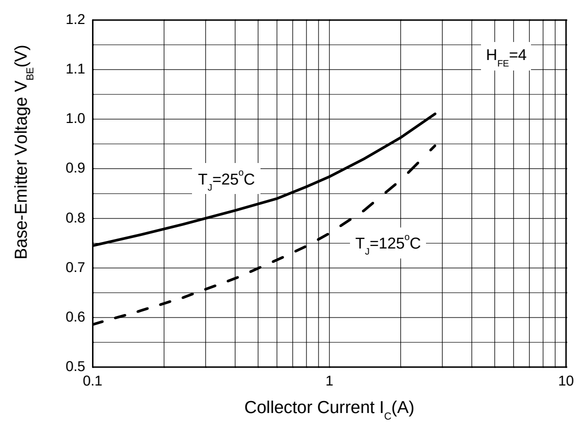
Static Characteristics



DC Current Gain



Collector-Emitter Saturation Region

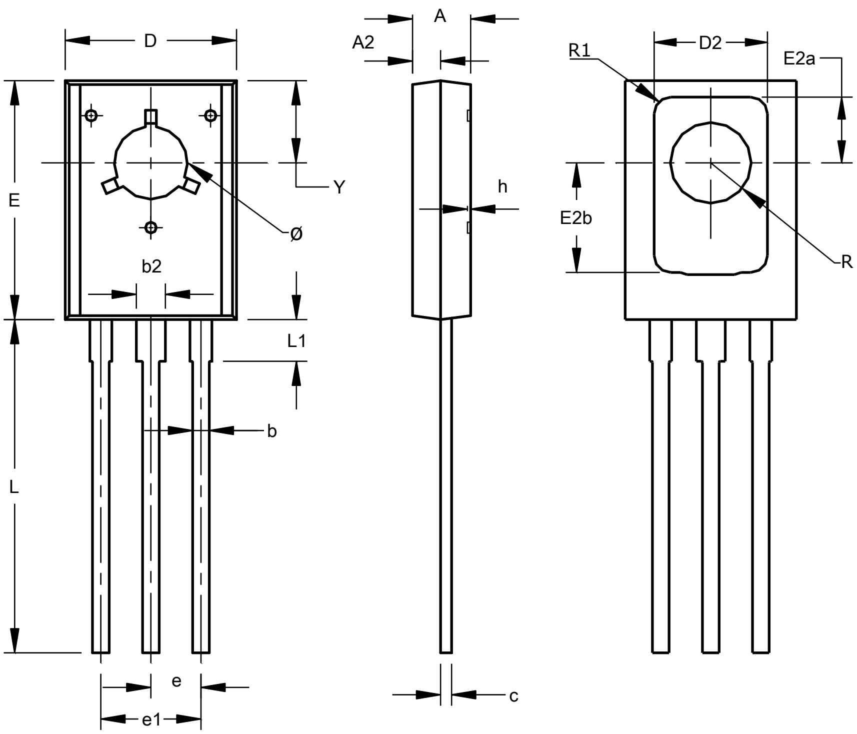


Base-Emitter Saturation Voltage

Package Outline Dimensions

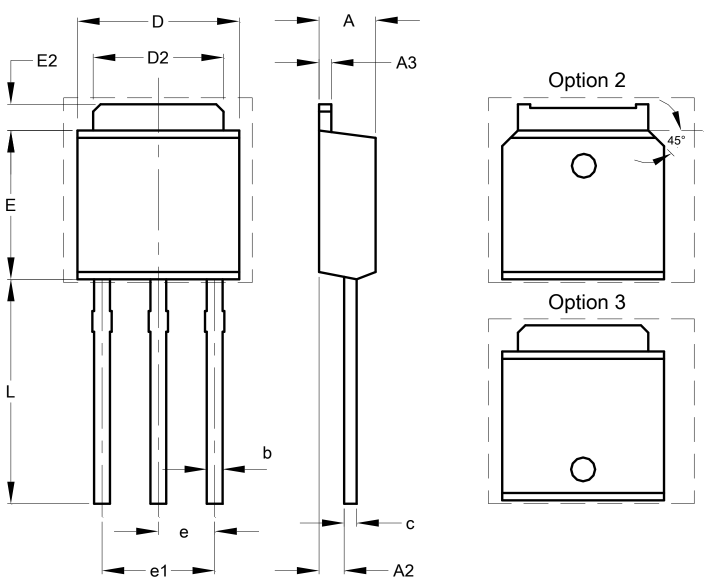
Please see AP02002 at http://www.diodes.com/datasheets/ap02002.pdf for the latest version.

(1) Package Type: TO126



TO126			
Dim	**Min**	**Max**	**Typ**
A	2.400	2.900	-
A2	1.060	1.500	-
b	0.660	0.860	-
b2	1.170	1.470	-
c	0.400	0.600	-
D	7.400	8.200	-
D2	5.010	5.310	-
E	10.60	11.20	-
E2a	2.850	3.150	-
E2b	4.850	5.150	-
e	-	-	2.280
e1	-	-	4.560
h	0.00	0.30	-
L	14.50	15.90	-
L1	1.700	2.100	-
R	-	-	1.840
R1	-	-	0.760
Y	3.600	3.900	-
Ø	3.100	3.550	-
All Dimensions in mm			

(2) Package Type: TO251

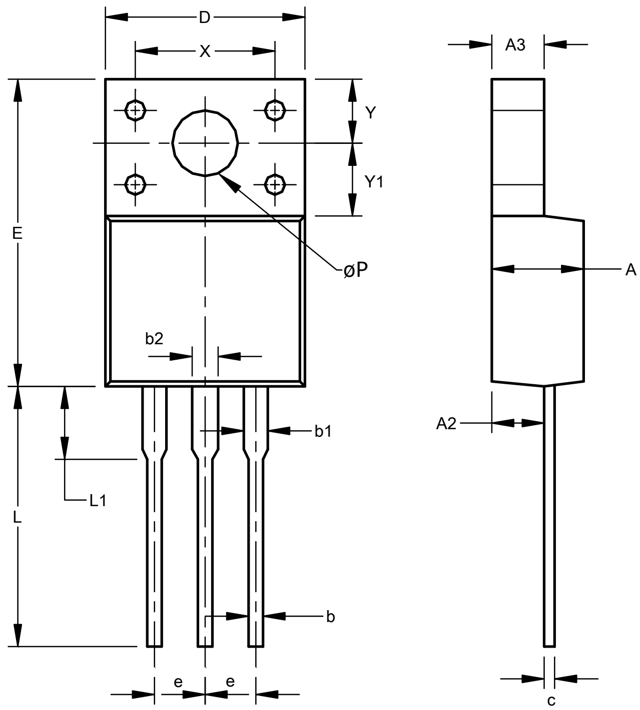


TO251		
Dim	**Min**	**Max**
A	2.200	2.400
A2	0.890	1.150
A3	0.450	0.550
b	0.550	0.740
c	0.450	0.570
D	6.400	6.750
D2	5.200	5.400
E	5.950	6.250
E2	0.900	1.250
e	2.240	2.340
e1	4.430	4.730
L	8.900	9.500
All Dimensions in mm		

Package Outline Dimensions (continued)

Please see AP02002 at http://www.diodes.com/datasheets/ap02002.pdf for the latest version.

(3) Package Type: ITO220AB (TYPE BR)



ITO220AB (TYPE BR)			
Dim	**Min**	**Max**	**Typ**
A	4.300	4.900	-
A2	2.520	2.920	-
A3	2.350	2.900	-
b	0.550	0.900	-
b1	1.000	1.400	-
b2	1.100	1.500	-
c	0.450	0.600	-
D	9.70	10.30	-
E	14.70	16.00	-
e	-	-	2.54
L	12.50	13.50	-
L1	2.790	4.500	-
X	6.90	7.10	-
Y	3.000	3.400	-
Y1	3.370	3.900	-
øP	3.000	3.550	-
All Dimensions in mm			

Note: For high voltage applications, the appropriate industry sector guidelines should be considered with regards to voltage spacing between terminals.

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A. Life support devices or systems are devices or systems which:

1. are intended to implant into the body, or

2. support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in significant injury to the user.

B. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or to affect its safety or effectiveness.

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www.diodes.com

...

The **Arduino Nano** is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0) or ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one. The Nano was designed and is being produced by Gravitech.

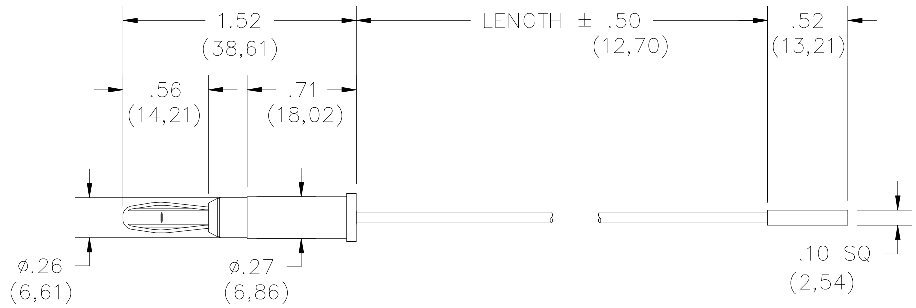
Technical Specification

Microcontroller	Atmel ATmega168 or ATmega328
Operating Voltage (logic level)	5 V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6-20 V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Flash Memory	16 KB (ATmega168) or 32 KB (ATmega328) of which 2 KB used by bootloader
SRAM	1 KB (ATmega168) or 2 KB (ATmega328)
EEPROM	512 bytes (ATmega168) or 1 KB (ATmega328)
Clock Speed	16 MHz
Dimensions	0.73" x 1.70"

If you want to give a closer look to this board we advice you to visit the official Arduino Nano page in the Hardware Section.

Pomona®

Model 4771
Square Pin Receptacle To Banana Plug



FEATURES:

- This patch cord is excellent for use as a jumper on circuit cards with 0.6 (.025) sq. pins and equipment with 4.2 (.166) dia. pin jacks.
- Mates to Model numbers 5790, 4521, and 5360.

MATERIALS:

Conn.: In-Line Banana Plug

Material: Spring – Beryllium Copper per QQ-C-533, Alloy 172, Cond. HT. Plug Body – Brass per QQ-B-626, Alloy 360, ½ Hard.

Finish: Nickel plated per QQ-N-290, Class 2, 200/300 microinches.

Insulation: Polypropylene molded to plug body and wire.

Color: Matches color of wire

Wire: 22 AWG, stranding 26 x 36 T.C., PVC Insulated, 1.63 (.064) O.D.

Color: See Ordering Information

Marking: "POMONA 4771-XX"

Conn: 0.64 (.025) Square Pin Receptacle

Material: Phosphor bronze.

Finish: Gold plated.

Housing Insulation: Polypropylene

Color: Black.

RATINGS:

Operating Temperature: +50º C (+122º F) Max

Operating Voltage: 1000 VDC

Current: 3 Amperes

ORDERING INFORMATION: Model 4771-XX-*

XX=Cable Lengths, Standard Lengths: 12" (305mm), 24" (610mm), 36" (914mm)

Additional lengths and colors can be quoted upon request.

*=Color, -0 Black, -2 Red

Ordering Example: 4771-12-2 Indicates 12" in length, color is Red.

All dimensions are in inches. Tolerances (except noted): .xx = ±.02" (,51 mm), .xxx = ± .005" (,127 mm).
All specifications are to the latest revisions. Specifications are subject to change without notice.

Sales: 800-490-2361 Fax: 425-446-5844
Technical Support: technicalsupport@pomonatest.com

Urethane Round Belt

Clear, 1/8" Diameter, 4" to 12" Outer Circle

Usually ships in 3 days.
$4.18 Each
3044K503

Diameter	1/8"
Outer Circle	4"- 12"
Core Construction	Solid
Color	Clear
Material	Urethane
Outer Circle (OC)	7" in.

Also known as O-ring and endless belts, these come ready to use.

Urethane—All urethane belts are chemical and abrasion resistant. Standard urethane belts are made from FDA-listed material for use with food and beverage. Inch sizes are made from FDA-listed material for use with food and beverage.

Choose outer circle (OC) in 1/4" increments.

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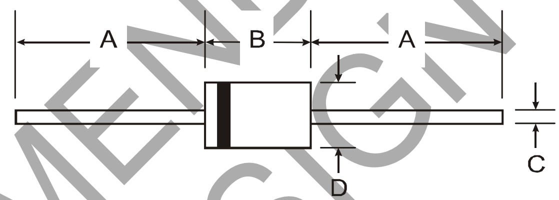
NOT RECOMMENDED FOR NEW DESIGN
USE S1A-S1M series

1N4001 - 1N4007
1.0A RECTIFIER

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**



Dim	DO-41 Plastic	
	Min	Max
A	25.40	—
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All Dimensions in mm		

Mechanical Data

- Case: DO-41
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020D
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Ordering Information: See Page 2
- Marking: Type Number
- Weight: 0.30 grams (Approximate)

Maximum Ratings and Electrical Characteristics (@T_A = +25°C unless otherwise specified.)

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

Characteristic	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ T_A =+75°C	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms Single Half Sine-Wave Superimposed on Rated Load	I_{FSM}	30							A
Forward Voltage @ I_F = 1.0A	V_{FM}	1.0							V
Peak Reverse Current @T_A = +25°C at Rated DC Blocking Voltage @ T_A = +100°C	I_{RM}	5.0 50							µA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +150							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

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USE S1A-S1M series

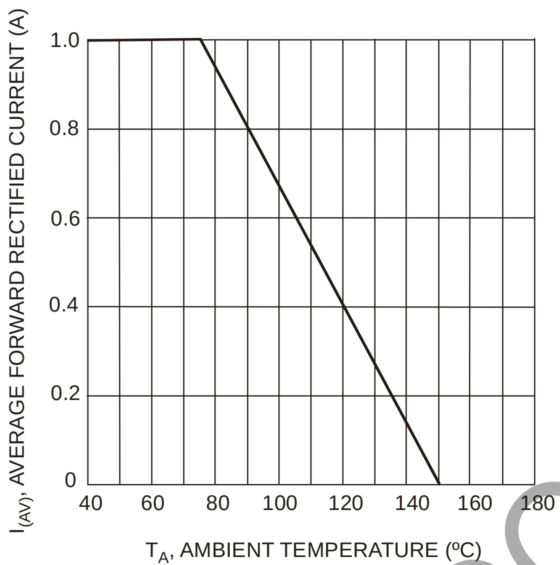

Fig. 1 Forward Current Derating Curve

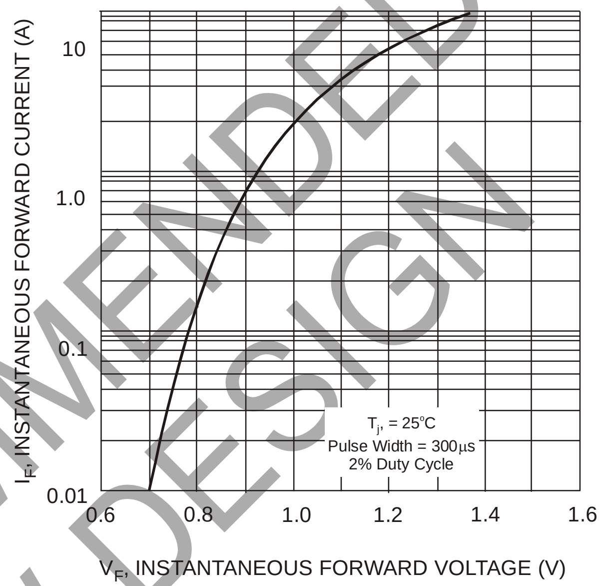

Fig. 2 Typical Forward Characteristics

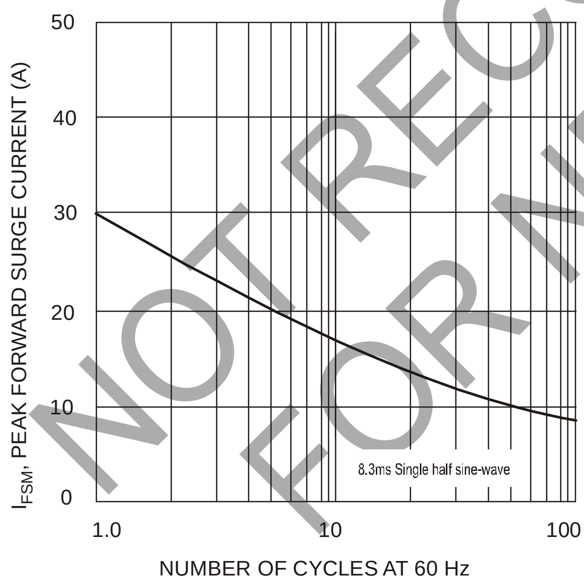

Fig. 3 Max Non-Repetitive Peak Fwd Surge Current

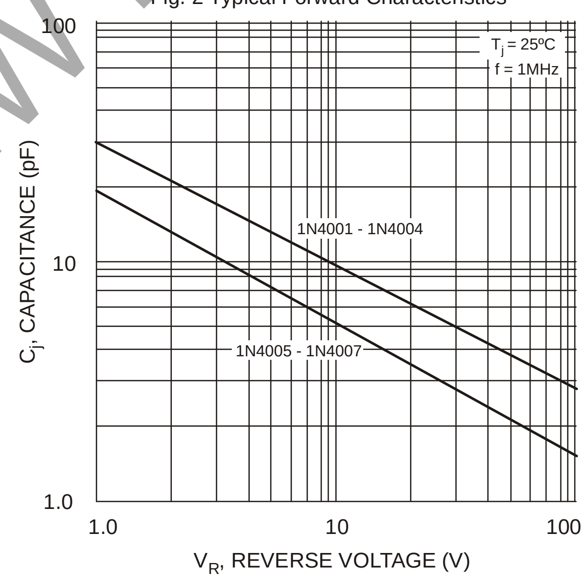

Fig. 4 Typical Junction Capacitance

Ordering Information (Note 4)

Device	Packaging	Shipping
1N4001-B	DO-41 Plastic	1K/Bulk
1N4001-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4002-B	DO-41 Plastic	1K/Bulk
1N4002-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4003-B	DO-41 Plastic	1K/Bulk
1N4003-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4004-B	DO-41 Plastic	1K/Bulk
1N4004-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4005-B	DO-41 Plastic	1K/Bulk
1N4005-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4006-B	DO-41 Plastic	1K/Bulk
1N4006-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4007-B	DO-41 Plastic	1K/Bulk
1N4007-T	DO-41 Plastic	5K/Tape & Reel, 13-inch

Note: 4. For packaging details, visit our website at http://www.diodes.com/datasheets/ap02008.pdf.

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MUELLER® DATASHEET

WI-M-18-XX-*

(Superior 18 AWG, Silicone Jacket Test Lead Wire)

- 18 AWG, 413/44 strand (7/59/.05mm) copper with a highly flexible, .140" (3.6mm) diameter silicone jacket.
- UL Listed: Style 3577
- Ratings: 3000V, 22 Amps. @ 150^{o}C
- Length: "XX" in model number indicates length in feet. Standard lengths are: -10 Ft. and -25 Ft. Custom lengths are available upon request
- Colors: designated by "*" in the part number: -0 black, -2 red,
- RoHS Compliant

Mueller Electric Company
1208 Massillon Rd. Ste. N-1500
Akron, OH 44306-4524

www.muellerelectric.com

Toll Free: 800.955.2629
Phone: 330.780.2525
Fax: 330.780.2524

Product Overview	
Digi-Key Part Number	1471-1232-ND
Quantity Available	**1,801** Can ship immediately
Manufacturer	MikroElektronika
Manufacturer Part Number	MIKROE-513
Description	WIRE JUMPER MALE-MALE 15CM 10PCS
Expanded Description	Jumper Wire Male to Male 5.91" (150.0mm) 10 per Pkg
Lead Free Status / RoHS Status	Not applicable / Not applicable
Moisture Sensitivity Level (MSL)	1 (Unlimited)
Manufacturer Standard Lead Time	4 Weeks

Price & Procurement

All prices are in USD.

Price Break	Unit Price	Extended Price
1	3.06000	3.06

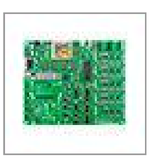
Submit a request for quotation on quantities greater than those displayed.

Documents & Media	
Online Catalog	Jumper Wire

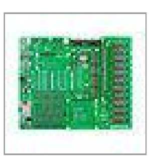
Product Attributes	
Categories	Prototyping Products Jumper Wire
Manufacturer	MikroElektronika
Series	-
Packaging	10 per Pkg
Part Status	Active
Style	Male to Male
Length	5.91" (150.0mm)
Color	Various
Wire Gauge	-

86 Remaining

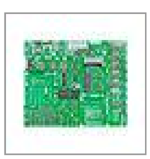
Kits



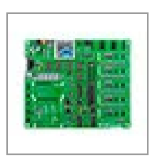
MIKROE-2058
MikroElektronika
MIKROLAB FOR PIC - BASIC
Unit Price 420.90000
1471-1548-ND



MIKROE-2014
MikroElektronika
MIKROLAB FOR AVR L
Unit Price 466.24000
1471-1533-ND



MIKROE-2018
MikroElektronika
MIKROLAB FOR 8051
Unit Price 466.24000
1471-1529-ND



MIKROE-2013
MikroElektronika
MIKROLAB FOR AVR
Unit Price 481.03000
1471-1534-ND

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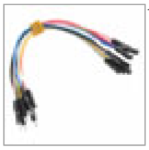
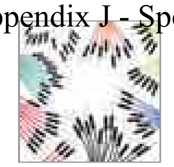
				
MIKROE-511 MikroElektronika WIRE JUMPER FEM-FEM 15CM 10PCS **Unit Price** 3.06000 1471-1230-ND	**MIKROE-512** MikroElektronika WIRE JUMPER MALE-FEM 15CM 10PCS **Unit Price** 3.06000 1471-1231-ND	**BC-32625** Bud Industries JUMPER WIRE BUNDLE 65PCS **Unit Price** 5.30000 377-2093-ND	**WK-2** B&K Precision JUMPER WIRE KIT 140 PC **Unit Price** 6.20000 BKWK-2-ND	**BB-32621** Bud Industries BREADBOARD SOLDERLESS 400 TIE **Unit Price** 4.50000 377-2094-ND

Additional Resources	
Standard Package	1
Other Names	1471-1232

10:45:13 2/10/2017

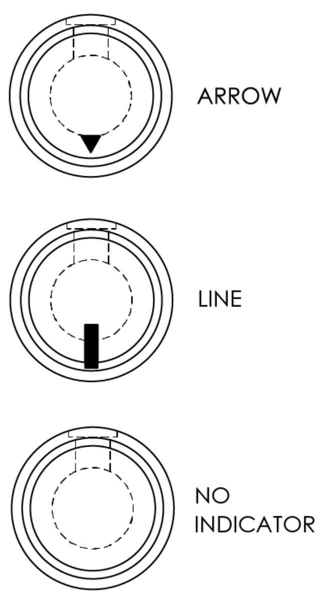
KILO INTERNATIONAL

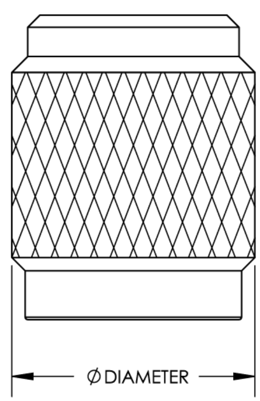
PART NUMBER BREAK DOWN

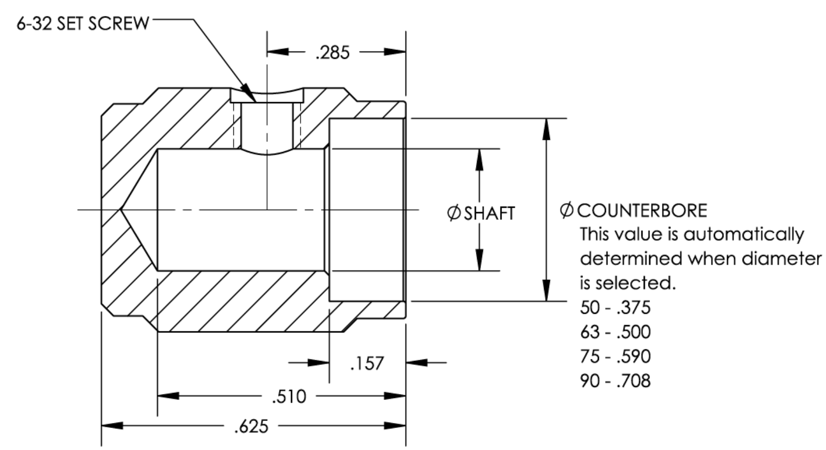
EXAMPLE: OEDA-90-4-7

OED	A	90	4	7
MODEL	**INDICATOR**	**DIAMETER**	**FINISH**	**SHAFT SIZE**
These letters are the model series name.	This value represents the the indication mark.	This value indicates the outer diameter sizing of the knob.	This value indicates the color and finish of the knob.	This value indicates shaft sizing.
	L - LINE	**50** - .500	**1** - CLEAR GLOSS	**5** - .250
	A - ARROW	**63** - .625	**2** - BLACK GLOSS	**6** - .125
	NI - NO IND.	**75** - .750	**3** - CLEAR MATTE	**7** - .2375 (6MM)
		90 - .920	**4** - BLACK MATTE	

INDICATOR STYLE







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Yescom 30V 10A 110V DC Power Supply Precision Variable Digital Adjustable w/ Clip Cable

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OVERVIEW

Features:

Durable steel case
Constant voltage and constant current operation mode (C.C and C.V. automatic conversion)
Multiple protections: over voltage (OVP), open circuit (OCP),over temperature (OTP)
Safe circuit design, high quality key components adopted, the power supply can be used in 24 hours with full load
Intelligent temperature control fan adjusts the speed according to the load situation, effectively reduce noise and prolong the life of fan

Specifications:

Input voltage:220V±10% 50Hz or 110V±10% 60Hz or 115V/230V±10%
Output voltage: DC 0-30V Continuous adjustable
Output current: DC 0-10A Continuous adjustable
Display resolution: voltage: 0.1V , current 0.1A.
Display precision: ±1% ±1digit
Voltage stabilization: «0.05% +1mV
Current stabilization: «0.1% +10mA
Load stabilization:CV«0.1% +1mV / CC«0.1% +10mA
Ripples and noises:CV«10mV£¨RMS£©/ CC«20mA£¨RMS£©
Cooling way£ºIntelligent temperature control fan. if the temperature is higher than 40 °F, the fan is started, if less than 95°F, the fan will stop which can reduce noise
Working conditions: -50°F - 104°F Relative humidity :< 80%
Storage conditions: -68°F - 176°F Relative humidity :< 80%
Dimension: 10.2 x 4.9 x 6.1 (inch)

Specifications:

1 x DC power supply
1x Power Cord
1x Clip cable
1x User Manual

SPECS

Model

Brand	Yescom USA, Inc.
Model	15SDS019DCP3010D09

Details

Engine Brand	Yescom

Manufacturer Contact Info

Website: http://www.yescomusa.com/
Support Phone: 626-336-2829
Support Email: support@yescomusa.com
Support Website

Return Policies

This item is covered by Yescom Return Policy.

