Tilton Clutch Release Load Tester

by

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Automated Clutch Release Measurement Device

Final Design Report

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Critical Design Review
February 14, 2013

Executive Summary

This report documents and summarizes progress made on the design of the Automated Clutch Release Measurement Device for Tilton Engineering, Inc. Contained within are all project decisions made up to February 13, 2013 prior to the Critical Design Review meeting with Tilton Engineering and project sponsor Casey Lund.

This report contains the following:

- Discussion and analysis of the client's need for such a product

- Outline of background research

- Presentation of initial conceptual designs and design refinement process

- Full outline of final design, component-by-component.

- Description and justification of all design and component decisions, including mathematical analysis of critical components.

- Manufacturing considerations, component sourcing information, and all necessary info to build completed design.

- Documentation of cost analysis for all components.

- Provides documentation of process for future reference.

We feel that the device described in the following pages is the very best solution to satisfy Tilton's need for a device that tests new and rebuilt clutches for release load. Upon completion of the Critical Design Review with Tilton on February 14, 2013 and approval of the final design report, it is recommended to proceed with the project as specified in the project timeline. This includes moving forward with component sourcing, material sourcing, and manufacturing.

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1.1: Introduction

Sponsor Background and Needs

This proposal is for the development of an automated clutch release measurement device for Tilton Engineering, Inc. Tilton has expressed its desire for a piece of test equipment to supplement their existing CT2000 clutch clamp load testing machine. This device will acquire release load and travel data for the pressure plate of a clutch immediately after it is tested for clamp load on the CT2000 machine, and will serve as a quality control check for Tilton's clutches before they are sent out to the customer.

Tilton wants a clutch release test machine to ensure that their assembly and manufacturing processes are meeting their engineering specifications. They will also be able to gather more data during R&D which will help with the creation of better quality products.

Currently Tilton does not have an accurate method of measuring clutch release load and travel for their rebuilt clutches. This would be a useful verification to ensure that the clutch has been rebuilt to specification. Being able to pass this information on to the customer would also provide an extra level of verification and data.

This machine will do the following for Tilton:

1. Help the customer select the best Tilton clutch for their requirements and their needs.
2. Verify that their clutch has been rebuilt to their satisfaction as well as Tilton's specifications.
3. Verify that the release force of the rebuilt clutch is the same (or similar) to a brand new unit.

4. Allow Tilton Engineering to accurately measure and document the release loads for all clutches in the product line. This will allow Tilton to publish this data for customers that may need it and to establish upper and lower levels of what will be acceptable for quality control.
5. Provide release load data to the customer for their specific new and/or rebuilt clutch assemblies.
6. Support new research and development of new components and assemblies to augment the product line.
7. Provide a new tool for returned goods evaluation and failure analysis.

This project has a number of individuals and organizations who are invested in the success of the project. These include:

- Tilton Engineering, Inc. – Sponsor
- Casey Lund – Contact
- Cal Poly Mechanical Engineering Department
- Dr. Tom Mase – Advisor
- Ryan Bylard, Kevin Campbell, Trevor Hebbel – Team Members

Our goal is to produce a complete, working, fully documented device by Thursday, May 30th, 2013, the date of the Cal Poly Senior Project Expo. In addition, we aim to fulfill all customer requirements and meet our self-set engineering targets, deliver the project within necessary budget constraints, and produce full documentation of each step of the process.

Objectives / Specification Development

Our goal is to create a working machine that integrates with the CT2000 and measures the clutch release load with respect to displacement. This data must be electronically acquired and sent to a computer for analysis.

The test machine required for this application brings about very specific customer requirements.

This machine will be used for quality control on rebuilt clutches as well as have uses as a research and development tool. Also, the integration with the CT2000 offers various constraints that will help to define our technical goals.
In order to get a better grasp on what the customer needed we visited Tilton's facility to see the current set up and discuss one on one with our sponsor about the direction we should head in. This initial visit allowed us to construct a set list of customer requirements, which we then used in our QFD that can be found in Appendix A. These requirements are as follows.