NMB-MAT

SR-YDC 10521

SPECIFICATION
納入仕様書

MESSRS.

Digi-Key Corporation 御中

MODEL
機種名 PPN7PA12C1

07/Dec/2010 発行/ISSUE

RECEIVED BY:
貴社ご受領印：

CHECKED 検　印	CHECKED 検　印	CHECKED 検　印	PREPARED 担当者

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SR-YDC 10521

納入仕様書変更経歴書 / SPECIFICATION REVISON HISTORY

DATE 日付	PAGES ページ	No. 符号	REASON OR CONTENTS 変更理由・変更内容	PREPARED 担当	CHECKED 検印
7-Dec-10	–	–	New. 新規。		

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APPLICATION:適用範囲

This specification applies to the motor PPN7PA12C1 which is to be delivered by MINEBEA MOTOR MANUFACTURING CORPORATION.

本仕様書はミネベアモータ株式会社が製造する PPN7PA12C1 について規定し、適用する。

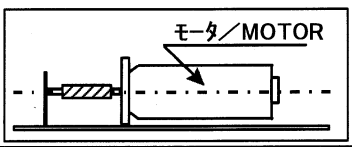
■1. STANDARD OPERATING CONDITION:標準使用状態及び条件。
(Reliability tests to be in item−4 : 但し、信頼性は4項による。)

	ITEMS : 項目	SPECIFICATION : 規格
1-1	Rated Voltage 定格電圧	5 V DC
1-2	Rated Load 定格負荷	0.49 mN·m
1-3	Rated Load Speed 定格負荷回転数	11600 min^{-1}
1-4	Rotating Direction 回転方向	Direction CW & CCW when viewed from output shaft. 出力軸よりみて　両方向。
1-5	Operationg Position モータ姿勢	Output shaft all direction.　When inspected , the shaft is vertical up. 出力軸全方向。　検査時は出力軸上方向にて。
1-6	Side Pressure 側圧	0.49 ～ 0.98N at a position 5mm above motor installation surface. モータ取付け面より5mm上部にて 0.49 ～ 0.98N。
1-7	Grounding Polarity 接地極性	No polarity. 無し。
1-8	Operating Voltage 使用電圧範囲	1.0 ～ 7.0 VDC.　Power supply voltage ripple is less than 0.3%. 電源リップル0.3%以内。
1-9	Operating Load 使用負荷範囲	0.10 ～ 0.98 mN·m.
1-10	Operating Speed 使用回転数範囲	Less than 15000rpm. 15000rpm 以下。
1-11	Operating Temperature 使用温度範囲	−20 ～ +70℃.　At normal humidity./常湿にて。
1-12	Storage Temperature 保存温度範囲	−40 ～ +85℃.　At normal humidity./常湿にて。
1-13	Thrust Load スラスト圧	Less than 0.98N. 0.98N以下。
1-14 ※	Type of Load 負荷種類	Gear or worm gear. 平ギア　又は　ウォームギア。

■2. CONSTRUCTION : 外観仕様

	ITEMS : 項目	TEST CONDITIONS : 測定条件	SPECIFICATION : 規格
2-1	Appearance 外観	Visual. 目視。	Appropriate for usage. 特に見苦しく無いこと。
2-2	Dimension 外観寸法	Measured by caliper or micrometer. ノギス又はマイクロメータにて測定。	Refer to construction drawing. 別紙外観図に基づく。
2-3	Mass 質量	Measured by scale. 計量器にて測定。	Average 10 g. 約
2-4	Shaft Diflection シャフト振れ。	5mm from mounting surface by dial gauge. モータ取付面より5mmの距離をダイヤルゲージにて。	Less than 0.03mm. 0.03mm以下。
2-5	Shaft End Play 出力軸エンドプレー	Measured by dial gauge. ダイヤルゲージにて。	0.02 ～ 0.50mm.

※ Keep hold top of the shaft when use warm gear.
ウォームギアご使用の際はシャフト先端を受けてください。



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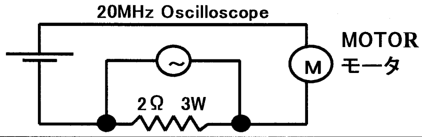
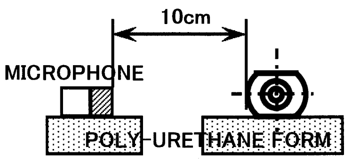
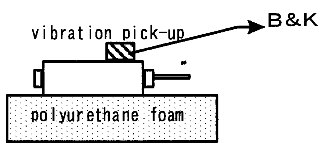
■3. INITIAL CHARACTERISTICS ： 初期特性仕様

In standard test , measurement is to be made at +5℃ to +30℃ and relative humidity 45% to 85%.
If the judgement is questionable , the measuremnent is to be made at +20℃ and 65%RH.
温度20℃、相対湿度65%を標準とする。但し、測定に疑義を生じない場合は温度5～30℃、相対湿度45～85%の環境下(常温)において行なっても可とする。

	ITEMS ： 項目	TEST CONDITIONS ： 測定条件	SPECIFICATION ： 規格
3-1	Rated Load Speed 定格負荷回転数	Rated voltage and rated load. 定格電圧・定格負荷にて。	11600 min^{-1} ± 15%.
3-2	Rated Load Current 定格負荷電流	Rated voltage and rated load. 定格電圧・定格負荷にて。	270 mA max. 以下。
3-3	No Load Speed 無負荷回転数	Rated voltage and no load. 定格電圧・無負荷にて。	14000 min^{-1} ± 15%.
3-4	No Load Current 無負荷電流	Rated voltage and no load. 定格電圧・無負荷にて。	120 mA max. 以下。
3-5	Starting Current 起動電流	At 5V(2-points method). 0 & 0.49mN·m. 5V、2点法にて。 0 & 0.49mN·m	1300 mA max. 以下。
3-6	Starting Torque 起動トルク	At 5V(2-points method). 0 & 0.49mN·m. 5V、2点法にて。 0 & 0.49mN·m	2.8 mN·m ± 25%.
3-7	No Load Starting Voltage 無負荷起動電圧	No load. 無負荷にて。	0.5 V max. 以下。
3-8	Terminal Resisitance 端子間抵抗	At 20℃ and rotor position is at 2R/3. 温度20℃、ロータ位置2R／3にて。	4.4 Ω ± 10%.
3-9	Insulation Resistance 絶縁抵抗	Measured between terminal and frame with 100V DC megger. フレームと端子間をDC100Vメガーにて。	1 MΩ min. 以上。
3-10	Electrical Noise 電気雑音	Rated voltage and no load. 定格電圧、無負荷にて。  	4 Vp-p max. 以下。
3-11	Mechanical Noise 機械雑音	Measured at rated speed & no load operation. 定格負荷回転数、無負荷にて。 Background noise/暗騒音 : 20dB max. Measuring instruments/測定計器 : B&K  	55 dB max. 以下。 At A-weighting. Aレンジにて。
3-12	Vibration 振動	Measured at rated speed & no load operation. 定格負荷回転数、無負荷にて。 Background vibration/暗振動 : -40dB max. Measuring instruments/測定計器 : B&K $0dB=9.8m/s^2$  	5 dB max. 以下。 At 1st fundamental frequency. 1回転成分にて。
3-13	Current Waveform 電流波形	At 2V DC and no load. 2V、無負荷にて。	Free from off point. オフ点なき事。

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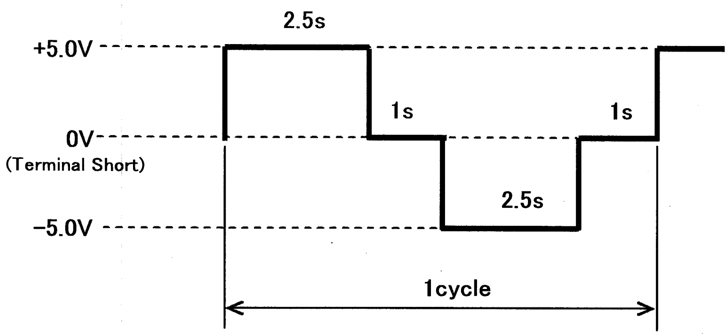
■4. RELIABILITY and SPECIAL TEST : 信頼性・特殊試験

	ITEMS : 項目	TEST CONDITIONS : 測定条件 & SPECIFICATION : 規格
4-1	Life Test 寿命	Motor test condition are listed as below. A motor is considered as meeting life expectation when either of the criteria described met. 下記試験条件により実施し下記に示す判定基準のいずれかになった時を寿命とする。



Position 姿勢	Voltage 電圧	Load 負荷	Environment 環境	Life Time 寿命時間
Horizontal 水平	Shown in the above. 上記モード。	0.49mN·m	20℃ 65%	20000cycle min. 以上。

※ Test detail shown in below. / 試験条件詳細は下記参照。

・JUDGEMENT
・判定基準

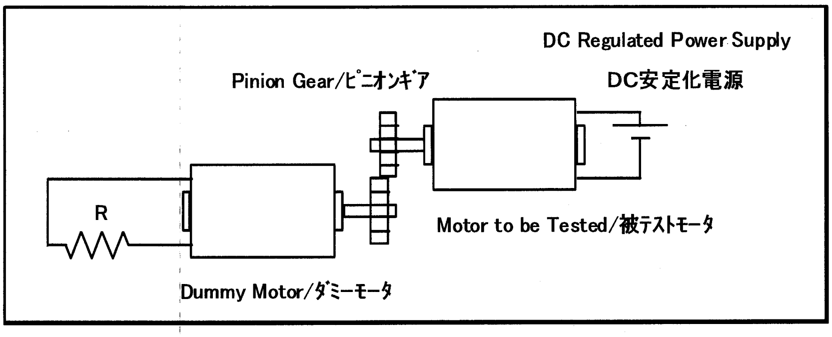
1)Rated load speed varies more than ±30% from the initial.
2)Rated load current varies more than ±30% from the initial.

1)定格負荷回転数変化が初期値に対し、±30%を越えた時。
2)定格負荷電流変化が初期値に対し、±30%を越えた時。

・Life test conditon
・ライフテスト条件

Power source/電源 — Regulated DC power supply should be used. DC安定化電源を使用。

Loading/負荷 — Dummy motor is connected through pinion gear. Load current can be adjusted by resistance value connected to dummy motor terminal.
ピニオンギアを介してダミーモータに接続する。
負荷の調整はダミーモータの抵抗又は端子間の抵抗値で行なう。



<table>
<tr><td rowspan="3">MODEL: PPN7PA12C1</td><td rowspan="3">SPECIFICATION / 納入仕様書</td><td>NO.</td><td>SR-YDC 10521</td></tr>
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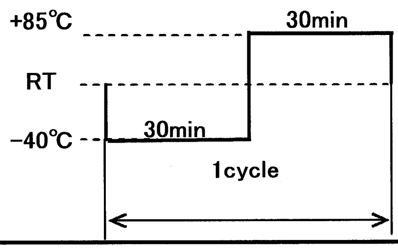
<tr><td>DATE</td><td>07/Dec/2010</td></tr>
</table>

<table>
<tr><th></th><th>ITEMS ： 項目</th><th>TEST CONDITIONS ： 測定条件</th><th>SPECIFICATION ： 規格</th></tr>
<tr><td>4-2</td><td>Withstand Vibration Test
耐振動試験</td><td>Smallest packing subjected to 2mm amplitude and 1000/60(Hz) vibration for 30min, each Up-Down , Left-Right and Back-Front.
最小梱包状態にて、全振幅2mm、振動数1000/60(Hz)の振動を上下・前後・左右 各30min加える。</td><td rowspan="4">Rated load speed varies within ±20% from the initial.
定格負荷回転数変化が初期値に対し±20%以内のこと。

Rated load current varies within ±30% from the initial.
定格負荷電流変化が初期値に対し±30%以内のこと。</td></tr>
<tr><td>4-3</td><td>Withstand Shock Test-1
耐衝撃試験-1</td><td>$980m/s^2$ impact is applied for 6ms to the motor that is mounted to the plate.
The impact shall be applied 1 time for each direction that are Up-Down , Left-Right and Back-Front.
モータ取付け状態にて、取付板に$980m/s^2$の衝撃を6ms、上下・前後・左右、各1回加えた後測定を行なう。</td></tr>
<tr><td>4-4</td><td>Withstand Shock Test-2
耐衝撃試験-2</td><td>Smallest packing dropped on wooden block of 10cm thickness from 100cm height , once for each 6 faces of the packing.
最小梱包状態にて厚さ10cmの木片上に高さ100cmから6面各一回の自然落下をおこなう。</td></tr>
<tr><td>4-5</td><td>Storage Test
保存試験</td><td>A motor shall be made storage test as below. Measurement shall me made after the motor is returned in 20℃ for 24h.
*Each storage test is indipendent.
下記条件にて放置試験を行ない、20℃中に24h放置した後、測定を行なう。
*下記の放置試験は各々独立した試験とする。
<table>
<tr><th></th><th>Environment/環境</th><th>Time/放置時間</th></tr>
<tr><td>1</td><td>+85℃ 20～65%</td><td>300h</td></tr>
<tr><td>2</td><td>-40℃</td><td>300h</td></tr>
<tr><td>3</td><td>+60℃ 90%</td><td>300h</td></tr>
</table></td></tr>
<tr><td>4-6</td><td>Heat Shock Test
熱衝撃試験</td><td>A motor shall be made heat shock test as below for 20cycles. Measurement shall be made after the motor is returned in 20℃ for 24h.
下記条件にて20サイクル放置試験を行ない、20℃中に24h放置した後、測定を行なう。
</td><td>Rated load speed varies within ±30% from the initial.
定格負荷回転数変化が初期値に対し±30%以内のこと。

Rated load current varies within ±30% from the initial.
定格負荷電流変化が初期値に対し±30%以内のこと。</td></tr>
</table>

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IMPORTANT NOTES FOR SAFETY／安全上のご注意

※ Be sure to observe the following items. / 必ず遵守下さい。

CAUTION : 警告

①.【Protection Circuit / 安全回路】

(a) Toward the end of motor life or unexpected failure in motor , commutator slit short or short between brush and frame might occure. Then short current might flow into power supply of the set.
(b) When motor shaft is locked or continuous over-load while motor is electrical conducting , excessive heat might generate and burn motor parts.
(c) Motor control circuit or semiconductor may be damaged by supplied voltage exceeded allowable limit , supplied voltage in reverse polarity or electrical contact partial open or short circuit.
Safety confirmation test shall be conducted on the above-mentioned (a) , (b) and (c) items.
Consider adding protection devices such as a fuse , a protection circuit or other devices to the motor.

(a) モータライフエンド近くで、もしくは故障モードとして整流子のスリット間ショート及びブラシ・フレームケース間ショートが発生する場合があります。 その場合、セットの電源回路にショート電流が流れます。
(b) モータをロック状態、もしくは過負荷状態で持続しますとモータの一部が発熱・焼損します。
(c) 過電圧、逆バイアス、コネクタ端子の一部オープン、ショート等の異常使用はモータ回路、半導体の破壊を招きます。

従いまして上記(a)～(c)に対するセット実装での不安全試験を実施して頂き、ヒューズ・保護回路等の安全装置を設置し安全確保対策を実施ください。

②.【Surrounding Atmosphere / 使用雰囲気】

For proper operation , storage and operating environment should not contain corrosive gases - e.g. H2S,SO2, NO2,CL2 and etc.
In addition storage environment should not have meterials that emit corrosive gases especially from silicic , cyanic formalin and phenol group. In a mechanisim or a set , existence of corrosive gases may cause no rotation in motor.

腐食性ガス（H2S、SO2、NO2、CL2等）はもとより、有害なガス雰囲気中及び有害なガスを発生させる物質（特に有機シリコン系、シアン系、ホルマリン系、フェノール系物質等）が存在する場所でのご使用、保管は避けてください。
特に、セット内においても上記物質が存在しないようにしてください。モータ故障・停止の原因になります。

③.【Condensation from Atmosphere / 結露】

A motor should be protected from temperature extremes which could cause condensation.
This might lead to short circuit or current leakage. Condensation should be considered in set design.
A safety devices , such as condensation senser , is recommended to add on set to cut off power supply.

回路部の結露は電気的リークによりモータ回路、半導体の破壊を招きます。セット側で使用環境をご確認の上、必要に応じ結露センサー等で主電源を切る保護対策を実施ください。

④.【Electrification / 帯電】

(a) Belt Electrification
Static electricity may be generated by friction between pulley and belt. When belt discharges electrostatic accumulated , electrical noise is generated in a motor. This may cause motor or semiconductor failure in a set.
(b) Earth-Electrostatic Protection
Electrification and leakage can cause motor circuit or semiconductor failure. Proper grounding is required for soldering iron and conveyer belt during the motor terminal or leadwire is soldered to a mechanism or a set.

(a) ベルトの帯電
ベルトとプーリの摩擦によりモータに帯電、又は帯電し放電する時、電気ノイズの発生によるパルス発生が加わりモータ及びセットにおける半導体の破壊を招きます。
(b) アース、静電対策
帯電及び漏電によりモータ回路、半導体が破壊します。
モータ取り扱い時の工程での静電気対策及び半田付け時のアースの接地等の対策を実施ください。

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⑤.【Electric Conduction / 通電】

To use connector for interface , ensure complete pin insert. Connector contacts do not fully insert or disconnect when power supply is on , might cause damage to control circuit or senmiconductor in motor or circuit components in set.

インターフェース用コネクタの全ピンを確実に挿入した事を確認した後に通電ください。
不完全接続や通電したままでのコネクタの抜き差しはモータ回路、半導体の破壊、又はセット本体回路の破壊を招きます。

⑥.【Motor Mounting / モータ取付け】

(a) In case , a mounting screw is longer than our recommended lengh , the screw may touch and damege a rotor. Motor will not be able to perform. Suitable screw length should be used for mounting motor to the chassis. The recommended screw length is indicated in the construction drawing on this specification. And good flatness matching between a chassis and a motor should be used. In case a screw tightening surface is not flat , motor jam might be occur.

(b) Ultrasonic welding for motor mounting may damage motor and control circuit due to its vibration.

(c) Load Used :

・Screwing Type
Do not use a large screw that will cause unbalance to a motor.
Motor vibration may be enlarged by balance motor rotation and cause motor failure.

・Adhesive Type
Do not let adhesive material overflow motor bearing.
Overflowed adhesive may cause motor shaft locked and motor caused rotation.

・Force Insert Type
Do not exert over load to the motor. Overload may cause a shaft deformed or a shaft support broken.
Motor might not rotate. Proper force is indicated in the construction drawing in this specification.

(d) Usage of a Motor
Do not dismantle motor , and do not apply any shock to a motor. Shock may cause stress mark on bearing metal.

(a) モータをセットに取り付けるビス長さは所定の長さを遵守ください。所定の長さを越えた場合、モータが回転しなくなる等の不具合を生じます。 ビス長さについては本納入仕様書中のモータ外観寸法図に記載しております。
又、セットの取付け面が歪んでいますとモータがこじれます。 セット取付け面の平面度にご注意ください。

(b) モータを超音波溶着にて取付ける場合、振動によりモータ及び回路の破壊を招きます。

(c) モータ出力軸に負荷を取付ける時

・ビス締めタイプ
ビス締めの場合は回転アンバランスが生じる様な大きなビスは使用しないで下さい。モータ振動が大きくなります。

・接着タイプ
接着剤が出力軸を伝わって軸受部に流入しないようにしてください。モータ出力軸が固定されます。

・圧入タイプ
圧入の場合は異常な荷重が加わらないようにして下さい。出力軸が変形したりシャフト保持部の変形、破損を招き所定の特性を満足しなくなります。 圧入圧力は本納入仕様書中のモータ外観寸法図に記載しております。

(d) モータ取扱い
モータの分解はしないで下さい、又衝撃を加えないで下さい。軸受内面に傷を生じる恐れがあります。

☆ Investigate the usage of a motor carefully. Failure to follow caution items could result in damage to a motor.
We do not guarantee against any improper usage to a motor.

上記警告事項に反する使用でのトラブルについては弊社では保証致しません。モータご使用に当たっては充分にご注意お願いします。

MODEL:	PPN7PA12C1	SPECIFICATION / 納入仕様書	NO.	SR-YDC 10521
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IMPORTANT NOTES : 注意

(1) Confirm the matching and reliability of motor on actual set or unit application.
This include confirmation on set or unit life , electrical noise , mechanical noise , vibration , static electricity, electric power noise , drift electric resonance between motor and control circuit , mechanical resonance between motor and chassis , irregular movement of set due to motor noise , irregular movement of set in strong electromagnetic field , damaged by lightning surge , earthing method and etc.

セット実装によるマッチング確認、寿命確認についてはセットメーカ側にてご確認及び品質保証を実施ください。
セット実装におけるマッチング確認事項例
寿命・電気雑音・機械雑音・振動・耐静電気ノイズ・耐電源ノイズ・ドリフト・回路とモータの電気的共振・セットとモータの機械的共振・モータノイズによる機器の誤動作及び高電界、高磁場における誤動作・雷サージによる破壊・アース方法等。

(2) When high inrtia fan , turntable or pulley is attached to motor shaft directly , motor reliability and characteristics may be affected. Confirmation on the actual set is needed.

慣性質量の大きいファン、ターンテーブル及びプーリ等をモータの出力軸に直結してご使用の場合はモータ特性・信頼性が低下することがありますので予め実装状態にてご確認ください。

(3) Motor bearing oil may cause plastic part cracked. Please confirm bearing oil influence on plastic material of set.

樹脂の種類によってはモータ軸受オイルによりクラックが入るものがあります。セット側樹脂へのモータ軸受オイルの影響は予め実装状態で確認下さい。

(4) When impedance is connected series to the motor , reliability of motor may be affected. Please avoid using impedance. If necessary , minimize the impedance value and confirm reliability of the motor under that condition.