- Integrates with existing equipment.
- Quick to set up.
- Ability to acquire load and travel data accurately.
- Automation during test.
- Maximum travel for safety.
- Simple user interface

From the list above we were able to construct a list of technical requirements that we felt were necessary in order to achieve what Tilton was asking for. We used a QFD to determine the how strongly each of the technical requirements correlated with the customer needs. This helped to insure that the list of technical requirements below would facilitate ideation.

- Minimum of five inches of travel.
- One inch of measurement travel maximum.
- 2000 to 3000 pounds of dynamic load.
- Minimum Deflection of five percent.
- Ten pound maximum force exerted by the operator.
- Additional 30 seconds of setup time.

The minimum five inches of travel is a necessary physical parameter because of the various sizes of clutches. Depending on the diameter of the clutch and how many friction surfaces are contained within the clutch, the height differences can be significantly large. Five inches was based on a safety factor to insure that the machine will work with the entire range of Tilton products.

The distance traveled after the release piston has made contact with the clutch springs determines measurement travel. This is the actual physical distance that the springs can be moved through. One inch was determined through correspondence with our sponsor. From the Tilton product catalogue we were able to determine that one-inch of travel was plenty to release any of the clutches Tilton currently makes. This distance also insures that the clutches will not be damaged due to over-travel and corresponds directly with the maximum travel for safety requirement.

Tilton's clutches take a maximum of about 1000 pounds to release when bolted onto the flywheel of a car. The exact data can be found in Appendix B. From this data and conversation with Tilton we determined that an acceptable dynamic load should be somewhere from 2000 to 3000 pounds. This will ensure that each clutch Tilton examines can be completely released. From correspondence with our sponsor we learned that this machine may also be used to enhance Tilton's product line, and that they may be constructing clutches with higher release loads in the future. The extra 1000 to 2000 pounds will provide Tilton with the with a machine that can handle their future ventures. This technical requirement corresponds with the customer requirement of being able to acquire load and travel data accurately as well.

The minimum deflection of five percent corresponds with gathering data accurately as well. It refers specifically to the deflection of the frame and therefore the piston while under load. Any amount of deflection will of our test machine will cause our travel measurements to be incorrect giving false data to the engineers at Tilton.

The next two technical targets that we decided upon both correlate with the quick to set requirement. The operator has tests about five to six clutches a day. Set up includes removing the clutch that is bolted onto the CT2000, and depending on clutch size, possibly replacing the plate that the clutch is bolted onto. We want to make any machine that we integrate as easy to work with as possible. If you have to move our machine out of the way to change a clutch then we think that ten pounds of force is reasonable to where the operator would not be worn out. We also figured that in order to keep the same rate of five to six clutches a day we would not be able to extend setup time by a lengthy amount. This is why we decided that it should take no more than an extra 30 seconds with our machine attached.

The three customer requirements above that have not been discussed directly are integrates with existing equipment, automation during test, and simple user interface. Every technical requirement we set above has the ability to integrate with the existing setup. This requirement has more use in the actual ideation and design concepts that we discuss in method of approach. The last two are controls based requirements. We decided on creating a secondary list for all technical controls requirements, as the controller will be based primarily off of the physical components we decide to use. The list is as follows.

- No more than 4 input commands from operator.
- Safety to protect clutch from over-travel.
- Plots data accurately.

These three targets cover a broad range of controller design and we are confident that we will be able to meet the customer's requirements. More specifically we decided that a simple interface for the amount of different clutches that Tilton will test with this machine should have no more than 4 input commands. These commands would be general prompts asking what size, type, disk number, and other defining parameters so that the machine would know exactly what test to run. The safety would be built into the test parameters for the different clutch categories. Lastly, Tilton wants to be able to plot this data in a useable format. This will allow Tilton to ensure that the clutch has been rebuilt to specification and gives them data that can be referred back to.