モータに直列にインピーダンスを接続することは信頼性への影響が考えられる為に極力避けて頂く様お願いいたします。
やむを得ず接続される場合、出来るだけ小さく設定して頂きモータの信頼性確認を充分に実施下さい。

(5) In case of low or no side pressure to the motor shaft , clearance noise between shaft and bearing may occur. Confirmation on actual set is needed.

モータ出力軸に加わる側圧が低い場合、軸受とシャフト間より軸受音が発生する場合がありますので予めセット実装にてご確認願います。

(6) For safety standard , e.g. UL , CSA ect , customer should apply and get certification.

UL、CSA等の安全規格についてはセット側にて申請いただき承認を得て頂きます様お願いいたします。

(7) Make arrengement to limit the storage period to 6 months or less.
Do not store motor in high or low temperature or high humidity environment.
Condensation of atmosphere should be avoided in motor usage or opening the packaging of the motor.

保管の際は6ヶ月以内にとどめて頂き、高温・低温・多湿環境下での保管は避けて下さい。
尚、取扱い・開梱に際し結露が発生しない様に充分にご配慮お願いいたします。

MODEL:	PPN7PA12C1	SPECIFICATION / 納入仕様書	NO.	SR-YDC 10521
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(8) CONNECTIONS / 接続

☐ ・Avoid excessive stress on the printed circuit board in connector insertion.
・コネクタ挿入時にはプリント基板に無理なストレスを加えない様に充分にご注意下さい。

☑ ・Limit soldering time to be less than 3s to avoid any damage to motor leadwire or terminal. Soldering iron temperature should be less than 350℃. Avoid bending or pushing against motor terminal. Terminal bent might cause motor locked.
・モータのリード線や端子に半田付けの際は3秒以内、半田コテ先温度350℃以下にてご使用ください。尚、端子には端子を曲げたり押し込んだりするような力を加えない様にして下さい。モータがロックします。

☐ ・When leadwire or terminal soldering is made on metal based printed circuit board , insulation layer on printed circuit board should not be dameged.
・金属タイプのプリント基板ランドへのリード線・端子等の半田付けに際しては絶縁層の破壊が生じない様に注意してください。耐圧、絶縁不良等の特性不良を誘発します。

(9) When reverse voltage or terminal short is applied to produce bracking mode , this may affect the motor reliability. Motor reliability should confirmed before use.

モータ端子をショートしたり、逆電圧を加えてモータを停止させる場合、モータ寿命に影響を与える場合がありますので事前に充分にご確認下さい。

(10) Please take note that we do not guarantee motor operations or conditions not described in specification.

本仕様書記載範囲を越えてのご使用につきましては保証できませんので充分にご注意下さい。

GENERAL INSTRUCTIONS : 一般事項

(1) Any revisions on this specification shall be done on mutual discussion and agreement.

本仕様書記載内容の変更は双方協議の上実施するものとします。

(2) In order to continuous improve the performance within the scope of specification , parts or materials are subjected to change.

本仕様書を満足する範囲内において性能の向上等の為に、部品等を一部変更する場合がありますのでご了承下さい。

(3) Ant items , needed to be added into specification , will be determined based on customer prior request. If no information given , motor will be delivered based on our standard judgement.

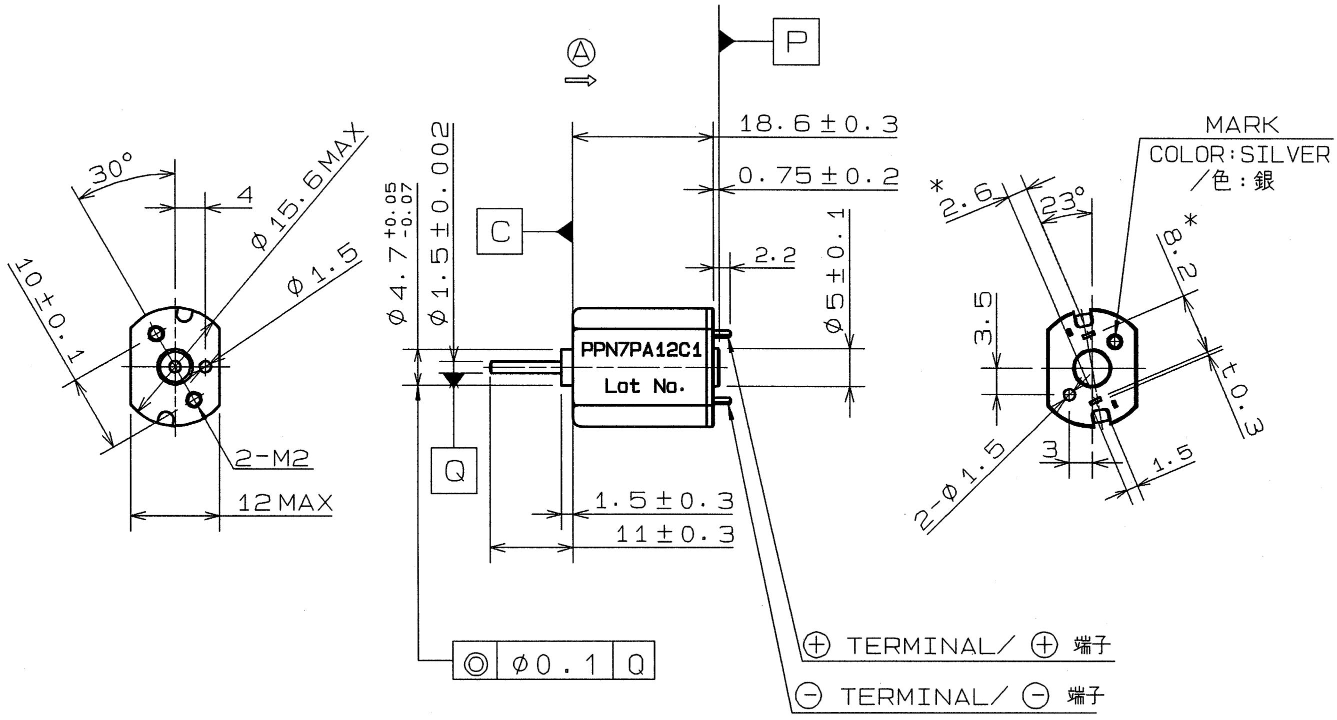
本仕様書に記載されていない事項で取り決めの必要がある項目は事前にご連絡ください。別途協議させて頂きます。ご連絡の無い場合はセットとして発生する不具合は無い物として当方の標準に準拠して納入させて頂きます。

(4) When any trouble occures , both parties shall discuss base on this specifications to solve the matters. In this case , our guarantee is only limited for motors.

不具合事項発生時は本納入仕様書記載事項に基づき双方協議の後、処置を決定し実施するものとします。この場合の品質保証につきましてはモータのみに限定いたします。

General Dimension Tolerance (±)								
Assembly					Angle		Dimension of A (Shorter Side)	
Up to 6	Over 6 to 30	Over 30 to 120	Over 120 to 300	Over 300	Up to 10	Over 10 to 50	Over 50 to 100	Over 100
0.3	0.5	0.7	1.2	2.0	5°	3°	1.5°	45'

ΔSYM	NO.	DATE	REVISION	SIGNED	CHECKED



LOT NO. EXAMPLE
ロットNo. 記入例

07Z10[ ][ ]

- DATE: 日
- MONTH: 月
  - JAN. ~SEP. : 1~9月 1~9
  - OCT. : 10月 X
  - NOV. : 11月 Y
  - DEC. : 12月 Z
- A.D. : 年
- PRODUCT SYMBOL: 製造密番

NOTE

1. THE SHAFT LENGTH(11±0.3) IS NOT INCLUDING END-PLAY. MEASURED WITH PRESSING ON TO DIRECTION Ⓐ.
2. WHEN PRESS IN GEAR OR PULLY ON SHAFT, THE PRESSURE SHOULD BE 98N MAX, [P] SIDE SHOUDE BE SUPPORTED AND Ⓐ DIRECTION ONLY.
3. THE LENGTH OF THE MOUNTING SCREW SHOULD BE SETTLED 1.4mmMAX FROM [C]. THE STRENGTH OF SCREW SHOULD BE 147mN·m MAX.
4. THE RUST WHICH IS NOT HARMFUL TO THE MOTOR OR ON THE EDGE ARE ACCEPTABLE.
5. MOTOR ROTATION SHOULD BE CW WHEN VOLTAGE IS SUPPLIED AS INDICATION.
6. THE MODEL NAME AND LOT NUMBER MUST BE STAMPED ON THE MOTOR FRAME DESIGNATION.
7. SET SURFACE FOR MOTOR MOUNTING SHOULD BE FLAT. IF THE SURFACE IS NOT FLAT, MOTOR MIGHT BE JAMED.
8. THE MARK "*" IS THE DIMENSION AT THE BASE OF TERMINAL. THE LEAN AND THE CURVATURE OF THE TERMINAL IS TO BE LESS THAN ±30°.
9. IT IS ACCEPTABLE THAT LOGOMARK IS NOT DESIGNATED.

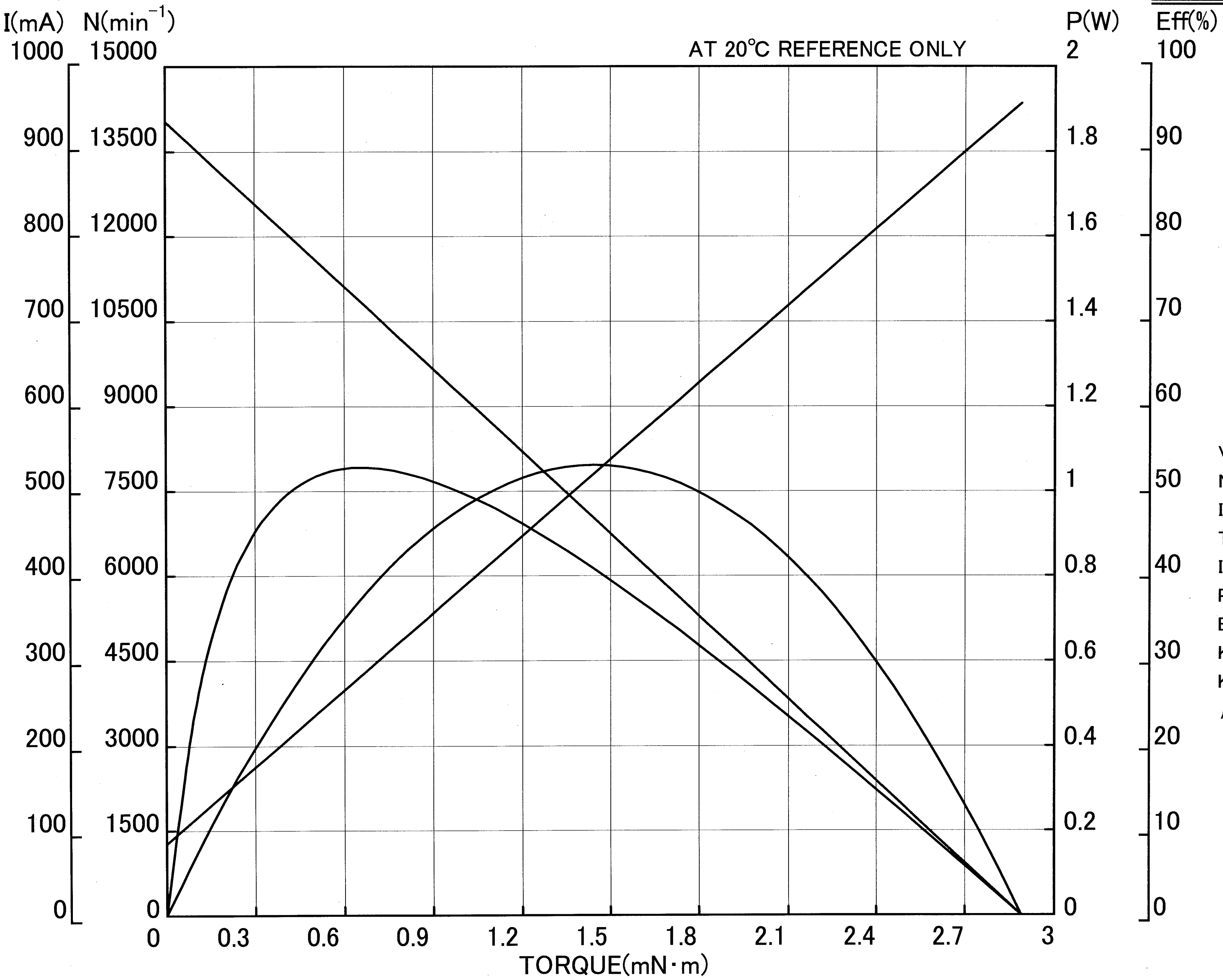
注　記

1. シャフト寸法(11±0.3)はエンドプレー(スラスト)を含まず、自然状態時の寸法とします.(磁気スラストは Ⓐ 方向)
2. 出力軸にギヤ及びプーリを圧入する際は、[P] 面を受けシャフトに垂直方向以外の圧力を加えない様御配慮下さい. 圧入力は98N以下でお願いします.
3. 本モータを御使用願う場合、モータの取付けネジはモータ端面より1.4mm以上にならない様御注意願います.(モータ取付けネジ締め付けトルク147mN·m以下)
4. モータ端子板端面及び実用上問題ない範囲の錆は可とします.
5. 端子に極表示通り接続した場合、出力軸はCW回転のこと.
6. 機種名及びロットNo.はモータフレームの平面に捺印のこと.
7. 本モータを取り付ける際、セット面が歪んでいますとモータがコジれる恐れがありますので、セット取付け面の平面度にご注意下さい.
8. *マークは、端子根元の寸法. 端子板の傾き・曲がりは±30°以内のこと.
9. ロゴマーク 表示については無くても可とします.

Scale	Minebea Motor Manufacturing Corporation				Model	PPN7PA12C1
1 : 1	3rd Angle System			Unit:mm	Name	DRAWING
Designed	Drawn	Checked	Checked	Checked	No.	SR-YDC1052101
MOCHIZUKI	MOCHIZUKI					
2010/12/07	2010/12/07	7 Dec 2010		7/Dec/2010		

CHARACTERISTICS OF PPN7PA12C1

No.: SR-YDC 10521



DATA

Vcc(V)	= 5.0
NO(min^{-1})	= 14033
IO(mA)	= 84.2
TS(mN·m)	= 2.890
IS(mA)	= 956.9
Pmax(W)	= 1.0618
Effmax(%)	= 52.73
Kt(mN·m/mA)	= 0.00331
Ka(mV/min^{-1})	= 0.3466
μ (min^{-1}/mN·m)	= 4855.7

Minebea Motor Manufacturing Corporation

RC4558 Dual General-Purpose Operational Amplifier

1 Features

- Continuous Short-Circuit Protection
- Wide Common-Mode and Differential Voltage Ranges
- No Frequency Compensation Required
- Low Power Consumption
- No Latch-Up
- Unity-Gain Bandwidth: 3 MHz Typ
- Gain and Phase Match Between Amplifiers
- Low Noise: 8 nV/√Hz Typ at 1 kHz

2 Applications

- DVD Recorders and Players
- Pro Audio Mixers

3 Description

The RC4558 device is a dual general-purpose operational amplifier, with each half electrically similar to the μA741, except that offset null capability is not provided.

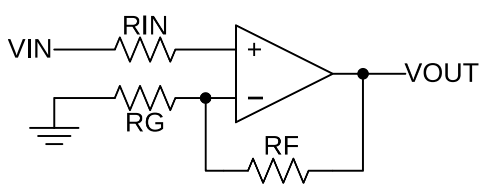
The high common-mode input voltage range and the absence of latch-up make this amplifier ideal for voltage-follower applications. The device is short-circuit protected, and the internal frequency compensation ensures stability without external components.

Device Information(1)

PART NUMBER	PACKAGE (PIN)	BODY SIZE
RC4558	SOIC (8)	4.90 mm × 3.91 mm
	SOIC (8)	3.00 mm × 3.00 mm
	PDIP (8)	9.81 mm × 6.35 mm
	TSSOP (8)	3.00 mm × 4.40 mm
	SOP (8)	6.20 mm × 5.30 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Noninverting Amplifier Schematic



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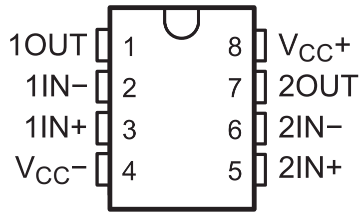
4 Revision History

Changes from Revision F (September 2010) to Revision G **Page**

- Added *Applications*, *Device Information* table, *Handling Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section. 1
- Removed *Ordering Information* table. 1

5 Pin Configuration and Functions

D, DGK, P, PS, OR PW PACKAGE
(TOP VIEW)



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
1IN+	3	I	Noninverting input
1IN-	2	I	Inverting Input
1OUT	1	O	Output
2IN+	5	I	Noninverting input
2IN-	6	I	Inverting Input
2OUT	7	O	Output
V_{CC}+	8	—	Positive Supply
V_{CC}-	4	—	Negative Supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
V_{CC+}	Supply voltage(2)		18	V
V_{CC-}			–18	
V_{ID}	Differential input voltage(3)		±30	V
V_I	Input voltage (any input)(2)(4)		±15	V
	Duration of output short circuit to ground, one amplifier at a time(5)	Unlimited		
T_J	Operating virtual junction temperature		150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
(3) Differential voltages are at IN+ with respect to IN–.
(4) The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
(5) Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

6.2 Handling Ratings

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		-65	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per AEC Q100-002(1)	0	500	V
		Charged device model (CDM), per AEC Q100-011 (2)	0	1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

			MIN	MAX	UNIT
V_{CC+}	Supply voltage		5	15	V
V_{CC-}			–5	–15	
T_A	Operating free-air temperature	RC4558	0	70	°C
		RC4558I	–40	85	

6.4 Thermal Information

THERMAL METRIC(1)		RC4558					UNIT
		D	DGK	P	PS	PW	
		8 PINS					
$R_{\theta JA}$	Junction-to-ambient thermal resistance	97	172	85	95	149	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics

at specified free-air temperature, V_{CC+} = 15 V, V_{CC-} = –15 V

PARAMETER			TEST CONDITIONS(1)	T_A (2)	MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage		V_O = 0	25°C		0.5	6	mV
				Full range			7.5	
I_{IO}	Input offset current		V_O = 0	25°C		5	200	nA
				Full range			300	
I_{IB}	Input bias current		V_O = 0	25°C		150	500	nA
				Full range			800	
V_{ICR}	Common-mode input voltage range			25°C	±12	±14		V
V_{OM}	Maximum output voltage swing		R_L = 10 kΩ	25°C	±12	±14		V
			R_L = 2 kΩ	25°C	±10	±13		
				Full range	±10			
A_{VD}	Large-signal differential voltage amplification		R_L ≥ 2 kΩ, V_O = ±10 V	25°C	20	300		V/mV
				Full range	15			
B_1	Unity-gain bandwidth			25°C		3		MHz
r_i	Input resistance			25°C	0.3	5		MΩ
CMRR	Common-mode rejection ratio			25°C	70	90		dB
k_{SVS}	Supply-voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)		V_{CC} = ±15 V to ±9 V	25°C		30	150	μV/V
V_n	Equivalent input noise voltage (closed loop)		A_{VD} = 100, R_S = 100 Ω, f = 1 kHz, BW = 1 Hz	25°C		8		nV/√Hz
I_{CC}	Supply current (both amplifiers)		V_O = 0, No load	25°C		2.5	5.6	mA
				T_A min		3	6.6	
				T_A max		2.3	5	
P_D	Total power dissipation (both amplifiers)		V_O = 0, No load	25°C		75	170	mW
				T_A min		90	200	
				T_A max		70	150	
V_{O1}/V_{O2}	Crosstalk attenuation	Open loop	R_S = 1 kΩ, f = 10 kHz	25°C		85		dB
		A_{VD} = 100				105		

(1) All characteristics are measured under open-loop conditions with zero common-mode input voltage, unless otherwise specified.
(2) Full range is 0°C to 70°C for RC4558 and –40°C to 85°C for RC4558I.

6.6 Operating Characteristics

V_{CC+} = 15 V, V_{CC-} = –15 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_r	Rise time	V_I = 20 mV, R_L = 2 kΩ, C_L = 100 pF		0.13		ns
	Overshoot	V_I = 20 mV, R_L = 2 kΩ, C_L = 100 pF		5%		
SR	Slew rate at unity gain	V_I = 10 V, R_L = 2 kΩ, C_L = 100 pF	1.1	1.7		V/μs

6.7 Typical Characteristics

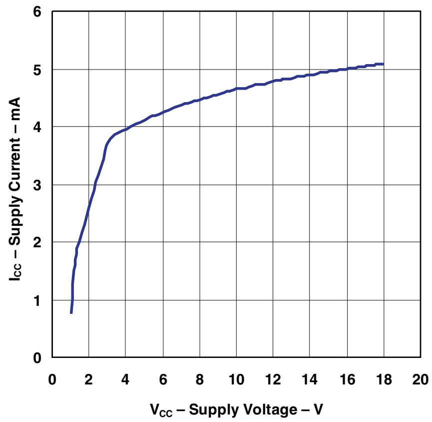


Figure 1. Supply Current vs Supply Voltage (T_A = 25°C)

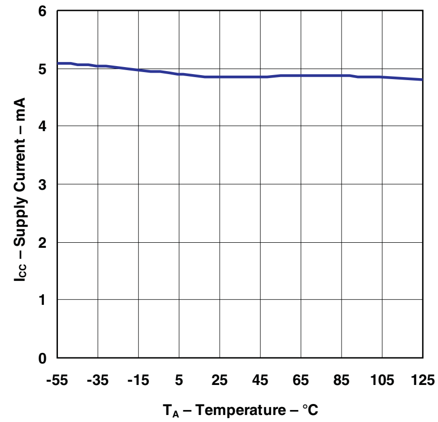


Figure 2. Supply Current vs Temperature (V_{CC} = ±15 V)

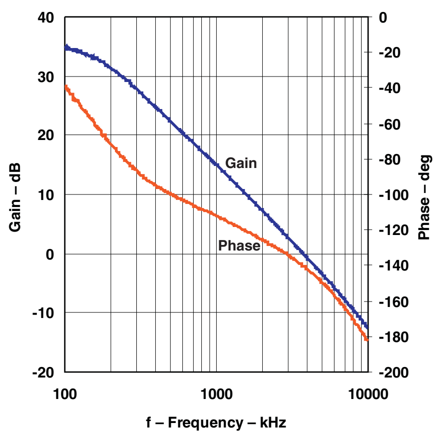


Figure 3. Gain and Phase vs Frequency (V_{CC} = ±15 V, R_L = 2 kΩ, C_L = 22 pF)

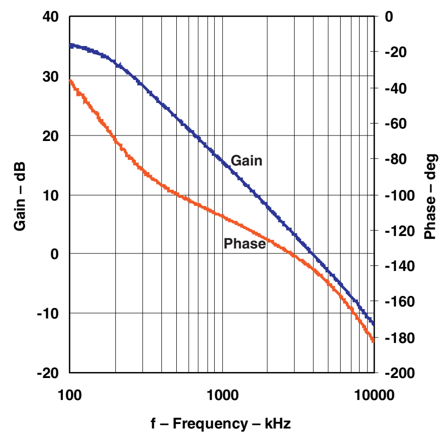


Figure 4. Gain and Phase vs Frequency (V_{CC} = ±15 V, R_L = 10 kΩ, C_L = 22 pF)

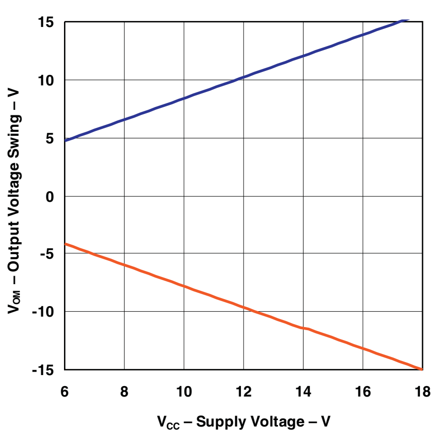


Figure 5. Output Voltage Swing vs Supply Voltage (R_L = 2 kΩ, T_A = 25°C)

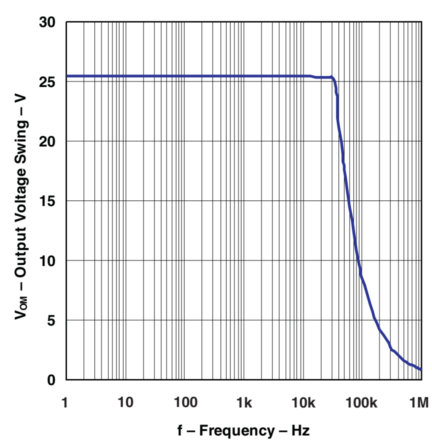


Figure 6. Output Voltage Swing vs Frequency (V_{CC} = ±15 V, R_L = 2 kΩ, T_A = 25°C)

Typical Characteristics (continued)

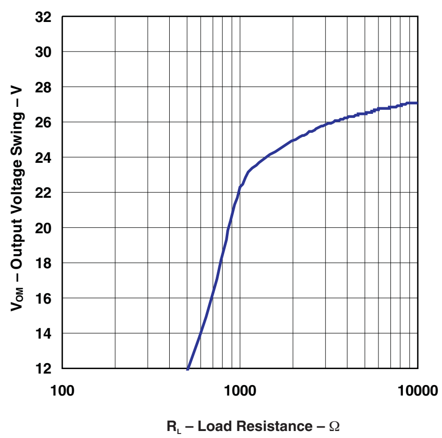


Figure 7. Output Voltage Swing vs Load Resistance (V_{CC} = ±15 V, T_A = 25°C)

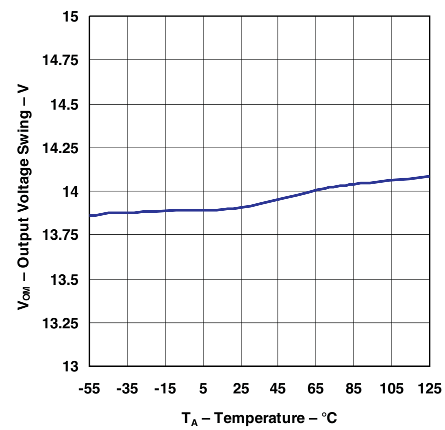


Figure 8. Output Voltage Swing vs Temperature (V_{CC} = ±15 V, R_L = 10 kΩ)

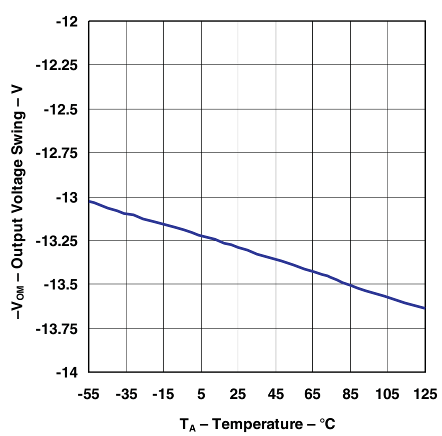


Figure 9. Negative Output Voltage Swing vs Temperature (V_{CC} = ±15 V, R_L = 10 kΩ)

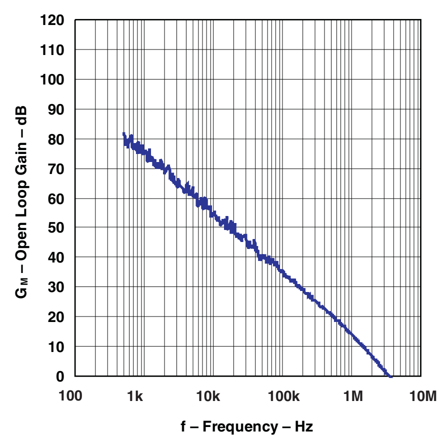


Figure 10. Open Loop Gain vs Frequency (V_{CC} = ±15 V, R_L = 2 kΩ, C_L = 22 pF, T_A = 25°C)

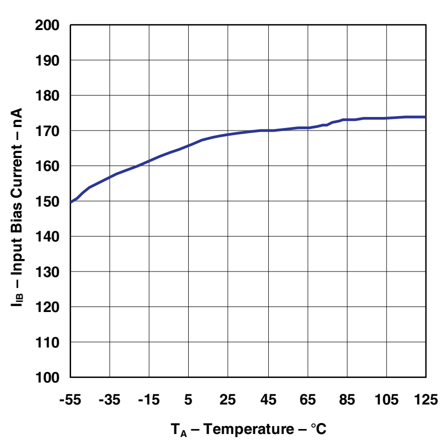


Figure 11. Input Bias Current vs Temperature (V_{CC} = ±15 V)

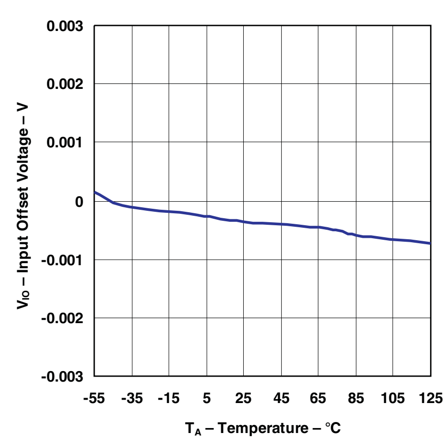


Figure 12. Input Offset Voltage vs Temperature (V_{CC} = ±15 V)

Typical Characteristics (continued)

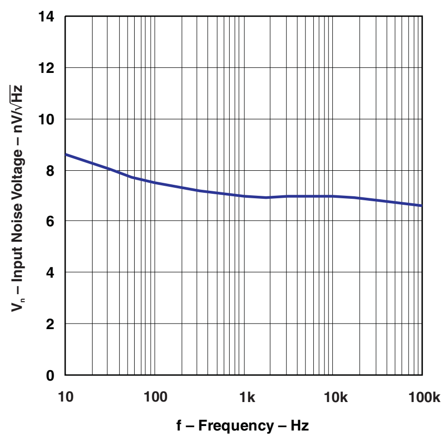


Figure 13. Input Noise Voltage vs Frequency
(V_{CC} = ±15 V, T_A = 25°C)

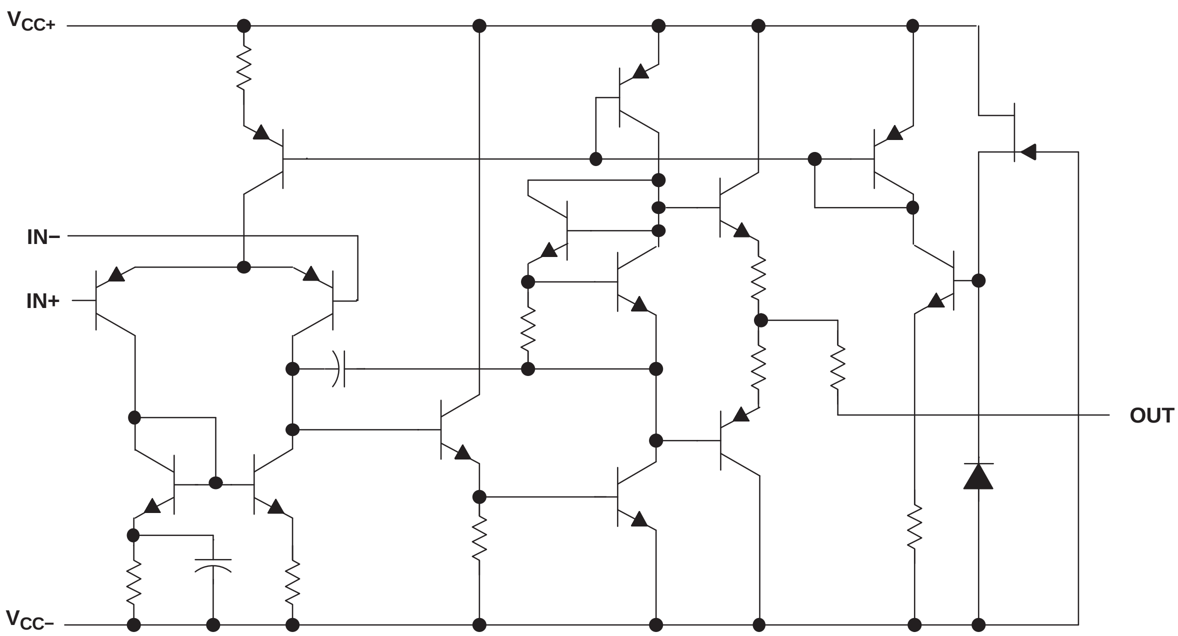
7 Detailed Description

7.1 Overview

The RC4558 device is a dual general-purpose operational amplifier, with each half electrically similar to the μA741, except that offset null capability is not provided.

The high common-mode input voltage range and the absence of latch-up make this amplifier ideal for voltage-follower applications. The device is short-circuit protected, and the internal frequency compensation ensures stability without external components.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Unity-Gain Bandwidth

The unity-gain bandwidth is the frequency up to which an amplifier with a unity gain may be operated without greatly distorting the signal. The RC4558 device has a 3-MHz unity-gain bandwidth.

7.3.2 Common-Mode Rejection Ratio

The common-mode rejection ratio (CMRR) of an amplifier is a measure of how well the device rejects unwanted input signals common to both input leads. It is found by taking the ratio of the change in input offset voltage to the change in the input voltage, then converting to decibels. Ideally the CMRR is infinite, but in practice, amplifiers are designed to have it as high as possible. The CMRR of the RC4558 device is 90 dB.

7.3.3 Slew Rate

The slew rate is the rate at which an operational amplifier can change its output when there is a change on the input. The RC4558 device has a 1.7 V/μs slew rate.

7.4 Device Functional Modes

The RC4558 device is powered on when the supply is connected. Each of these devices can be operated as a single supply operational amplifier or dual supply amplifier depending on the application.

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Typical Application

Some applications require differential signals. Figure 14 shows a simple circuit to convert a single-ended input of 2 V to 10 V into differential output of ±8 V on a single 15-V supply. The output range is intentionally limited to maximize linearity. The circuit is composed of two amplifiers. One amplifier acts as a buffer and creates a voltage, V_{OUT+}. The second amplifier inverts the input and adds a reference voltage to generate $V_{OUT–}$. Both V_{OUT+} and $V_{OUT–}$ range from 2 V to 10 V. The difference, V_{DIFF}, is the difference between V_{OUT+} and $V_{OUT–}$.

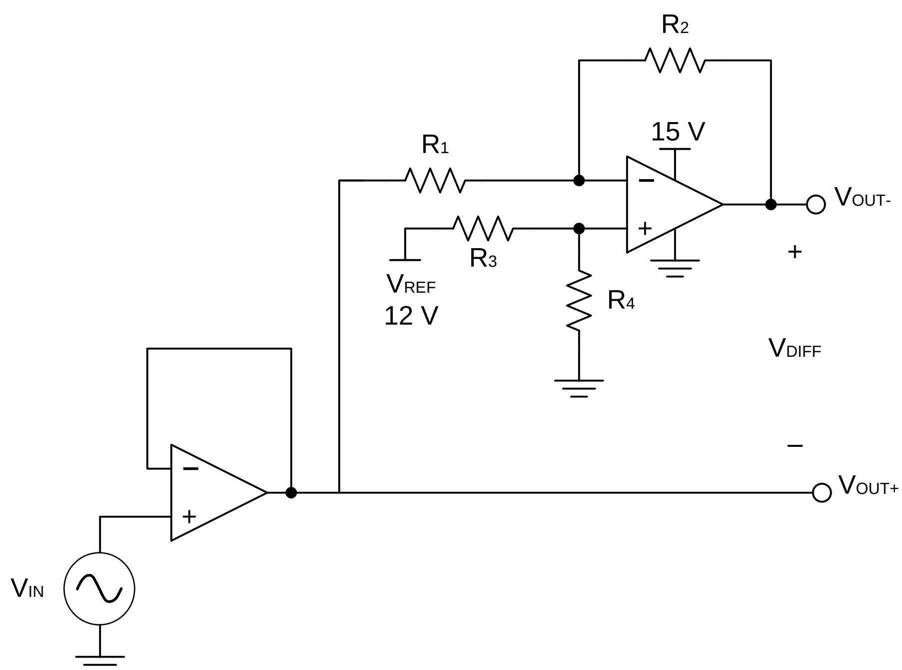


Figure 14. Schematic for Single-Ended Input to Differential Output Conversion

Typical Application (continued)

8.1.1 Design Requirements

The design requirements are as follows:

- Supply voltage: 15 V
- Reference voltage: 12V
- Input: 2 V to 10 V
- Output differential: ±8 V

8.1.2 Detailed Design Procedure

The circuit in Figure 14 takes a single-ended input signal, V_{IN}, and generates two output signals, V_{OUT+} and V_{OUT-} using two amplifiers and a reference voltage, V_{REF}. V_{OUT+} is the output of the first amplifier and is a buffered version of the input signal, V_{IN} (see Equation 1). V_{OUT-} is the output of the second amplifier which uses V_{REF} to add an offset voltage to V_{IN} and feedback to add inverting gain. The transfer function for V_{OUT-} is Equation 2.

$$V_{OUT+} = V_{IN} \tag{1}$$

$$V_{OUT-} = V_{REF} \times \left(\frac{R_4}{R_3 + R_4}\right) \times \left(1 + \frac{R_2}{R_1}\right) - V_{IN} \times \frac{R_2}{R_1} \tag{2}$$

The differential output signal, V_{DIFF}, is the difference between the two single-ended output signals, V_{OUT+} and V_{OUT-}. Equation 3 shows the transfer function for V_{DIFF}. By applying the conditions that $R_1 = R_2$ and $R_3 = R_4$, the transfer function is simplified into Equation 6. Using this configuration, the maximum input signal is equal to the reference voltage and the maximum output of each amplifier is equal to the V_{REF}. The differential output range is $2 \times V_{REF}$. Furthermore, the common mode voltage will be one half of V_{REF} (see Equation 7).

$$V_{DIFF} = V_{OUT+} - V_{OUT-} = V_{IN} \times \left(1 + \frac{R_2}{R_1}\right) - V_{REF} \times \left(\frac{R_4}{R_3 + R_4}\right)\left(1 + \frac{R_2}{R_1}\right) \tag{3}$$

$$V_{OUT+} = V_{IN} \tag{4}$$

$$V_{OUT-} = V_{REF} - V_{IN} \tag{5}$$

$$V_{DIFF} = 2 \times V_{IN} - V_{REF} \tag{6}$$

$$V_{cm} = \left(\frac{V_{OUT+} + V_{OUT-}}{2}\right) = \frac{1}{2} V_{REF} \tag{7}$$

8.1.2.1 Amplifier Selection

Linearity over the input range is key for good dc accuracy. The common mode input range and the output swing limitations determine the linearity. In general, an amplifier with rail-to-rail input and output swing is required. Bandwidth is a key concern for this design. Because RC4558 has a bandwidth of 3 MHz, this circuit will only be able to process signals with frequencies of less than 3 MHz.

8.1.2.2 Passive Component Selection

Because the transfer function of V_{OUT-} is heavily reliant on resistors (R_1, R_2, R_3, and R_4), use resistors with low tolerances to maximize performance and minimize error. This design used resistors with resistance values of 36 kΩ with tolerances measured to be within 2%. But, if the noise of the system is a key parameter, the user can select smaller resistance values (6 kΩ or lower) to keep the overall system noise low. This ensures that the noise from the resistors is lower than the amplifier noise.

Typical Application (continued)

8.1.3 Application Curves

The measured transfer functions in Figure 15, Figure 16, and Figure 17 were generated by sweeping the input voltage from 0 V to 12 V. However, this design should only be used between 2 V and 10 V for optimum linearity.

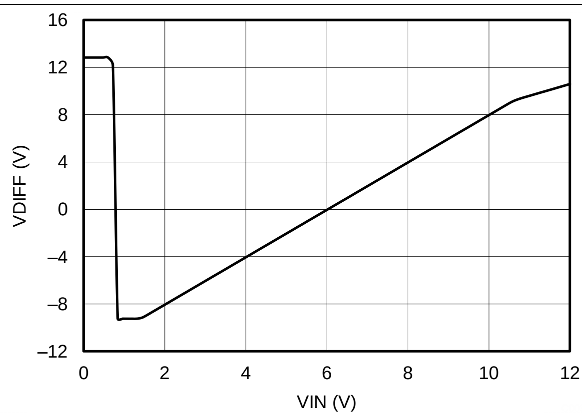


Figure 15. Differential Output Voltage Node vs Input Voltage

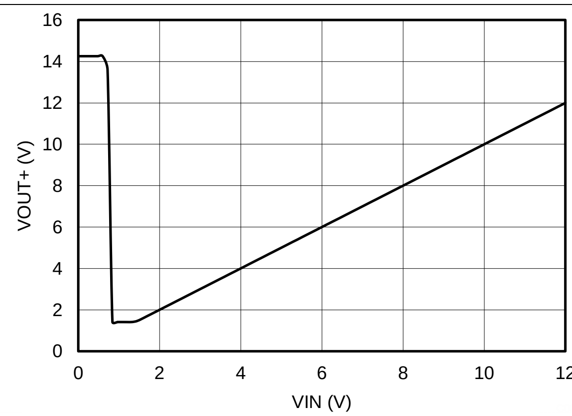


Figure 16. Positive Output Voltage Node vs Input Voltage

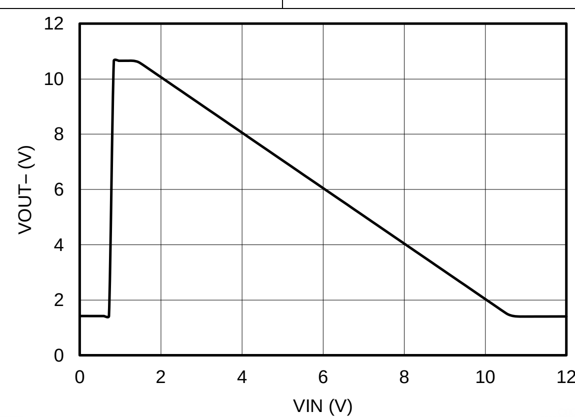


Figure 17. Positive Output Voltage Node vs Input Voltage

9 Power Supply Recommendations

The RC4558 device is specified for operation from ±5 V to ±15 V; many specifications apply from –0°C to 70°C. The *Typical Characteristics* section presents parameters that can exhibit significant variance with regard to operating voltage or temperature.

CAUTION

Supply voltages outside of the ±18-V range can permanently damage the device (see the *Absolute Maximum Ratings*).

Place 0.1-µF bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high impedance power supplies. For more detailed information on bypass capacitor placement, refer to the *Layout Guidelines*.

10 Layout

10.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices, including:

- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and the operational amplifier. Bypass capacitors are used to reduce the coupled noise by providing low impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1-μF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single supply applications.
- Separate grounding for analog and digital portions of circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds, paying attention to the flow of the ground current. For more detailed information, refer to *Circuit Board Layout Techniques*, (SLOA089).
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If it is not possible to keep them separate, it is much better to cross the sensitive trace perpendicular as opposed to in parallel with the noisy trace.
- Place the external components as close to the device as possible. Keeping RF and RG close to the inverting input minimizes parasitic capacitance, as shown in *Layout Example*.
- Keep the length of input traces as short as possible. Always remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.

10.2 Layout Example

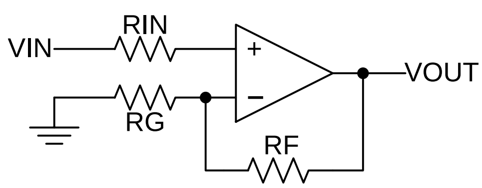


Figure 18. Operational Amplifier Schematic for Noninverting Configuration

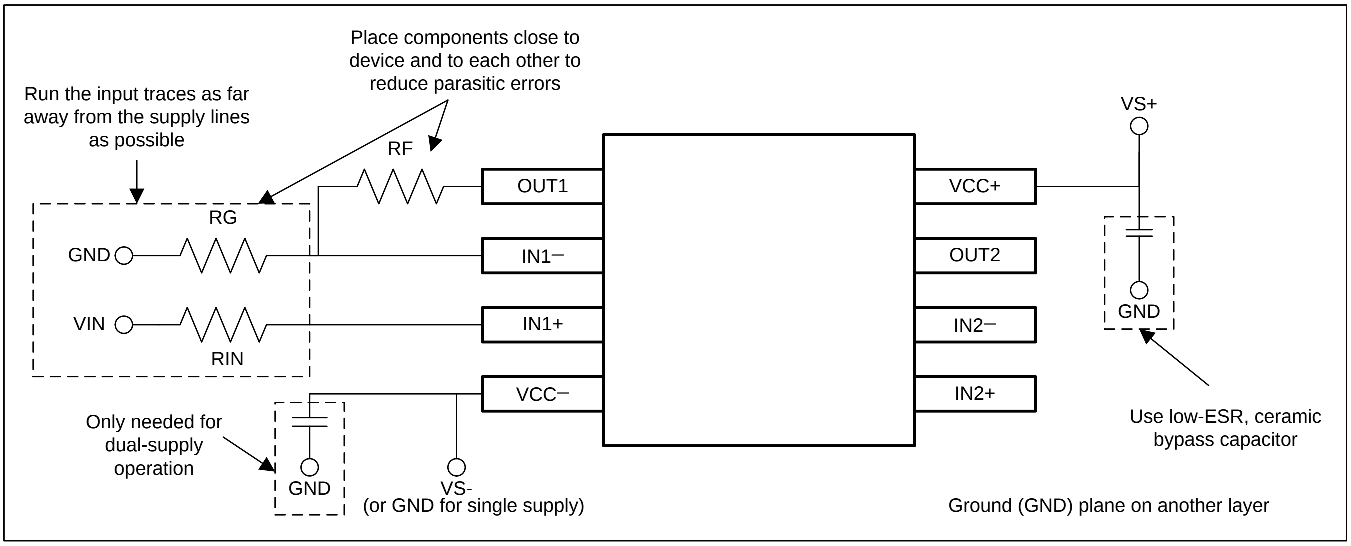


Figure 19. Operational Amplifier Board Layout for Noninverting Configuration

11 Device and Documentation Support

11.1 Trademarks

All trademarks are the property of their respective owners.