2.1 - Background & Design Development

Existing Products

There are several products on the market that solve a similar problem; however our machine will be designed to augment the existing CT2000. The CT2000 clutch load clamp machine has the capability to test the clutch clamp load but cannot test the release load or the associated displacement. We will build a machine that can accomplish both of these tasks.

While designing this machine, we may need to follow certain ASME standards. For example, if we use a hydraulic system, there will be standards regulating the design of those systems.

We will most likely use steel as the structural material because it is cheap and has many different compositions with varying mechanical properties, therefore we will need to find an appropriate type of steel to handle the loads that will be applied. These can be found in Mil Handbook 5 along with many other material properties that we may need.

Many of the currently available machines have an automated hydraulic clamp that holds the clutch to the measurement table. We will not be attempting this because the CT2000 is the base unit for our test machine. Another feature on many of the existing products is multiple pressure sensors on the clutch back plate which allows for an evenness of lift measurement. This will also be neglected because the clamp load force is measured with the existing CT2000.

To depress the Belleville spring, we will use a throw-out bearing or similar device so that it will model a real system as close as possible. We will use a Tilton bearing so that there will be no error caused by incompatible components.

Method of Approach/Concept Development

We have developed a specific schedule that outlines important deadlines, and describe how we will go about meeting those deadlines.

Specification development/planning - (September – December)

We have analyzed Tilton's needs and requirements in order to set guidelines which we can use to make all our future design decisions. This analysis has been based primarily off the problem definition that we have stated earlier in this proposal. The needs and requirements that have been developed from this problem statement serve as the basis for our QFD/House of Quality, where they have been converted to quantifiable decision criteria. These criteria will be used to determine whether or not our design will meet Tilton's needs.

Understanding the design problem was the next crucial stage in the development process. We visited Tilton's facility to get a first-hand look at the existing CT2000 test machine and see some of the design constraints associated with building around an existing piece of hardware. From here we developed an initial project proposal which was submitted to our advisor and Tilton Engineering for review. After receiving feedback, we re-evaluated our requirements to more accurately express Tilton's needs, updated the QFD to give us a basis for evaluating competing ideas, and then formed a Gantt chart, which outlines the schedule for the remainder of this project. This chart can be seen in Appendix F.

We began concept generation and ideation by breaking up the overall mechanism into a few key components and then individually coming up with ideas that would become pieces of the overall machine. These components were the structure, actuation method, and measurement method. Once we each had a few possibilities, we came together and compared the ideas with the QFD to eliminate ideas that could not meet the design requirements. This yielded a shorter list of possibilities for individual components which we turned into full machine design, which we analyzed against our technical targets to determine their potential. Our top three ideas, which can be seen in Appendix G, were a combination of different solutions to the three component- level problems.

Concept 1

This is a bolt on system that will be attached to the top of the CT2000. It has a horizontal pivot to allow clutch installation and removal, and it uses a hydraulic actuator. For measurement, it will use a force transducer and an LVDT. We were worried about having enough room on top of the CT2000 to mount this system, but after seeing the setup at Tilton, we found that this was a very viable option.

Concept 2

This is a larger device that contains the CT2000 affixed permanently in its center. It swings open vertically for clutch loading and also features a hydraulic actuator. One problem with vertical pivots is that the entire weight of the actuator and measurement systems will need to be lifted by the machine operator, adding a physical fatigue component to the test procedure. We wanted to avoid this which is the main reason for not choosing this concept.

Concept 3

This idea uses a rail system to slide the CT2000 into and out of its center. It then has a ball screw actuator positioned below the clutch to move a linkage system which in turn actuates the clutch. This system also uses a string potentiometer for the linear measurement. We had three main concerns with this design. First, having actuator that acts on a linkage instead of directly on the clutch adds complexity and has a potential for failure and inaccurate measurements. Second, the rail system has the potential to break or need cleaning more than a sealed roller bearing, and aligning the CT2000 machine inside our device might prove problematic. Finally, this structure would have a relatively large footprint, which would require Tilton to buy a new workbench to place our assembly on.