11.2 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.3 Glossary

SLYZ022 — *TI Glossary.*

This glossary lists and explains terms, acronyms and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser based versions of this data sheet, refer to the left hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
RC4558-W	ACTIVE	WAFERSALE	YS	0		TBD	Call TI	Call TI			Samples
RC4558D	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558DE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558DG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558DGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	0 to 70	(YRP ~ YRS ~ YRU)	Samples
RC4558DGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	(YRP ~ YRS ~ YRU)	Samples
RC4558DR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558DRG3	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558DRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	RC4558	Samples
RC4558ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	R4558I	Samples
RC4558IDGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	-40 to 85	(YSP ~ YSS ~ YSU)	Samples
RC4558IDGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	(YSP ~ YSS ~ YSU)	Samples
RC4558IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	R4558I	Samples
RC4558IDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	R4558I	Samples
RC4558IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	RC4558IP	Samples
RC4558IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	RC4558IP	Samples
RC4558IPW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	R4558I	Samples

PACKAGE OPTION ADDENDUM

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
RC4558IPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 85	R4558I	Samples
RC4558IPWRE4	ACTIVE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 85		Samples
RC4558IPWRG4	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 85		
RC4558P	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	RC4558P	Samples
RC4558PE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	RC4558P	Samples
RC4558PSLE	OBSOLETE	SO	PS	8		TBD	Call TI	Call TI	0 to 70		
RC4558PSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	R4558	Samples
RC4558PSRG4	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	R4558	Samples
RC4558PW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	R4558	Samples
RC4558PWLE	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	0 to 70		
RC4558PWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	R4558	Samples
RC4558PWRE4	ACTIVE	TSSOP	PW	8		TBD	Call TI	Call TI	0 to 70		Samples
RC4558PWRG4	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	0 to 70		
RC4558Y	OBSOLETE	DIESALE	Y	0		TBD	Call TI	Call TI			

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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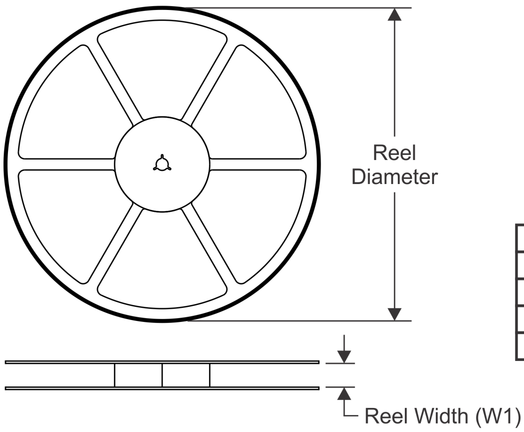
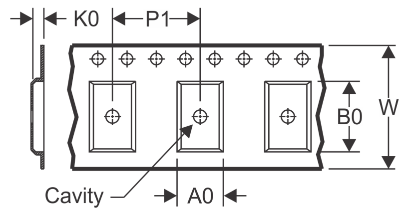
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

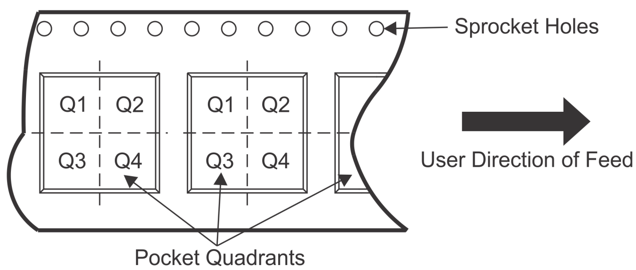


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

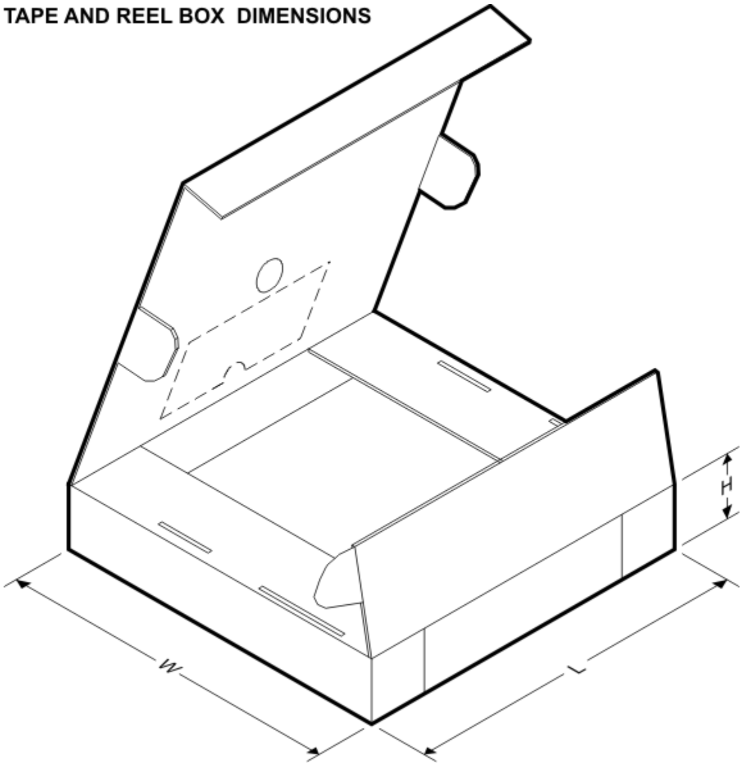
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
RC4558DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
RC4558DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
RC4558DR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
RC4558DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
RC4558DRG3	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
RC4558DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
RC4558DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
RC4558IDGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
RC4558IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
RC4558IPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
RC4558IPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
RC4558PSR	SO	PS	8	2000	330.0	16.4	8.2	6.6	2.5	12.0	16.0	Q1
RC4558PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
RC4558PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1

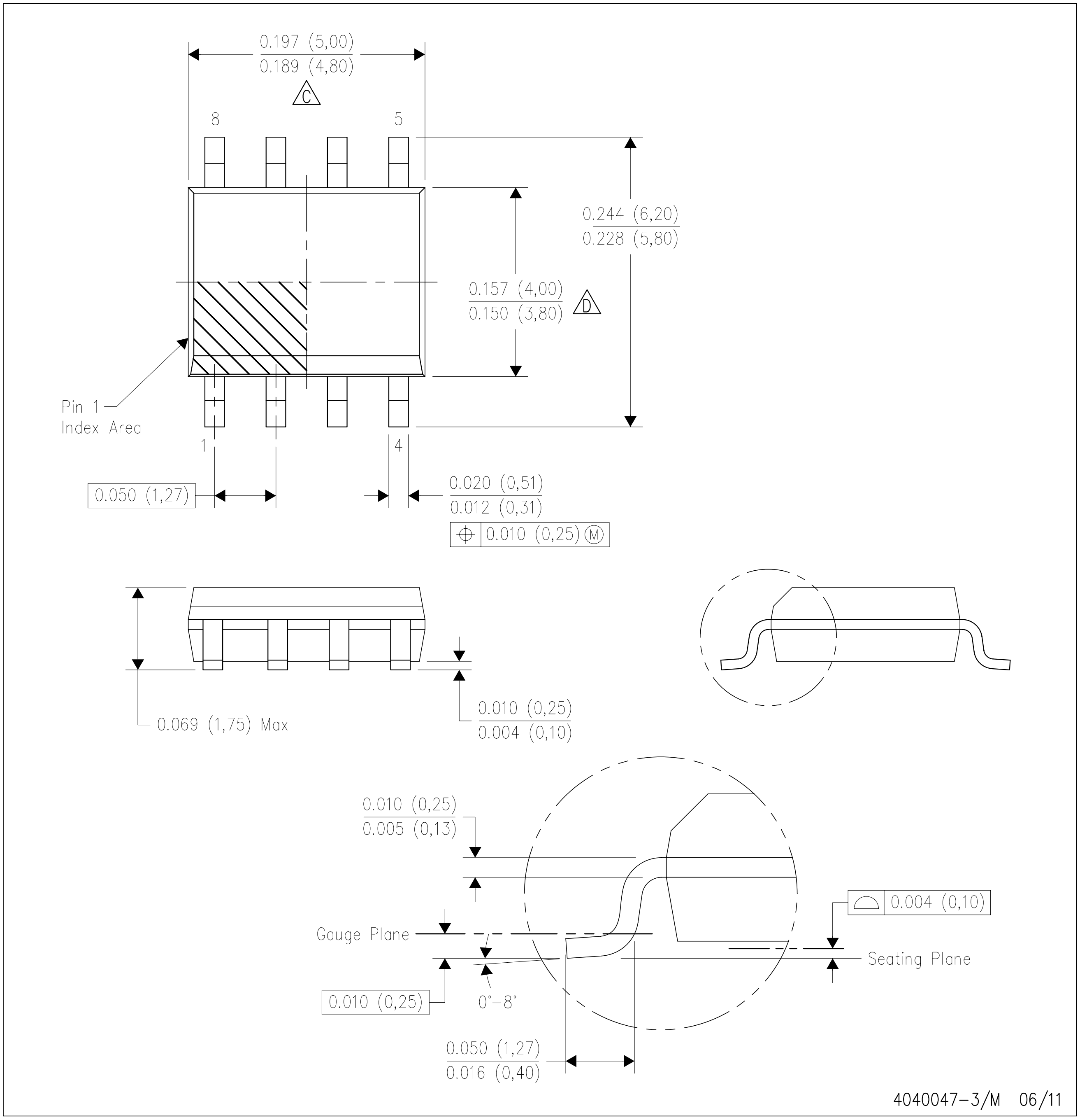
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

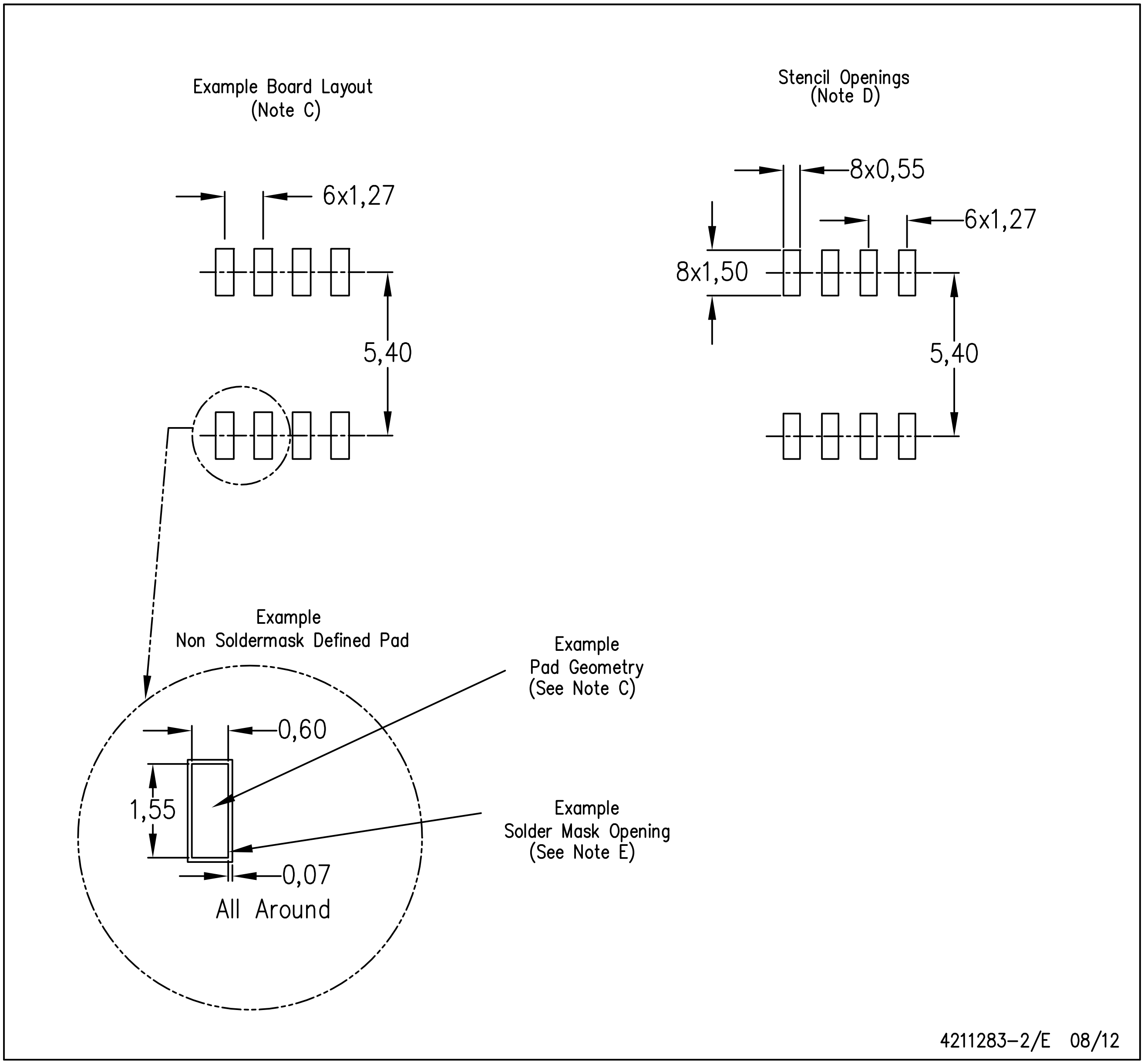
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
RC4558DGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
RC4558DR	SOIC	D	8	2500	340.5	338.1	20.6
RC4558DR	SOIC	D	8	2500	364.0	364.0	27.0
RC4558DR	SOIC	D	8	2500	367.0	367.0	35.0
RC4558DRG3	SOIC	D	8	2500	364.0	364.0	27.0
RC4558DRG4	SOIC	D	8	2500	340.5	338.1	20.6
RC4558DRG4	SOIC	D	8	2500	367.0	367.0	35.0
RC4558IDGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
RC4558IDR	SOIC	D	8	2500	340.5	338.1	20.6
RC4558IPWR	TSSOP	PW	8	2000	364.0	364.0	27.0
RC4558IPWR	TSSOP	PW	8	2000	367.0	367.0	35.0
RC4558PSR	SO	PS	8	2000	367.0	367.0	38.0
RC4558PWR	TSSOP	PW	8	2000	367.0	367.0	35.0
RC4558PWR	TSSOP	PW	8	2000	364.0	364.0	27.0

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
- E. Reference JEDEC MS–012 variation AA.

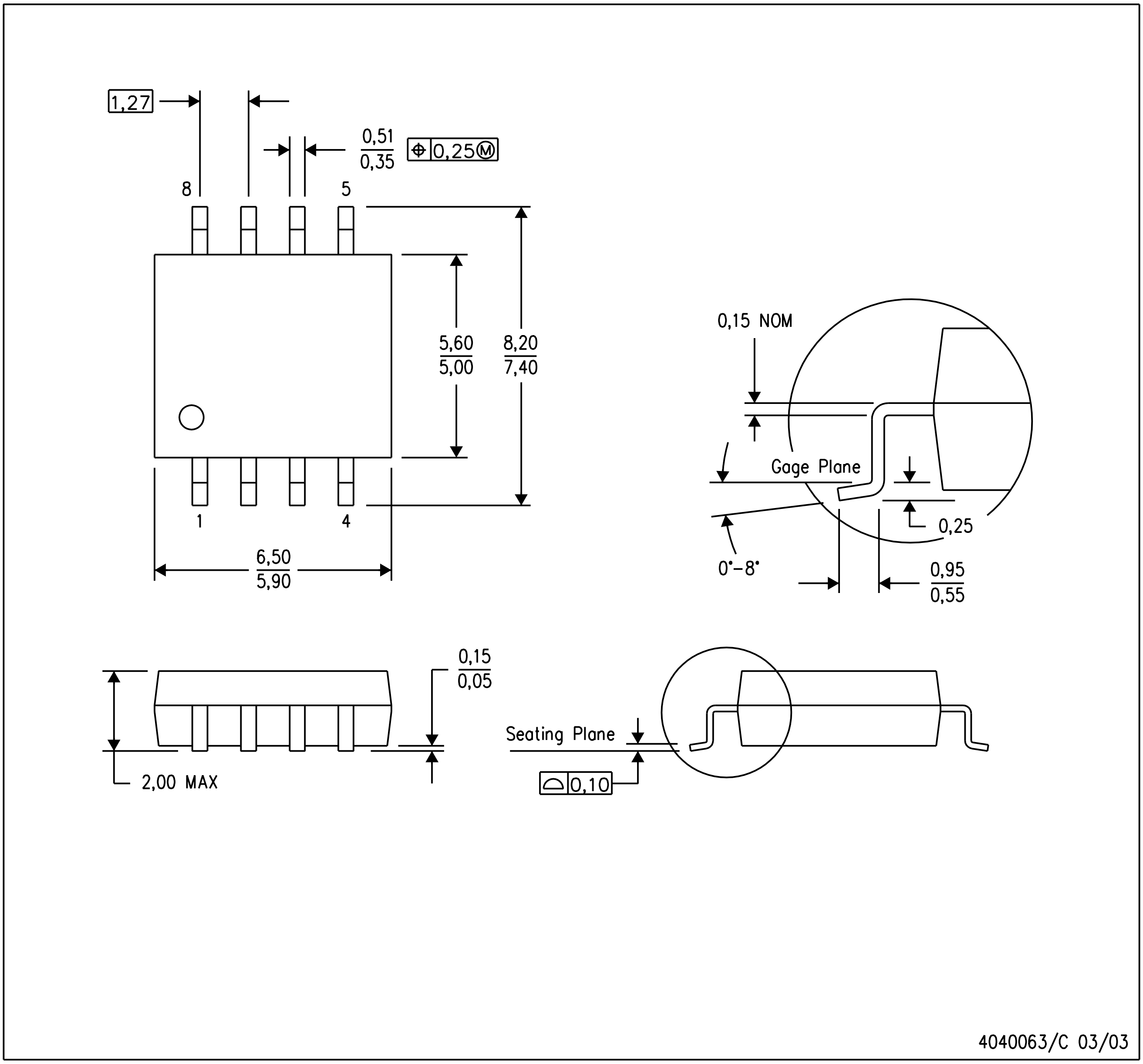
D (R-PDSO-G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

MECHANICAL DATA

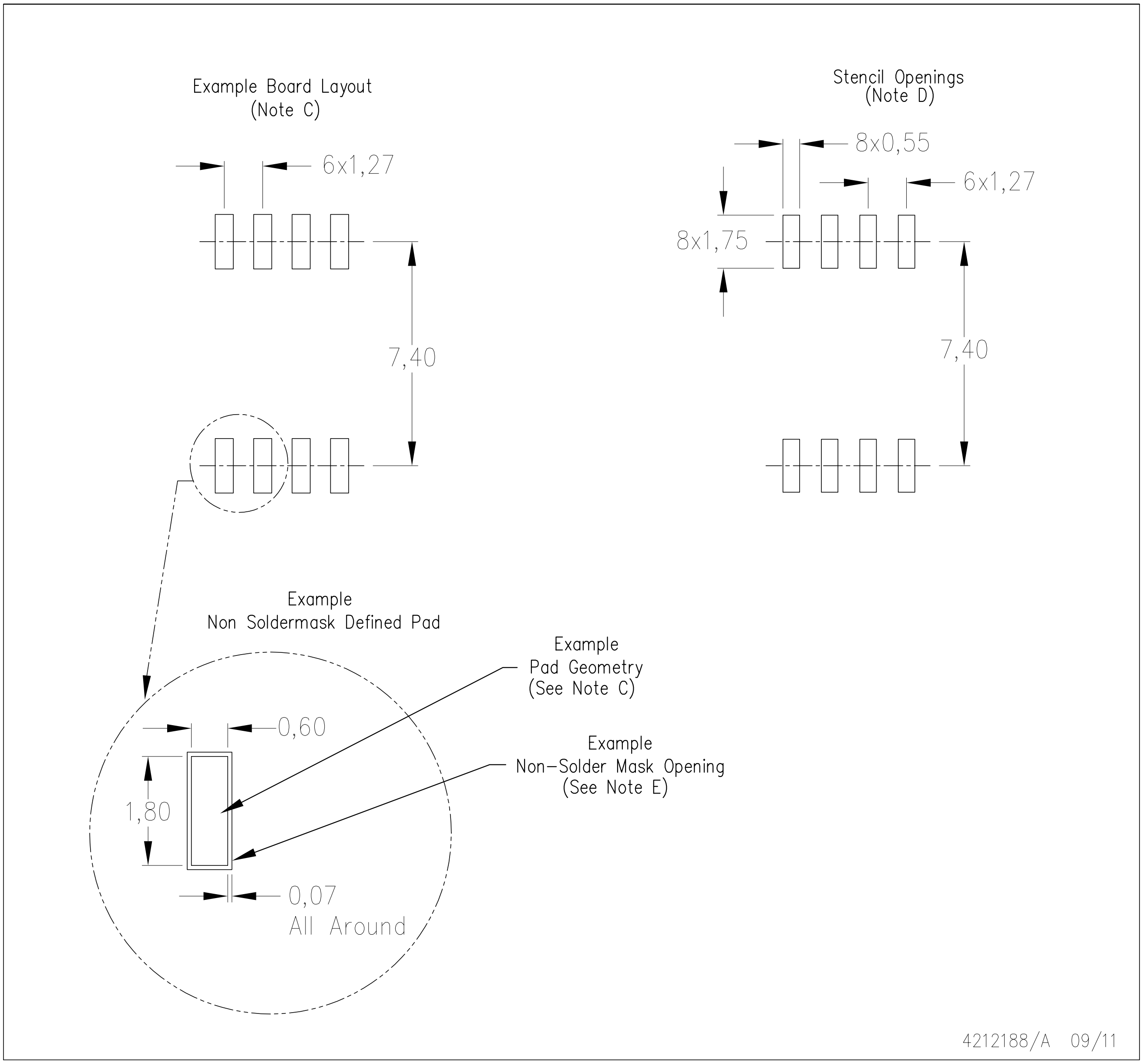
PS (R-PDSO-G8) **PLASTIC SMALL-OUTLINE PACKAGE**



NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

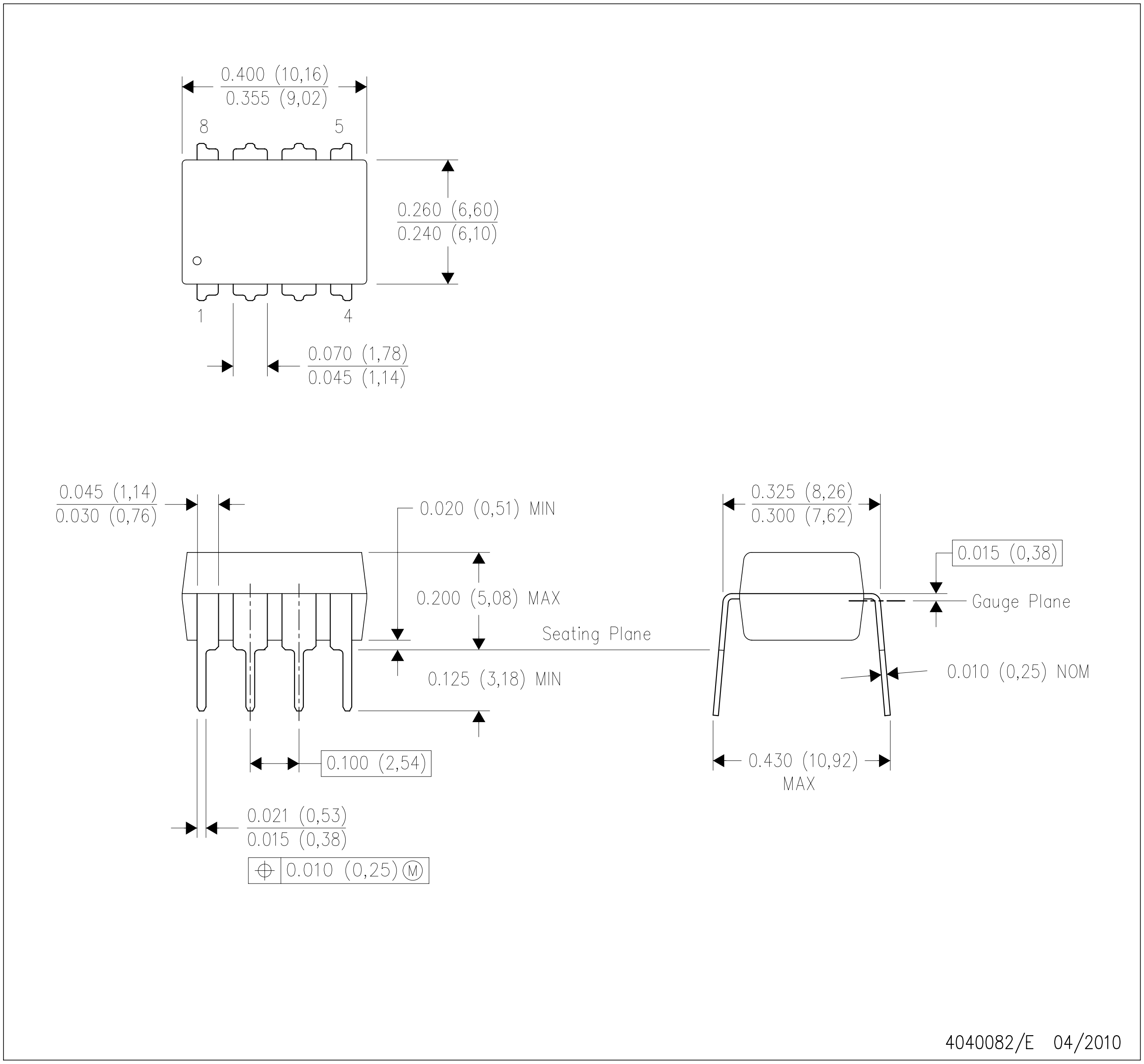
LAND PATTERN DATA

PS (R-PDSO-G8) PLASTIC SMALL OUTLINE



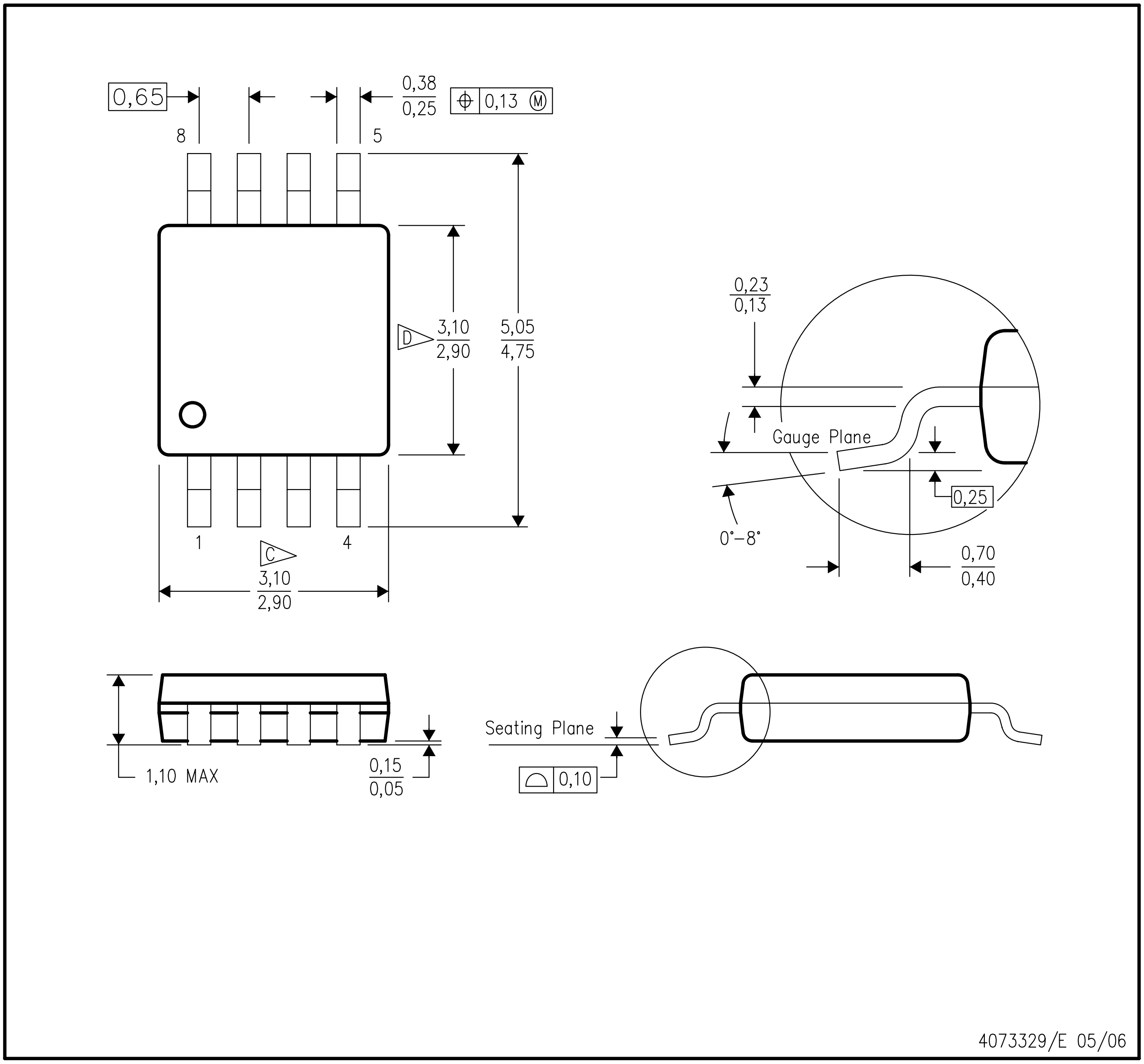
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE



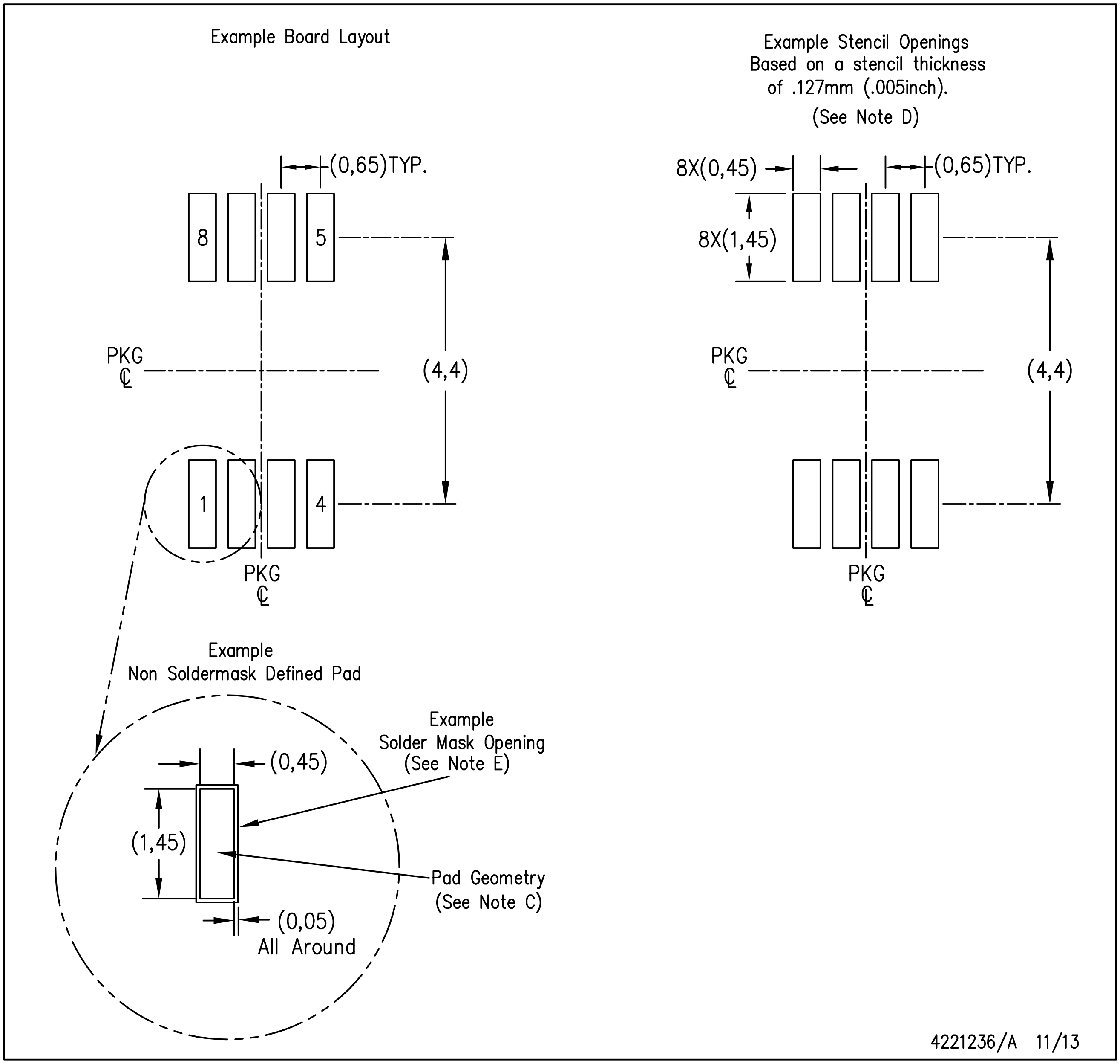
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

DGK (S–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



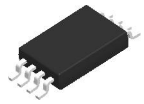
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO–187 variation AA, except interlead flash.

DGK (S-PDSO-G8) PLASTIC SMALL OUTLINE PACKAGE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

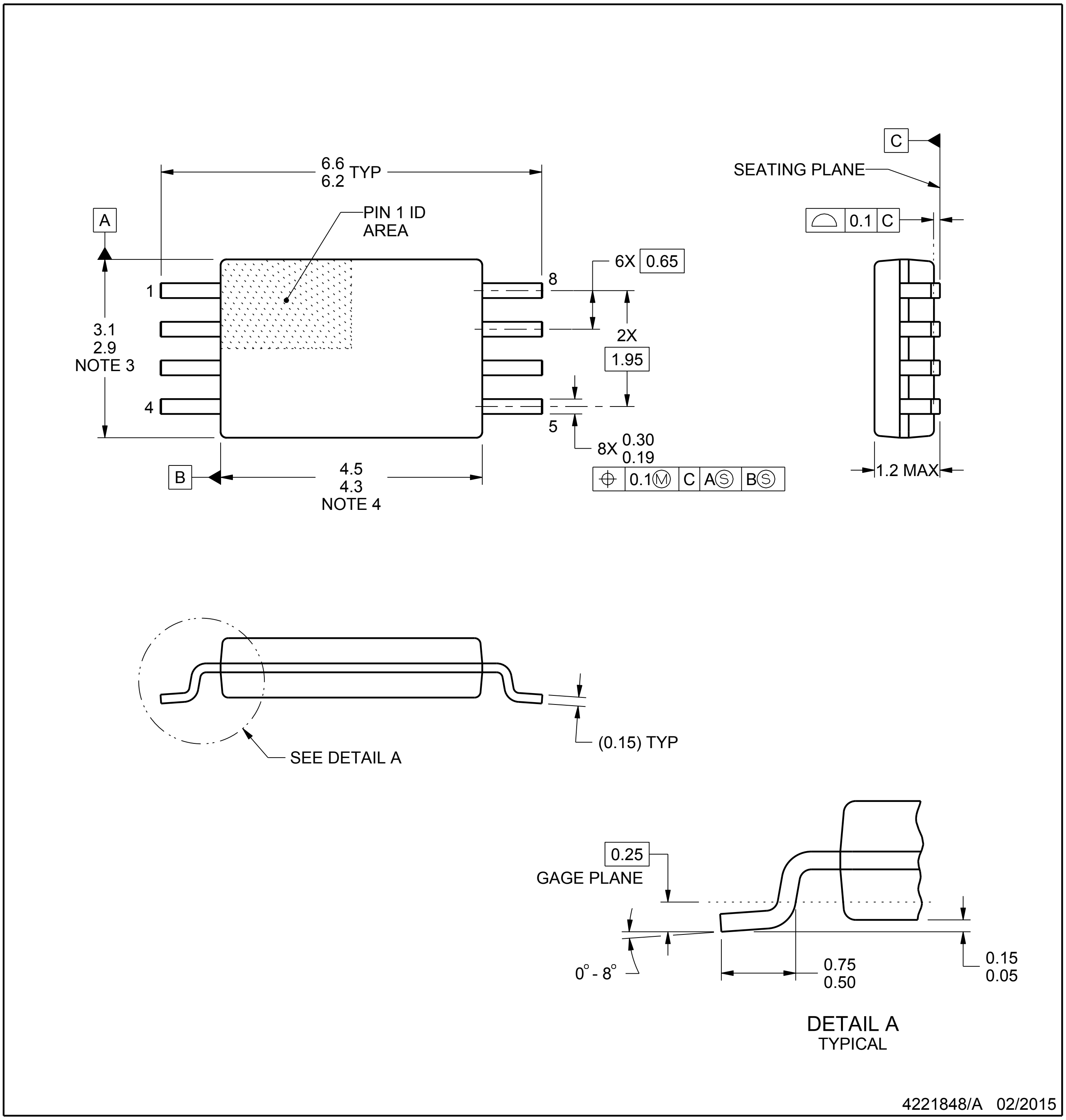
PACKAGE OUTLINE



PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



NOTES:

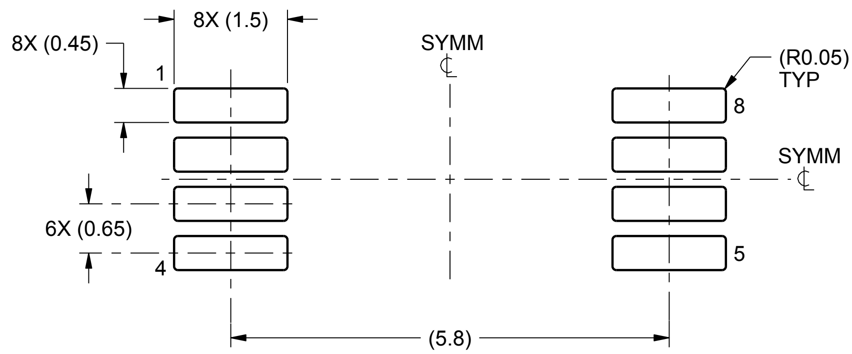
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.

EXAMPLE BOARD LAYOUT

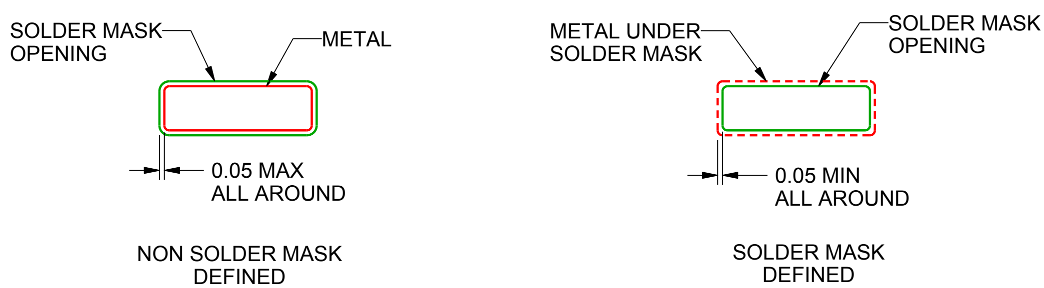
PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:10X



SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

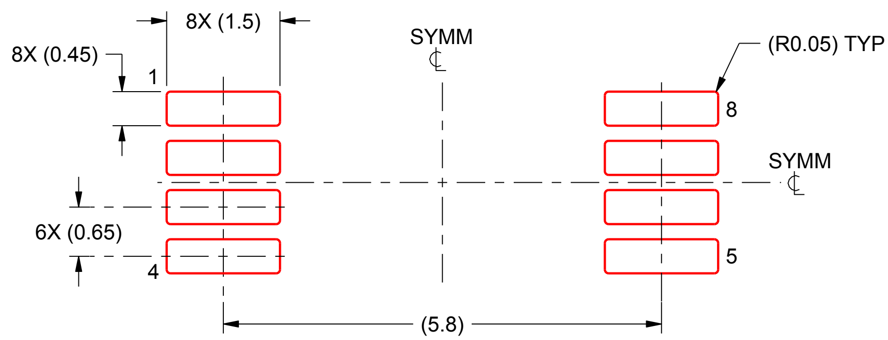
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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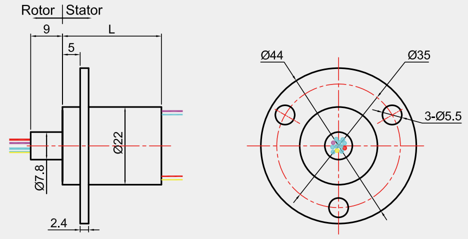
SRC022系列
SRC022 Series

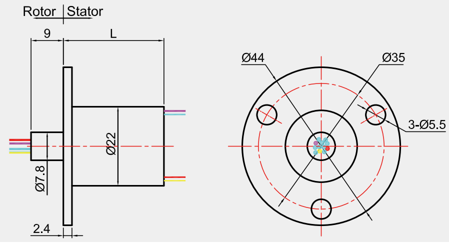
型号 TYPE	外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm



MODEL	L(mm)
SRC022-6	19
SRC022-12	28
SRC022-15	29.5
SRC022-18	33.4
SRC022-24	41.2
SRC022-36	56.8

标准型(Standard Type) SRC022

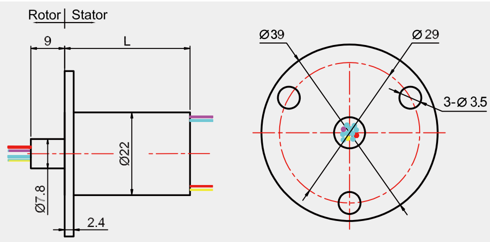
型号 TYPE	外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm



MODEL	L(mm)
SRC022A-6	19
SRC022A-12	28

A型 ("A"Type) SRC022A

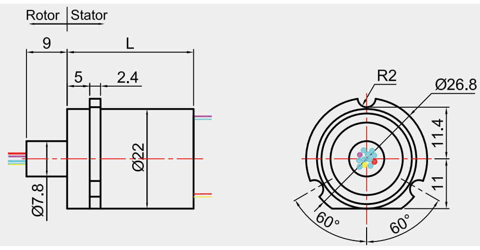
型号 TYPE	外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm



MODEL	L(mm)
SRC022A1-18	33.4

A1型 ("A1"Type) SRC022A1-18

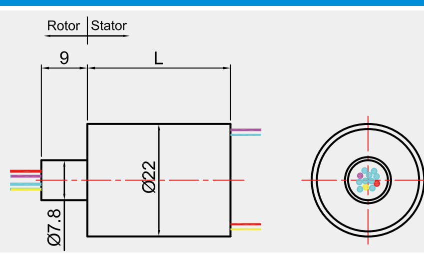
型号 TYPE	外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm



MODEL	L(mm)
SRC022B-6	19
SRC022B-12	28
SRC022B-18	33.4
SRC022B-24	41.2

B型 ("B"Type) SRC022B

型号 TYPE	外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm

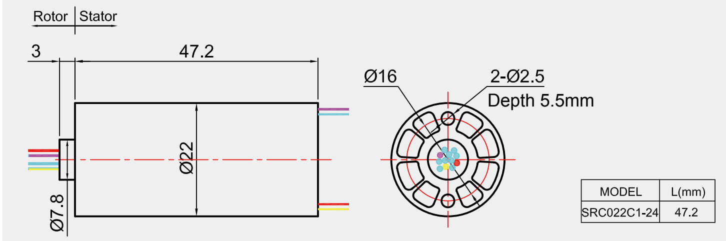


MODEL	L(mm)
SRC022C-6	19
SRC022C-12	28
SRC022C-18	33.4
SRC022C-24	41.2

C型 ("C"Type) SRC022C

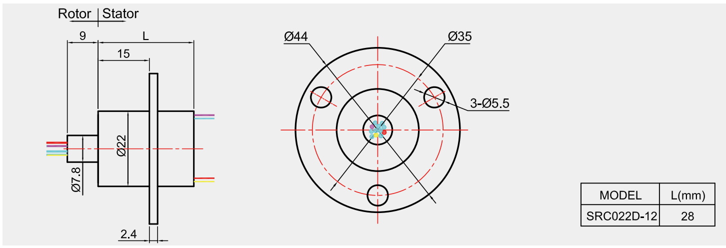
PROSPER

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



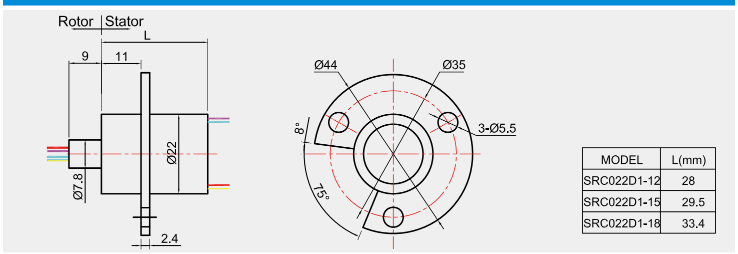
C1型 ("C1"Type) SRC022C1

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



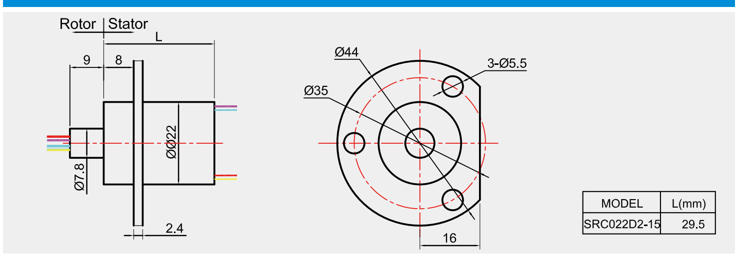
D型 ("D"Type) SRC022D

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



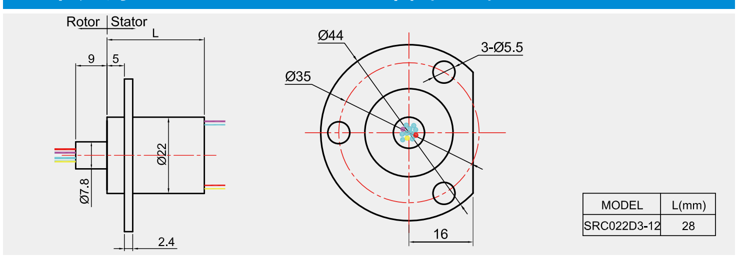
D1型 ("D1"Type) SRC022D1

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



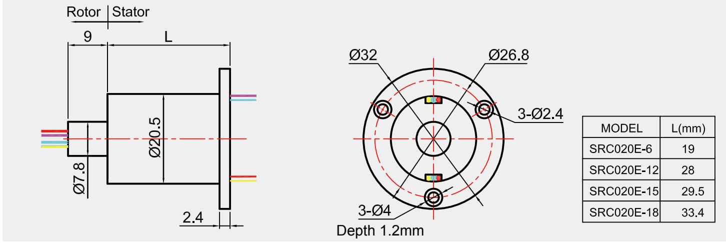
D2型 ("D2"Type) SRC022D2

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



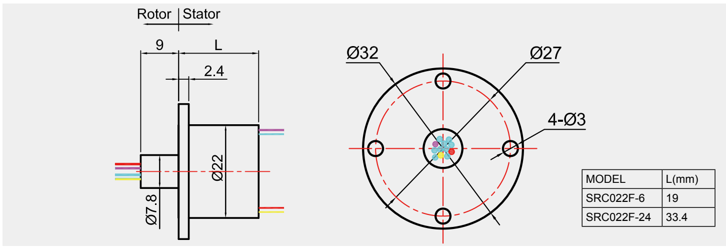
D3型 ("D3"Type) SRC022D3

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



E型 ("E"Type) SRC020E

型号 TYPE | **外形尺寸 OUTLINE DIMENSION 单位(UNIT) mm**



F型 ("F"Type) SRC022F

电气技术指标 Electrical data

参数 Specification	数值 Values
额定电压 Rated Voltage	240VDC/240VAC
额定电流 Rated Current	标准每环为2A 2A/ring
导线规格 Lead Size	AWG26 彩色镀银铁氟龙绝缘 AWG26, color coded, FEP insulated, silver plated copper
导线长度Lead Length	250mm或根据客户要求提供 250mm (or as request)
绝缘体强度 Dielectric Strength	500VAC@50Hz，60s
绝缘电阻 Insulation Resistance	1000MΩ/500VDC
动态电阻变化值 Electrical Noise	＜0.01Ω

机械技术指标 Mechanical data

参数 Specification	数值 Values
工作速度Operating Speed	0~300rpm
工作温度 Temperature Range	–20℃ – +80℃
工作湿度 Operating Humidity	60%RH 或更高 60%RH or higher
接触材料 Contact Material	贵金属 Precious Metals
壳体材料 Housing Material	工程塑料 Engineering Plastics

规格表 Specification List

型号 Type	环数 NO. of Rings	额定电流 Rated Current			长度 "L"
		2	6	10	
SRC022-6	6	6			19
SRC022-7	7	7			19
SRC022-12	12	12			28
SRC022-12-2P/2S	4	2	2		28
SRC022-15	15	15			29.5
SRC022-18	18	18			33.4
SRC022-18-3P	3			3	33.4
SRC022-24	24	24			41.2
SRC022-24-4P/6S	10	6	4		41.2
SRC022-36	36	36			56.8

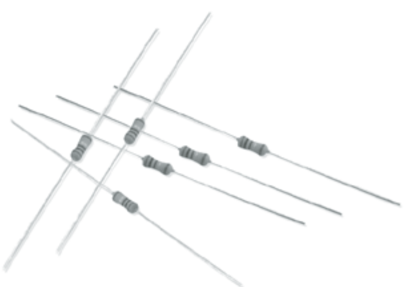
导线色码表 Lead Color Code

SRC022-6	1. 红RED	2. 黄YEL	3. 黑BLK	4. 蓝BLU	5. 绿GRN	6. 白WHT
SRC022-6 （短轴 Short axis）	1. 白WHT	2. 棕BRN	3. 黄YEL	4. 橙ORN	5. 黑BLK	6. 红RED
SRC022-8	1. 红RED	2. 绿GRN	3. 黄YEL	4. 紫PUP	5. 黑BLK	6. 蓝BLU
	7. 棕BRN	8. 橙ORN				
SRC022-12	1. 红RED	2. 绿GRN	3. 黄YEL	4. 紫PUP	5. 灰GRY	6. 黑BLK
	7. 蓝BLU	8. 深蓝DBLU	9. 棕BRN	10. 橙ORN	11. 白WHT	12. 土黄KHK
SRC022-15	1. 红RED	2. 绿GRN	3. 黄YEL	4. 紫PUP	5. 灰GRY	6. 黑BLK
	7. 蓝BLU	8. 深蓝DBLU	9. 棕BRN	10. 橙ORN	11. 白WHT	12. 土黄KHK
	13. 白-红 WHT-RED	14. 白-黑 WHT-BLK	15. 白-蓝 WHT-BLU			
SRC022-18	1. 红RED	2. 绿GRN	3. 黄YEL	4. 紫PUP	5. 灰GRY	6. 黑BLK
	7. 蓝BLU	8. 深蓝DBLU	9. 棕BRN	10. 橙ORN	11. 白WHT	12. 土黄KHK
	13. 白-红 WHT-RED	14. 白-黑 WHT-BLK	15. 白-蓝 WHT-BLU	16. 白-紫 WHT-PUP	17. 白-棕 WHT-BRN	18. 白-绿 WHT-GRN
SRC022-24	1. 红RED	2. 绿GRN	3. 黄YEL	4. 紫PUP	5. 灰GRY	6. 黑BLK
	7. 蓝BLU	8. 深蓝DBLU	9. 棕BRN	10. 橙ORN	11. 白WHT	12. 土黄KHK
	13. 白-红 WHT-RED	14. 白-黑 WHT-BLK	15. 白-蓝 WHT-BLU	16. 白-紫 WHT-PUP	17. 白-棕 WHT-BRN	18. 白-绿 WHT-GRN
	19.白-橙 WHT-ORN	20. 白-黄 WHT-YEL	21. 白-灰 WHT-GRY	22. 黑-红 BLK-RED	23. 黑-蓝 BLK-BLU	24. 黄-绿 YEL-GRN
SRC022-36	1/2. 红RED	3/4. 绿GRN	5/6. 黄YEL	7/8. 紫PUP	9/10. 灰GRY	11/12. 黑BLK
	13/14. 蓝BLU	15/16. 深蓝DBLU	17/18. 棕BRN	19/20. 橙ORN	21/22. 白WHT	23/24. 土黄KHK
	25/26. 白-红 WHT-RED	27/28. 白-黑 WHT-BLK	29/30. 白-蓝 WHT-BLU	31/32. 白-紫 WHT-PUP	33/34. 白-棕 WHT-BRN	35/36. 白-绿 WHT-GRN

Metal Film Resistors

High Power & Flame-Proof Type

Ultra Miniature Style [FMP Series]



INTRODUCTION

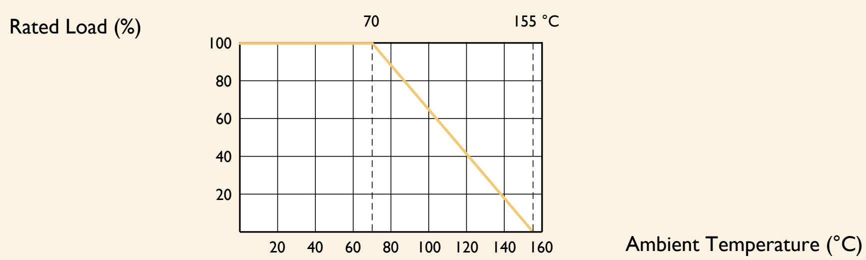
The FMP Series Metal Film High Power Resistors are manufactured using a vacuum sputtering system to deposit multiple layers of mixed metal alloys and passivative materials onto a carefully treated high grade ceramic substrate. After a helical groove has been cut in the resistive layer, tinned connecting leads of electrolytic copper are welded to the end-caps. The resistors are coated with layers of pink color lacquer.