We brought these ideas to Tilton for feedback, and after revisiting the site and looking at the CT2000, we decided on the first idea with only a few adjustments.

This final design meets each of the technical targets set above:

- Minimum of five inches of actuator travel, one inch of measurement travel, and 2000 to 3000 pounds of dynamic load will achieved through actuator selection. From what we have seen so far the actuators that meet these three criteria are lightweight and small enough to work well with this design.

- Minimum deflection of five percent will be made possible by frame geometry, bracing, material selection, and pivot design. The latch preloads the pivoting assembly, removing any slop in the channel before the test begins.
- Ten pound maximum force exerted by the operator and an additional 30 seconds of setup time was one of the key factors in choosing this design. The lightweight swing action of the actuator support allows for continued use without operator fatigue. Clutch removal is quick, and involves simply swinging the horizontal assembly out of the way.

Moving forward, our next step is to calculate possible loads and decide on an actuation method. We are currently looking at an electro-mechanical ball screw or a hydraulic system for the actuation method, both of which have positive and negative aspects. The ball screw is a clean device that can be controlled in open loop. However, it is a fairly large system and we do not want the machine to be too tall because the base is small and this could cause a tipping issue. The hydraulic actuator is a shorter device and it can produce large forces for its size, but hydraulic systems are inherently messy. They have a separate actuator, pump, and reservoir which are all connected by hydraulic lines and are prone to leakage. After searching for a solution to this problem, we found a compact electro-hydraulic actuator made by Parker that is a single, sealed unit which needs no maintenance and is not meant to be serviced. This eliminates our issues with hydraulic systems. After additional research into both types of actuation and the construction of a working prototype, a final choice will be made.

Prototype Design - (November – February)

The first step to prototype design will be the creation of a SolidWorks model. This must be completed first so we have something to follow while creating the prototype. We will then test our design against the quantified requirements. The prototype should be sufficient to test every design criterion which has been developed in our talks with our contact at Tilton. This may include several different operations, as certain pieces may require individual testing for quality assurance. Once we are satisfied that our components will meet each requirement we can begin to test them in conjunction with each other. This phase will be an iterative process in which the prototype will be tested and revised until it meets the original goals and standards. We will also decide on a final actuation method based our findings during testing. During this time we will also begin the design and implementation of the user interface and data acquisition system for the computer.

Critical Design Review – (February 14, 2013)

By this time we will have decided on a final design and specified most of the materials and components that we need. We will present our ideas both in class and at Tilton's headquarters in Buellton. This review will be the final presentation before spending money on hardware, and therefore we must have as much done as possible so Tilton can have a complete picture of the design and price of the project, as well as the capabilities and limitations of the proposed system. It will also give them a chance to voice any last minute requests or concerns before production.

Production - (February – March)

After taking the feedback from the critical design review and incorporating it into the final design, we will begin the production phase. At this point, we will have all the materials and components specified and ordered in preparation for the final manufacturing process. We will have decided how best to build the machine at this point and whether we will have components made by Tilton or if all manufacturing will be done in-house. This will depend greatly on budget, time, and the manufacturing constraints of the facilities at Cal Poly. We will maintain close contact with Tilton during this process in order to ensure that our final product can smoothly integrate with the CT2000 clamp load test machine.

Testing and Revision - (March – June)

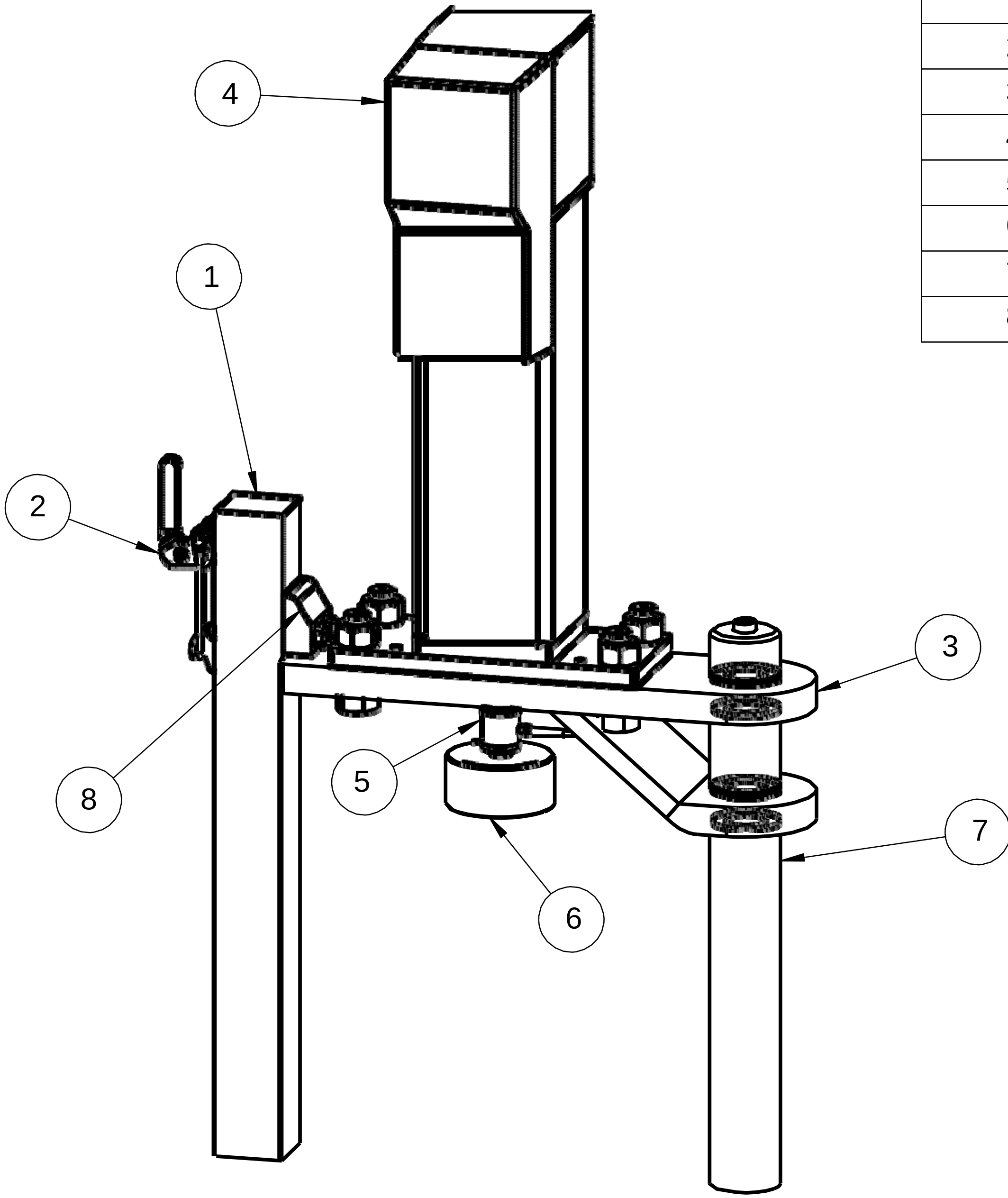
This iterative process will begin during the final build and continue until the machine is running at Tilton. We will test the machine using Tilton's various product lines to ensure that it meets the goals and standards that were agreed upon in the QFD.

Final Documentation and Presentation - (June)

The final presentation will be held on May 30, 2013 at the Senior Project Design Expo. The final report is due one week later on June 7, 2013. Prior to the final presentation, we will have gone through a conceptual design review and a critical design review which will guarantee that the final product fulfills the client's expectation.