FEATURES

Power Rating	1/2W, 1W, 2W, 3W,4W
Resistance Tolerance	±1%, ±5%
T.C.R.	±100ppm/°C
Flameproof Multi-layer Coating Meets	UL-94V-0
Flameproof Feature Meets Overload Test	UL-1412

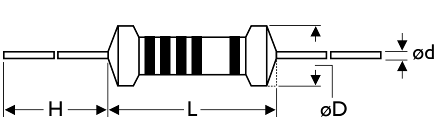
DERATING CURVE

For resistors operated in ambient temperatures above 70°C, power rating must be derated in accordance with the curve below.



DIMENSIONS

Unit: mm



STYLE	DIMENSION			
Ultra Miniature	**L**	**øD**	**H**	**ød**
FMP-50	3.4±0.3	1.9±0.2	28±2.0	0.45±0.05
FMP100	6.3±0.5	2.4±0.2	28±2.0	0.55±0.05
FMP200	9.0±0.5	3.9±0.3	26±2.0	0.55±0.05
FMP3WS	11.5±1.0	4.5±0.5	35±2.0	0.8±0.05
FMP300	15.5±1.0	5.0±0.5	33±2.0	0.8±0.05
FMP4WV	17.0±1.0	7.5±0.5	32±2.0	0.8±0.05

Note:

ELECTRICAL CHARACTERISTICS

STYLE	FMP-50	FMP100	FMP200	FMP3WS	FMP300	FMP4WV
Power Rating at 70°C	1/2W	1W	2W	3W		4W
Maximum Working Voltage	200V	350V	500V		750V	
Maximum Overload Voltage	400V	600V	700V		1,000V	
Voltage Proof on Insulation	300V	500V				
Resistance Range	1Ω - 10MΩ & 0Ω for E24 & E96 series value					
Operating Temp. Range	-55°C to +155°C					
Temperature Coefficient	±100ppm/°C					

Note: Special value is available on request

ENVIRONMENTAL CHARACTERISTICS

PERFORMANCE TEST	TEST METHOD		APPRAISE
Short Time Overload	IEC 60115-1 4.13	2.5 times RCWV for 5 Sec.	±0.5%+0.05Ω
Voltage Proof on Insulation	IEC 60115-1 4.7	in V-block for 60 Sec., test voltage by type	By type
Temperature Coefficient	IEC 60115-1 4.8	-55°C to +155°C	By type
Insulation Resistance	IEC 60115-1 4.6	in V-block for 60 Sec.	>1,000MΩ
Solderability	IEC 60115-1 4.17	235±5°C for 3±0.5 Sec.	95% Min. coverage
Solvent Resistance of Marking	IEC 60115-1 4.30	IPA for 5±0.5 Min. with ultrasonic	No deterioration of coatings and markings
Robustness of Terminations	IEC 60115-1 4.16	Direct load for 10 Sec. in the direction of the terminal leads	≥2.5kg (24.5N)
Periodic-pulse Overload	IEC 60115-1 4.39	4 times RCWV 10,000 cycles (1 Sec. on, 25 Sec. off)	±1.0%+0.05Ω
Damp Heat Steady State	IEC 60115-1 4.24	40±2°C, 90-95% RH for 56 days, loaded with 0.1 times RCWV	±2.0%+0.05Ω
Endurance at 70°C	IEC 60115-1 4.25	70±2°C at RCWV for 1,000 Hr. (1.5 Hr. on, 0.5 Hr. off)	±2.0%+0.05Ω
Temperature Cycling	IEC 60115-1 4.19	-55°C ⇨ Room Temp. ⇨ +155°C ⇨ Room Temp. (5 cycles)	±1.0%+0.05Ω
Resistance to Soldering Heat	IEC 60115-1 4.18	260±3°C for 10±1 Sec., immersed to a point 3±0.5mm from the body	±0.25%+0.05Ω
Accidental Overload Test	IEC 60115-1 4.26	4 times RCWV for 1 Min.	No evidence of flaming or arcing

Note: RCWV(Rated Continuous Working Voltage) = $\sqrt{\text{Power Rating} \times \text{Resistance Value}}$ or Max. working voltage listed above, whichever less.

Revision: 201304

EXPLANATIONS OF ORDERING CODE

MFR -12 F T F 52- 100R

MFR — Code 1 - 3
Series Name

See Index

-12 — Code 4 - 6
Power Rating

-05 = ød0.5mm
-06 = ød0.6mm
-07 = ød0.7mm
-08 = ød0.8mm
-10 = ød1.0mm
-14 = ød1.4mm
-12 = 1/6W
-25 = 1/4W
25S = 1/4WS
-50 = 1/2W
50S = 1/2WS
100 = 1W
1WS = 1WS
200 = 2W
2WS = 2WS
204 = 0.4W
207 = 0.6W
300 = 3W
3WS = 3WS
3WM = 3WM
400 = 4W
500 = 5W
5WS = 5WS
5SS = 5WSS
700 = 7W
7WS = 7WS
10A = 10W
20A = 20W
30A = 30W
40A = 40W
50A = 50W
10S = 10WS
15A = 15W
25A = 25W
10B = 100W
25B = 250W

F — Code 7
Tolerance

P = ±0.02 %
A = ±0.05 %
B = ±0.1 %
C = ±0.25%
D = ±0.5 %
F = ±1 %
G = ±2 %
J = ±5 %
K = ±10 %
\- = Base on Spec.

T — Code 8
Packing Style

T = Tape/Box
R = Tape/Reel
B = Bulk

F — Code 9
Temperature Coefficient of Resistance

\- = Base on Spec.
A = ±5 ppm/°C
B = ±10 ppm/°C
C = ±15 ppm/°C
S = ± 20ppm/°C
D = ±25 ppm/°C
E = ±50 ppm/°C
F = ±100 ppm/°C
G = ±200 ppm/°C
H = ±250 ppm/°C
I = ±300 ppm/°C
J = ±350 ppm/°C

52- — Code 10 - 12
Forming Type

26- = 26mm
52- = 52.4mm
73- = 73mm
81- = 81mm
91- = 91mm
F = F Type
FK = FK Type
FKK = FKK Type
FFK = F-form Kink
M = M-Type Forming
MB = M-form W/flat
MT = MT Type Forming
MR = MR Type
AV = AVIsert
PN = PANAsert

100R — Code 13 - 17
Resistance Value

0R1 = 0.1
100R = 100
10K = 10,000
10M = 10,000,000

EXCEPTION:

• Cement series:

<Code 8>: Special packing style code

B: Bulk with wirewound or metal oxide sub-assembly for resistance value
W: Bulk with ceramic based wirewound sub-assembly for resistance value
M: Bulk with metal oxide sub-assembly for resistance value
F: Bulk with Fiberglass based wirewound sub-assembly for resistance value

<Code 10-12>: Without forming code

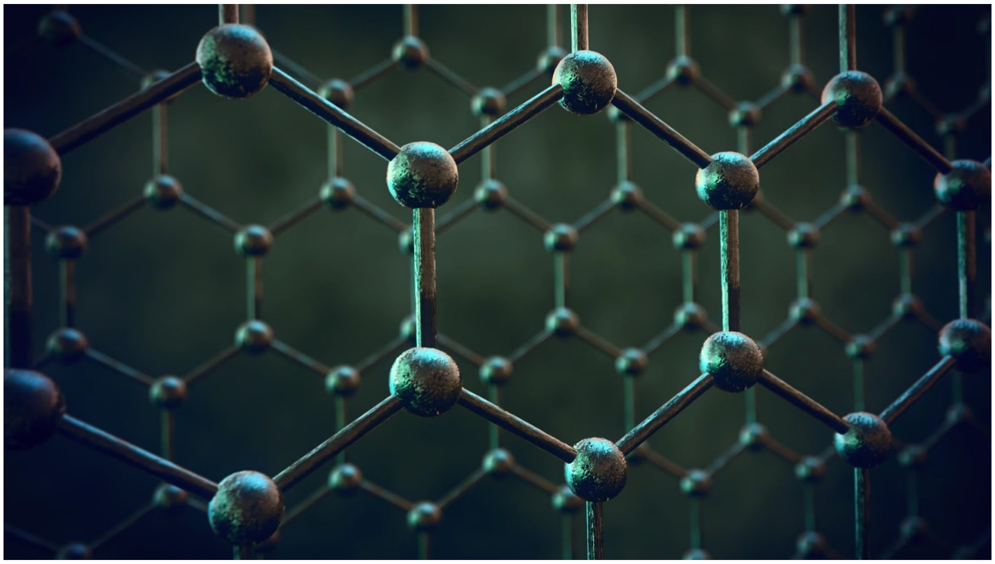
Example: **SQP500JB-10R**

• JPW series:

<Code 13-17>: without resistance value code

Example: **JPW-06-T-52-**

Graphene Twisters



Appendix K
Operator's Manual

Introduction

The following is the safety and operations manual for the drawing bath and graphene spinner. Inside find the detailed instructions for set-up, operation, and maintenance as well as some common guides to troubleshooting the device.

Safety

I. *Hazardous Chemicals*

- Baths in the assembly may contain chemical solutions that may be hazardous when in contact with skin. If contact is made, clean and rinse exposed area with water.

II. *Materials*

- The entire assembly is primarily composed of Type 1 Polyvinyl Chloride (PVC). For cleaning, use soapy water or isopropyl alcohol. **Under no circumstances** use **acetone, ammonia, iodine, etc.** for cleaning as they can dissolve the PVC. When in doubt, consult the supplied chemical resistance chart in appendix L.

III. *Cylinder Rotation*

- Considering the twisting mechanism was designed to reach speeds of 250 RPM, it is important to not place any hands/ feet/ or limbs in or near the mechanism during operation.

IV. *Circuitry*

- Electronic components are not covered, thus precautions should be taken to avoid getting them wet. Components may also heat up while running.

Setup and Operation

I. *Connecting Electrical Components - Drawing*

1. Make sure the leads at the front of the power supply are disconnected.
2. Push the power button on the power supply to turn it on.
3. Verify the power supply is set for 5-7 volts.
    a. If not, adjust the knobs on the front face until the display reads between 5 and 7 volts.
4. Plug the red banana lead into the red port on the power supply.
5. Plug the black banana lead into the black port on the power supply.

6. Use the brown and orange short leads to connect the ground and power rails of boards 1 and 2, respectively.
7. Locate the motor at the beginning end of the first bath and locate the wire connected to the side with the black stripe.
8. Connect this wire to column 20 on the bottom half of board 1.
9. Connect the other wire from this motor to the bottom power rail.
10. Repeat steps 9 through 11 for the remaining motor on the first bath, connecting it to column 10.
11. Connect the yellow short lead from column 4 on the bottom half of board 1 (not counting rightmost two columns) to column 57 on the bottom half of board 2.
12. Repeat steps 9 through 12 with the motors of the second bath and board 2.
13. Locate the black stripe on the motor of the auxiliary roller.
14. Connect this wire to column 20 on the bottom half of board 2.
15. Connect the other wire of that motor to the power rail of board 2.
16. Plug the red lead from the power supply to the uppermost red line (power rail) on board 1.

II. *Connecting Electrical Components - Twisting*

1. Make sure the leads at the front of the power supply are disconnected.
2. Push the power button on the power supply to turn it on.
3. Verify the power supply is set for 5-7 volts.
    a. If not, adjust the knobs on the front face until the display reads between 5 and 7 volts.
4. Plug the red banana lead into the red port on the power supply.
5. Plug the black banana lead into the black port on the power supply.
6. Locate the motor at the bottom of the twisting housing and locate the wire connected to the side with the black stripe.
7. Connect this wire to column 10 on the bottom half of board 3.
8. Connect the other wire from this motor to the bottom power rail.
9. Locate the wire in the housing that is marked with red tape.
10. Connect this wire to the power rail of board 3.
11. Locate the remaining free wire and connect it to column 20 on the bottom half of board three.
12. Locate the black stripe on the motor of the auxiliary roller.
13. Connect this wire to column 20 on the bottom half of board 3.
14. Connect the other wire of that motor to the power rail of board 2.
15. Plug the red lead from the power supply to the uppermost red line (power rail) on board 1.

III. *Setting Up the Coagulation and Drawing Baths*

1. Verify that the all bath components are properly assembled.
2. Fill the bath with approximately 12 oz of water and check for any leaks.
3. If the bath leaks, instructions for fixing it can be found in our bath troubleshooting guide.
4. If no leaks are found, dispose of the water in the bath using the proper disposal container and dry the inside.
5. Fill the bath with the appropriate fluid halfway to between the lower rollers and the top edge.
6. Run the tube from the end of the microfluidic channel over the first roller and under the second so that it deposits the graphene oxide solution at the base of the second roller.
7. Turn on the bath motors by connecting the black ground lead to the ground rail of board 1 and check that they are rotating properly.
    a. If the motors are not rotating properly, check the troubleshooting guide.
8. The coagulation bath rollers should rotate at the same speed.
    a. Adjust the speed of the first set of rollers by turning the knob on the bottom half of board 1.
    b. To adjust their relative speed, turn the knob on the upper half of board 1.
9. The first set of drawing bath rollers should rotate at the same speed as the previous set of rollers.
10. Set the speed of these rollers by turning the knob on the bottom half of the second board.
11. The second set of drawing bath rollers should be rotating approximately 2 times faster than the first set.
12. Adjust the rollers' relative speed by turning the knob on the upper half of board 2.
13. Hook the newly extruded graphene oxide and draw it to the far side of the bath.
14. Run the newly coagulated fiber under the third roller and over the fourth.
15. Run the fiber from the fourth roller to the auxiliary roller.

IV. *Setting Up the Auxiliary Roller*

1. Line up the auxiliary roller with the end of the bath.
2. Run the fiber over the roller until it begins to spool.

V. Setting Up the Cylinder

1. Lift the safety cover on the front of the cylinder and inspect to make sure the belt and rollers are in the proper groves.
2. Power the cylinder motor by connecting the ground wire to the ground rail of board 3 and verify that both the cylinder and spool are spinning.
3. Power off the cylinder by disconnecting the ground wire and wait for it to stop rotating.
4. Remove the spool from the cylinder and wrap the beginning portion of the fiber from the auxiliary roller around it.
5. Insert the spool into the cylinder.
6. Replace the safety cover and power the system by connecting the black ground lead the the ground rail of board 3.

Troubleshooting

I. Baths
   A. Bath leaks
      1. Using a phillips screwdriver or power drill, slightly tighten the screws on the side of the bath with the orange gasket. This will slightly compress the gasket further and prevent leaks.
      2. If the bath is leaking elsewhere than the orange gasket, use an automotive gasketing compound to place a small bead of sealant around where the leak is coming from.
   B. Bath rollers not spinning
      1. If the bath rollers are not spinning, begin by rotating the motor shaft by hand by about ⅓ of a revolution.
      2. If the issue persists, remove the gearbox cover and check the alignment of the worm and gear inside.
      3. If the gears are aligned, then verify if the roller spins without the cover in place.
      4. If this is the case, then reattach the gearbox cover making sure not to tighten the screws too much. Overtightening the screws results in shaft misalignment which will prevent the rollers from spinning.

II. Motors
   A. Motor does not spin
      1. Make sure the power supply is on and set to between 5 and 7 volts.

2. Make sure the board is powered up. Green and orange LEDs should be lit up on the arduino chip in the center of the board.
3. Check to make sure the motor is connected to its control electronics board properly.
4. Consult section I.B above.
5. If problem persists, motor could be broken. Remove motor from assembly completely and supply with 5 volts. It should turn freely and rapidly (on the order of 10,000 revolutions per minute).
6. If motor does not function, replace with new component.

B. Motor spins the wrong direction

1. Reverse the polarity of the motor by swapping its wire connections on the electronics control board with each other.

III. Rollers

A. Rollers do not spin

1. See section I.B above.

<u>Operation</u>

1. Set the syringe pump to the desired flow rate during the setup process.
2. Power the devices and make sure the fiber is properly being carried through each stage of the process.
3. Run until the syringe empties or until the fiber is of adequate length.

<u>Maintenance</u>

- ***Bath***

The coagulation and drawing baths should be cleaned periodically for proper function. Clean the bath to make sure there is not significant material build-up on the roller or bearing surfaces and to monitor component wear.

I. *Disassembly*

1. Disconnect electronics from power source.
2. Drain the bath of any working fluid.
3. On the side of the bath with the silicon gasket, use a phillips screwdriver or power drill to remove the 6 screws holding the side together.
    a. The side with the motor assemblies is permanently sealed. Do not attempt to remove this side.
4. With the screws removed, pull the side plate off the bath.

    a. There are 4 dowel pins used for alignment. Make sure these do not fall out or get lost.
    b. A rubber mallet may be useful for bath assembly and disassembly.
5. Remove the 4 rollers from inside of the bath.
    a. Every roller has a bearing on each end, 8 total. Ensure that these do not fall off and get lost.
6. Check the bearings and roller bearing surfaces for wear.

II. *Reassembly*

1. Check to make sure that each hole in the bath side has a bearing inserted into it.
2. The drive rollers with the hollow ends should be replaced before the inner rollers. They mount to the motor shafts in the upper set of holes, above the fluid line. Place the rollers so that the notch for the drive band is close to the wall.
3. Place the other rollers into the bottom holes in the bath side.
4. Place the two gasket halves onto the edge of the bath, putting the alignment pins through the appropriate holes.
5. Using the alignment pins to locate the position, place the bath side onto the bath, making sure that the roller ends go into their respective bearings.
    - A rubber mallet may be useful for bath assembly and disassembly.
6. Make sure each of the 8 8-32 screws has an appropriately sized washer on it.
7. Thread the 8 screws into the holes in the side and tighten with a phillips screwdriver or power drill.
    - Be careful not to overtighten the screws. They should be firm and snug, but not overly tight as that can cause damage to the threads. All that is needed is enough torque to slightly compress the silicone gasket.
8. Fill the bath with the requisite working fluid.
    - As the bath is filled for the first time, carefully check to make sure there are no leaks around any of the seals.
9. Reconnect the bath motors to the control board.

- ***Aux Roller***

The auxiliary roller assembly requires little maintenance. Throughout its lifespan, monitor wear, especially on rotating components, and replace if necessary. The auxiliary roller spring assembly can be disassembled by removing the central roller, removing the E-clip on the spring shaft, and sliding the assembly apart. Reassembly can be easily accomplished in the reverse.

- ***Gearbox***

The gearbox requires no maintenance, just monitoring of component wear. However, should a component break, disassembly for replacement will be necessary.

I. *Disassembly*

1. Disconnect the motor from the control board to prevent electrical shock.
2. Remove the gearbox from its parent assembly by using a phillips screwdriver or power drill to remove the two screws holding it on.
3. Using a phillips screwdriver or power drill, remove the four screws from the gearbox cover plate. This should allow access to the gears inside.
4. Using a 3/64” allen wrench loosen the set screw in the worm and slide the motor shaft out of the gearbox. The worm should fall out.

II. *If the motor needs to be replaced*

1. Gently pull the motor assembly off the rest of the gearbox. The motor shaft is inserted into a small plastic piece at the end of the drive shaft. Be careful not to tear or damage the flexible linkage when removing the motor.
2. Once the motor assembly is separate from the gearbox, remove the metal bracket by using a small phillips screwdriver to remove the two screws from the face of the motor where it meets the bracket.
    - These screws are very small and easy to lose. Take caution not to misplace them.
3. The motor should be free to come off at this point. Motor assembly is simply the reverse of the steps listed here.

III. *If the gears or bearings need to be replaced*

1. Using a screwdriver or power drill, remove the 4 screws on the front side of the gearbox
2. Pull of the front cover of the gearbox.
    a. The front cover has a small flange bearing inside of it. Make sure this does not get lost if it comes out.
3. From here, the drive shaft and white spur gear can be removed, along with the bearing in the back of the gearbox. Remove it now so it does not fall out and get lost later.
4. Turn the black worm gear until a small set screw is visible.
5. Using an appropriately sized allen key, loosen this screw. This will allow the motor shaft to slide out.

6. From here, the worm gear and the two flange bearing supporting it can slide out of the gearbox assembly.
7. The gearbox should be fully disassembled at this point. Gearbox reassembly is the reverse of the steps listed here.

- ***Cylinder Housing***

The Cylinder housing requires minimal maintenance. Simply monitor supports and drive belt throughout lifespan for wear and tear. In case of cylinder removal

I. *To Remove Cylinder*

1. First remove the pulley wheel from the motor shaft located directly beneath the cylinder. This will free up the drive belt(still attached to cylinder).
2. After belt is free, cylinder is now unconstrained and can be removed.
3. For reassembly, follow procedure in reverse(make sure belt is on cylinder prior to placing cylinder in housing).

II. *Disassembly of Housing*

1. In order to remove any panels/walls from the cylinder housing or disassembly in general, all screws can be removed with the use of a philips head screwdriver or power drill.
2. In order to reassemble again employ the use of a phillips head screwdriver or power drill.

- ***Cylinder***

The cylinder was designed for minimal maintenance. Monitor the wear on the internal components and slip ring and replace worn components as needed.

See section above to Remove Cylinder

I. *Disassembly of the Cylinder*

1. Remove the spool shafts supported by the cylinder walls.
2. Unscrew the 4 screws connected radially to the Cylinder sides. This should allow for all internal components to be removed as a single piece.
3. Disconnect the motor from its wires
4. Unscrew the four screws attaching the internal walls to the aluminum backing plate. This will separate the plate from the internal walls.

5. Remove the screws connecting the slip ring to the backing plate and remove the slip ring.

PVC Chemical Resistance Guide

FIRST EDITION

PVC CHEMICAL RESISTANCE GUIDE

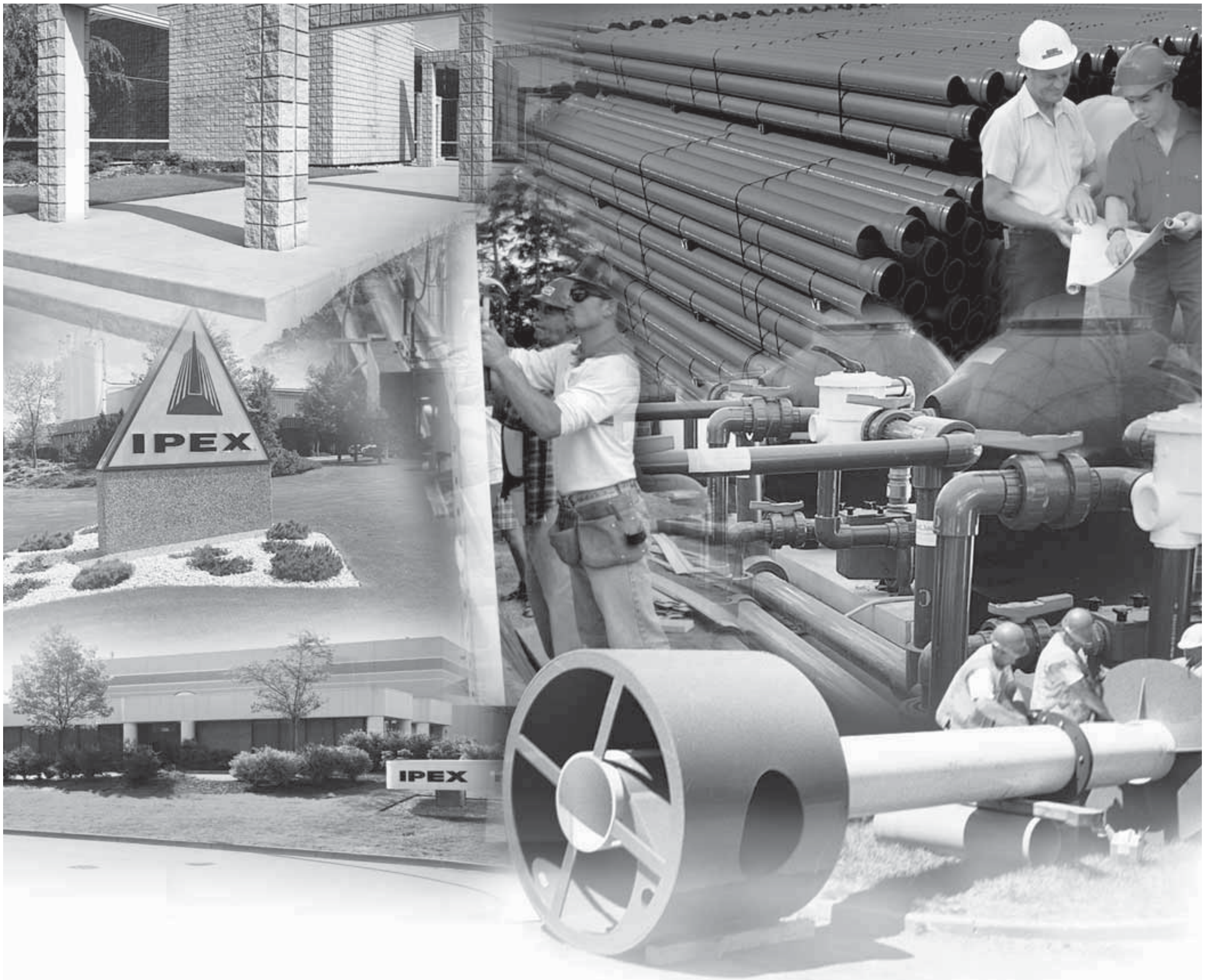
Thermoplastics:
Polyvinyl Chloride (PVC)

IPEX

Chemical Resistance Guide

Polyvinyl Chloride (PVC)

1st Edition



About IPEX

At IPEX, we have been manufacturing non-metallic pipe and fittings since 1951. We formulate our own compounds and maintain strict quality control during production. Our products are made available for customers thanks to a network of regional stocking locations from coast-to-coast. We offer a wide variety of systems including complete lines of piping, fittings, valves and custom-fabricated items.

More importantly, we are committed to meeting our customers' needs. As a leader in the plastic piping industry, IPEX continually develops new products, modernizes manufacturing facilities and acquires innovative process technology. In addition, our staff take pride in their work, making available to customers their extensive thermoplastic knowledge and field experience. IPEX personnel are committed to improving the safety, reliability and performance of thermoplastic materials. We are involved in several standards committees and are members of and/or comply with the organizations listed on this page.

For specific details about any IPEX product, contact our customer service department.

INTRODUCTION

Thermoplastics and elastomers have outstanding resistance to a wide range of chemical reagents. The chemical resistance of plastic piping is basically a function of the thermoplastic material and the compounding components. In general, the less compounding components used the better the chemical resistance. Thermoplastic pipes with significant filler percentages may be susceptible to chemical attack where an unfilled material may be affected to a lesser degree or not at all.

Some newer piping products utilize a multi-layered (composite) construction, where both thermoplastic and non-thermoplastic materials are used for the layers. Layered composite material pipe may have chemical resistance that differs from the chemical resistance of the individual material. Such resistance however, is a function both of temperatures and concentration, and there are many reagents which can be handled for limited temperature ranges and concentrations. In borderline cases, it will be found that there is limited attack, generally resulting in some swelling due to absorption. There are also many cases where some attack will occur under specific conditions, but for many such applications, the use of plastic will be justified on economic grounds when considered against alternative materials. Resistance is often affected (and frequently reduced) when handling a number of chemicals or compounds containing impurities. For this reason, when specific applications are being considered, it may be worthwhile to carry out tests using the actual product that will be encountered in service. The listing that follows does not address chemical combinations.

The information is based on immersion tests on unstressed coupons, experiments and, when available, actual process experience as well as data from tests inclusive of stress from temperature and pressure. The end user should be aware of the fact that actual service conditions will affect the chemical resistance.

Chemicals that do not normally affect the properties of an unstressed thermoplastic may cause completely different behavior (such as stress cracking) when under thermal or mechanical stress (such as constant internal pressure or frequent thermal or mechanical stress cycles). Chemical resistance data from immersion tests cannot be unconditionally applied to thermoplastic piping components subjected to continuous or frequent mechanical or thermal stresses.

When the pipe will be subject to a continuous applied mechanical or thermal stress, or to combinations of chemicals, testing that duplicates the expected field conditions, as closely as possible, should be performed on representative samples of the pipe product to properly evaluate plastic pipe for use in this application.

RATINGS

Ratings are according to the product and suppliers.

The absence of any class indication for any given materials, signifies the absence of data for such material(s) with respect to the specific chemical(s), temperature(s) and concentration(s).

Note: Chemical resistance data is found in a laboratory setting and cannot account for all possible variables of an installed application. It is up to the design engineer or final user to use this information as guidance for a specific application design.

If a material is chemically resistant to the concentrated form of a specific chemical, it should be resistant to the diluted form of that same chemical.

All Chemical Resistance data for Polyvinyl Chloride (PVC) contained within this manual has been provided, with written consent, by Uni-Bell.

Notes

POLYVINYL CHLORIDE (PVC)

All Chemical Resistance data for Polyvinyl Chloride (PVC) contained within this manual has been provided, with written consent, by Uni-Bell.

A pipe system may be subject to a number of aggressive chemical exposures, accidental or otherwise. Resistance of PVC pipe to attacks by chemical agents has been determined through years of research and field experience, demonstrating the capability to endure a broad range of both acidic and caustic environments.

Factors Affecting Resistance

Chemical reactions can be very complex. There are so many factors affecting the reaction of a piping system to chemical attack that it is impossible to construct charts to cover all possibilities. Some of the factors affecting chemical resistance are:

1. Temperature
2. Chemical (or mixture of chemicals) present
3. Concentration of chemicals
4. Duration of exposure
5. Frequency of exposure

PVC Pipe and Fittings

The chemical resistance information for PVC pipe provided in the following tables is based on short-term immersion of unstressed strips of PVC in various chemicals (usually undiluted), and may be useful in assessing the suitability of PVC under unusual or specific operating environments. Results of this type of test can be used only as a guide to estimate the response of PVC. These tables provide guidance to industrial users of pipe for conveying the chemicals listed, rather than design criteria for sewers that may experience occasional exposures or when diluted by other wastewater discharges.

An additional source of information on the chemical resistance of PVC pipe is the National Association of Corrosion Engineers publication entitled, "Corrosion Data Survey, Nonmetals Section." For critical applications it is recommended that testing be performed under conditions that approximate the anticipated field conditions.

In applications where exposure to harmful chemicals is frequent, of long duration or in high concentrations, further testing is recommended.

The following chemical resistance legend is used in the following PVC tables:

R	Generally resistant
C	Less resistant than R but still suitable for some conditions
N	Not resistant

POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
A		
Acetaldehyde	N	N
Acetaldehyde, aq 40%	C	N
Acetamide	-	-
Acetic acid, vapor	R	R
Acetic acid, glacial	R	N
Acetic acid, 25%	R	R
Acetic acid, 60%	R	N
Acetic acid, 85%	R	N
Acetic anhydride	N	N
Acetone	N	N
Acetylene	N	N
Acetyl chloride	N	N
Acetylnitrile	N	N
Acrylonitrile	N	N
Acrylic acid	N	N
Adipic acid	R	R
Alcohol, allyl	R	C
Alcohol, amyl	N	N
Alcohol, benzyl	N	N
Alcohol, butyl (n-butanol)	R	R
Alcohol, diacetone	N	N
Alcohol, ethyl (ethanol)	R	R
Alcohol, hexyl (hexanol)	R	R
Alcohol, isopropyl (2-propanol)	R	R
Alcohol, methyl (methanol)	R	R
Alcohol, propyl (1-propanol)	R	R
Alcohol, propargyl	R	R
Allyl chloride	N	N
Alums	R	R
except Aluminim fluoride	R	N
Ammonia, gas	R	R
Ammonia, liquid	N	N
Ammonium salts	R	R
except Ammonium Dichromate	R	N
Ammonium fluoride, 10%	R	R
Ammonium fluoride, 25%	R	C
Amyl acetate	N	N
Amyl chloride	N	N
Aniline	N	N

Chemical	23ºC (73ºF)	60ºC (140ºF)
Aniline chlorohydrate	N	N
Aniline hydrochloride	N	N
Anthraquinone	R	R
Antimony trichloride	R	R
Anthraquinone sulfonic acid	R	R
Aqua regia	C	N
Arsenic acid, 80%	R	R
Aryl-sulfonic acid	R	R
B		
Barium salts	R	R
except Barium nitrate	R	N
Beer	R	R
Beet sugar liquor	R	R
Benzaldehyde, 10%	R	N
Benzene (benzol)	N	N
Benzene sulfonic acid, 10%	R	R
Benzene sulfonic acid, > 10%	N	N
Benzoic acid	R	R
Black liquor – paper	R	R
Bleach, 12% active chlorine	R	R
Bleach, 5% active chlorine	R	R
Borax	R	R
Boric acid	R	R
Brine	R	R
Bromic acid	R	R
Bromine, aq	R	R
Bromine, liquid	N	N
Bromine, gas, 25%	R	R
Bromobenzene	N	N
Bromotoluene	N	N
Butadiene	R	R
Butane	R	R
Butynediol	R	N
Butyl acetate	N	N
Butyl stearate	R	N
Butyl phenol	R	N
Butylene, liquid	R	R
Butyric acid	R	N

R - Generally Resistant C - Less resistant than R but still suitable for some conditions N - Not resistant

IPEX

POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
C		
Cadmium Cyanide	R	R
Calcium salts	R	R
except Calcium bisulfide	N	N
Calcium hypochlorite, 30%	R	R
Calcium hydroxide	R	R
Calcium Nitrate	R	R
Calcium Oxide	R	R
Calcium Sulfate	R	R
Camphor	R	N
Cane sugar liquors	R	R
Carbon disulfide	N	N
Carbon dioxide	R	R
Carbon dioxide, aq	R	R
Carbon monoxide	R	R
Carbitol	R	N
Carbon tetrachloride	R	N
Carbonic Acid	R	R
Castor oil	R	R
Caustic potash, (potassium hydroxide), 50%	R	R
Caustic soda, (sodium hydroxide), < 40%	R	R
Cellosolve	R	N
Cellosolve acetate	R	N
Chloral hydrate	R	R
Chloramine, dilute	R	N
Chloric acid, 20%	R	R
Chlorine, gas, dry	C	N
Chlorine, gas, wet	N	N
Chlorine, liquid	N	N
Chlorine water	R	R
Chloracetic acid, 50%	R	R
Chloroacetyl Chloride	R	N
Chlorobenzene	N	N
Chlorobenzyl chloride	N	N
Chloroform	N	N
Chloropicrin	N	N
Chlorosulfonic acid	R	N
Chromic acid, 10%	R	R
Chromic acid, 30%	R	R
Chromic acid, 40%	R	C

Chemical	23ºC (73ºF)	60ºC (140ºF)
Chromic acid, 50%	N	N
Chromium potassium sulfate	R	N
Citric acid	R	R
Coconut oil	R	R
Coffee	R	R
Coke oven gas	R	R
Copper acetate	R	N
Copper salts, aq	R	R
Corn oil	R	R
Corn syrup	R	R
Cottonseed oil	R	R
Cresote	N	N
Cresol, 90%	N	N
Cresylic acid, 50%	R	R
Croton aldehyde	N	N
Crude oil, sour	R	R
Cupric Salts, aq	R	R
Cyclohexane	N	N
Cyclohexanol	N	N
Cyclohexanone	N	N
D		
Detergents, aq	R	R
Dextrin	R	R
Dextrose	R	R
Dibutoxyethyl phthalate	N	N
Diesel fuels	R	R
Diethylamine	N	N
Diethyl Ether	R	N
Disodium phosphate	R	R
Diglycolic acid	R	R
Dioxane -1,4	N	N
Dimethylamine	R	R
Dimethyl formamide	N	N
Dibutyl phthalate	N	N
Dibutyl sebacate	R	N
Dichlorobenzene	N	N
Dichloroethylene	N	N

R - Generally Resistant C - Less resistant than R but still suitable for some conditions N - Not resistant

POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
E		
Ether	N	N
Ethyl ether	N	N
Ethyl halides	N	N
Ethylene halides	N	N
Ethylene glycol	R	R
Ethylene oxide	N	N
F		
Fatty acids	R	R
Ferric salts	R	R
Fish Oil	R	R
Fluorine, dry gas	R	N
Fluorine, wet gas	R	N
Fluoboric acid	R	R
Fluosilicic acid, 50%	R	R
Formaldehyde	R	R
Formic acid	R	N
Freon - F11, F12, F113, F114	R	R
Freon - F21, F22	N	N
Fructose	R	R
Furfural	N	N
G		
Gallic acid	R	R
Gas, coal, manufactured	N	N
Gas, natural, methane	R	R
Gasolines	C	C
Gelatin	R	R
Glucose	R	R
Glue, animal	R	R
Glycerine (glycerol)	R	R
Glycolic acid	R	R
Glycols	R	R
Grape Sugar	R	R
Green liquor, paper	R	R

Chemical	23ºC (73ºF)	60ºC (140ºF)
H		
Heptane	R	R
Hexane	R	N
Hexanol	R	R
Hydraulic Oil	R	N
Hydrobromic acid, 20%	R	R
Hydrochloric acid	R	R
Hydrofluoric acid, 30%	R	N
Hydrofluoric acid, 50%	R	N
Hydrofluoric acid, 100%	N	N
Hydrofluosilic acid	R	R
Hydrocyanic acid	R	R
Hydrogen	R	R
Hydrogen cyanide	R	R
Hydrogen fluoride	N	N
Hydrogen phosphide	R	R
Hydrogen peroxide, 50%	R	R
Hydrogen peroxide, 90%	R	R
Hydrogen sulfide, aq	R	R
Hydrogen sulfide, dry	R	R
Hydroquinone	R	R
Hydroxylamine sulfate	R	R
Hydrazine	N	N
Hypochlorous acid	R	R
I		
Iodine, aq, 10%	N	N
J		
Jet fuels, JP-4 and JP-5	C	C
K		
Kerosene	R	R
Ketones	N	N
Ketchup	R	N
Kraft paper liquor	R	R

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POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
L		
Lactic acid, 25%	R	R
Lactic acid, 80%	R	N
Lard oil	R	R
Lauric acid	R	R
Lauryl acetate	R	R
Lauryl chloride	R	R
Lead salts	R	R
Lime sulfur	R	N
Linoleic acid	R	R
Linoleic oil	R	R
Linseed oil	R	R
Liqueurs	R	R
Lithium salts	R	R
Lubricating oils	R	R
M		
Magnesium salts	R	R
Maleic acid	R	R
Malic acid	R	R
Manganese sulfate	R	R
Mercuric salts	R	R
Mercury	R	R
Methane	R	R
Methoxyethl oleate	R	N
Methyl acetate	N	N
Methyl amine	N	N
Methyl bromide	N	N
Methyl cellosolve	N	N
Methyl chloride	N	N
Methyl chloroform	N	N
Methyl ethyl ketone	N	N
Methyl isobutyl carbinol	N	N
Methyl isobutyl ketone	N	N
Methyl isopropyl ketone	N	N
Methyl methacrylate	R	N
Methyl sulfate	R	N
Methyl sulfuric acid	R	R
Methylene bromide	N	N

Chemical	23ºC (73ºF)	60ºC (140ºF)
Methylene chloride	N	N
Methylene iodide	N	N
Milk	R	R
Mineral oil	R	R
Molasses	R	R
Monochloroacetic acid	R	R
Monochlorobenzene	N	N
Monoethanolamine	N	N
Motor oil	R	R
N		
Naphtha	R	R
Naphthalene	N	N
Natural Gas	R	R
Nickel acetate	R	N
Nickel salts	R	R
Nicotine	R	R
Nicotinic acid	R	R
Nitric acid, 0 to 40%	R	R
Nitric acid, 50%	R	C
Nitric acid, 70%	R	N
Nitric acid, 100%	N	N
Nitrobenzene	N	N
Nitroglycerine	N	N
Nitrous acid, 10%	R	R
Nitrous oxide, gas	R	N
Nitroglycol	N	N
O		
Oleic acid	R	R
Oleum	N	N
Olive oil	R	R
Oxalic acid	R	R
Oxygen, gas	R	R
Ozone, gas	R	R

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POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
P		
Palmitic acid, 10%	R	R
Palmitic acid, 70%	R	N
Paraffin	R	R
Pentane	C	C
Peracetic acid, 40%	R	N
Perchloric acid, 15%	R	N
Perchloric acid, 70%	R	N
Perchloroethylene	C	C
Perphosphate	R	N
Phenol	R	N
Phenylhydrazine	N	N
Phosphoric anhydride	R	N
Phosphoric acid	R	R
Phosphorus, yellow	R	N
Phosphorus, red	R	N
Phosphorus pentoxide	R	N
Phosphorus trichloride	N	N
Photographic chemicals, aq	R	R
Phthalic acid	C	C
Picric acid	N	N
Plating solutions, metal	R	R
Potash	R	R
Potassium amyl xanthate	R	N
Potassium salts, aq	R	R
except Potassium iodide	R	N
Potassium permanganate, 10%	R	R
Potassium permanganate, 25%	R	N
Propane	R	R
Propylene dichloride	N	N
Propylene Glycol, 25%	R	R
Propylene Glycol, 25 - 50%	C	C
Propylene Glycol, 50% +	N	N
Propylene oxide	N	N
Pyridine	N	N
Pyrogallic acid	R	N
R		
Rayon coagulating bath	R	R

Chemical	23ºC (73ºF)	60ºC (140ºF)
S		
Salicylic acid	R	R
Salicylaldehyde	N	N
Selenic acid, aq.	R	R
Silicic acid	R	R
Silicone oil	R	N
Silver salts	R	R
Soaps	R	R
Sodium salts, aq	R	R
except Sodium chlorite	N	N
except Sodium chlorate	R	N
except Sodium hypochlorite	R	N
Stannic chloride	R	R
Stannous chloride	R	R
Starch	R	R
Stearic acid	R	R
Stoddard solvent	N	N
Succinic acid	R	R
Sulfamic acid	N	N
Sulfate & Sulfite liquors	R	R
Sulfur	R	R
Sugars, aq	R	R
Sulfur dioxide, dry	R	R
Sulfur dioxide, wet	R	N
Sulfur trioxide, gas, dry	R	R
Sulfur trioxide, wet	R	N
Sulfuric acid, up to 80%	R	R
Sulfuric acid, 90 to 93%	R	N
Sulfuric acid, 94 to 100%	N	N
Sulfurous acid	R	R
T		
Tall Oil	R	R
Tannic acid	R	R
Tanning liquors	R	R
Tar	N	N
Tartaric acid	R	R
Terpineol	C	C
Tetrachloroethane	C	C

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POLYVINYL CHLORIDE (PVC)
CHEMICAL RESISTANCE DATA

Chemical	23ºC (73ºF)	60ºC (140ºF)
Tetraethyl lead	R	N
Tetrahydrofuran	N	N
Tetralin	N	N
Tetra sodium	R	R
Thionyl chloride	N	N
Thread cutting oils	R	N
Titanium tetrachloride	C	N
Toluene	N	N
Tomato juice	R	R
Transformer oil	R	R
Tributyl phosphate	N	N
Tributyl citrate	R	N
Trichloroacetic acid	R	R
Trichloroethylene	N	N
Triethanolamine	R	N
Triethylamine	R	R
Trimethyl propane	R	N
Trisodium phosphate	R	R
Turpentine	R	R
U		
Urea	R	R
Urine	R	R
V		
Vaseline	N	N
Vegetable oils	R	R
Vinegar	R	R
Vinyl acetate	N	N
W		
Water, deionized	R	R
Water, distilled	R	R
Water, salt	R	R
White Liquor	R	R
Whiskey	R	R

Chemical	23ºC (73ºF)	60ºC (140ºF)
Wines	R	R
X		
Xylene	N	N
Z		
Zinc salts	R	R

Source: PPI TR-19 Plastics Pipe Institute Wayne, NJ, 1991; Uni-Bell Handbook of PVC Pipe

These tables are meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data is provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

R - Generally Resistant   C - Less resistant than R but still suitable for some conditions   N - Not resistant

Notes

SALES AND CUSTOMER SERVICE

Canadian Customers call IPEX Inc.
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www.ipexinc.com

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As leading suppliers of thermoplastic piping systems, the IPEX Group of Companies provides our customers with some of the largest and most comprehensive product lines. All IPEX products are backed by more than 50 years of experience. With state-of-the-art manufacturing facilities and distribution centers across North America, we have established a reputation for product innovation, quality, end-user focus and performance.

Markets served by IPEX group products are:

- Electrical systems
- Telecommunications and utility piping systems
- PVC, CPVC, PP, ABS, PEX, FR-PVDF and PE pipe and fittings (1/4" to 48")
- Industrial process piping systems
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- Plumbing and mechanical piping systems
- PE Electrofusion systems for gas and water
- Industrial, plumbing and electrical cements
- Irrigation systems

IPEX

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```
int motor1Pin = 11;  //PWM pin for motor1
int motor2Pin = 10;  //PWM pin for motor2
int potIn1 = 0; //Variable to store motor1 input signal
int potIn2 = 0; //Variable to store motor2 input signal
int motor1Out = 0;  //Variable to store motor1 output signal
int motor2Out = 0;  //Variable to store motor1 output signal

void setup() {
  // put your setup code here, to run once:
  pinMode(motor1Pin, OUTPUT);  //Set output pin for motor1
  pinMode(motor2Pin, OUTPUT);  //Set output pin for motor2
  pinMode(13, OUTPUT);        //Set output pin for 5V signal
  digitalWrite(13, 5);        //Set output to high
}

void loop() {
  // put your main code here, to run repeatedly:
  potIn1 = analogRead(A0);  //Read voltage signal for motor1
  potIn2 = analogRead(A1);  //Read voltage signal for motor2

  motor1Out = potIn1/4; //Divide potentiometer input (0-1023) by
4 (0-225)
  motor2Out = potIn2/4; //Divide potentiometer input (0-1023) by
4 (0-225)

  analogWrite(motor1Pin, motor1Out);  //Set motor1 speed
  analogWrite(motor2Pin, motor2Out);  //Set motor2 speed

}
```