3.1: Overall Description/Layout

ITEM NO.	DESCRIPTION	QTY.
1	Square Verticle Post	1
2	Latch and Catch Plate	1
3	Horizantal Crossbar	1
4	Tritex2M-X090	1
5	Load Cell	1
6	Release Bearing Adapter	1
7	Cirular Post and Collar	1
8	Support Block	1



Cal Poly Mechanical Engineering ME 251 - Winter 2013	Date:2/12/13	Clutch Release Load Tester

Our clutch release load tester has been designed as an extension of the existing CT 2000 clutch clamp load testing machine. It will be mounted to the top plate of the existing machine so that it sits directly over the clutch to be tested. It consists of two vertical supports and a horizontal cross member. The actuator is bolted directly to the top of the horizontal cross member. The actuator and cross member pivot around the right hand side support by a collar system and captured thrust bearings. All sizing, material selection, and component design/selection has been done considering a maximum actuator load of 3000 lb.

3.2 Detailed Design Description

1. Square Vertical Post

The square vertical post is made of 1.75" by 1.75" square 4140 steel bar. The bottom is drilled and tapped with a 1/2-13 UNC tap and will accept a bolt that will be fed through a new hole drilled in the top plate of the existing CT2000 machine. The inside-facing side will be left flat, while the outside face will have a slight radius cut into it to match the curvature of the CT2000 top plate. This will prevent overhanging edges that are unsightly and can catch on clothing or skin. The radius will only extend approximately halfway up the bar; here the bar will become square again, as we need a flat surface at the top of the bar to mount our latch. Near the top of the bar there is a pocket feature cut into the bar, which acts as a latching interface with the horizontal crossbar. A section cut of the bar at this feature would reveal an "L" cross section - the crossbar is cut with an upside down "L" cross section that mates into this feature. The "L" cross section was chosen because it removes as little material as possible from the vertical bar's cross section, allowing it to maintain strength and stiffness. Above this cross section, there are two drilled and tapped holes on the outside face of the bar to accept mounting screws for our draw latch. On the inside face, there will also be two drilled and tapped holes. These holes will accept bolts that hold on a rectangular steel attachment plate, designed to help distribute loads transmitted from the crossbar into a larger cross-sectional area of the beam. At this time we are investigating adding a small safety switch that would sense when the horizontal crossbar is closed and locked and place. This safety switch would not allow the actuator to cycle unless it was depressed.

The vertical post will require both lathe and CNC machining. The tapped hole in the bottom of the post will be done on a manual lathe *before* any other machining takes place, as the CNC work will prevent it from being held in a chuck. The square bar can be gripped in a 4-jaw lathe chuck, and the hole can be drilled and tapped manually. The curved edge and pocketed latch profile will be done on a 3-axis vertical CNC mill. The four tapped holes in the top of the bar can either be done on a CNC or manual mill.

2. Latch + Catch Plate

Our latch and catch plate configuration uses a Protex Draw-Action Toggle Clamp and a matching Protex striker/catchplate. This latch will be mounted and operated vertically, and serves the purpose of preloading the frame assembly before running the actuation cycle. It also serves the purpose of preventing the crossbar from opening during actuation, should any unusual horizontal forces occur during a test cycle. Although the latch mechanism is primarily designed to provide clamp force along its vertical axis, its over-center locking mechanism can also resist reasonable amounts of horizontal force. We do not anticipate to any horizontal forces on either the square vertical bar or the latch, but if a clutch breaks, is mounted improperly, or an operator bumps the frame during testing and a horizontal force component is induced, the latch mechanism will ensure that the assembly stays safely closed.

The catch/striker plate is a steel piece supplied by Protex, and it mounts to our horizontal crossbar using two screws that mate into tapped holes on the crossbar.

3. Horizontal Crossbar

The horizontal crossbar is made of 0.75" thick by 3.54" wide 4140 steel bar. It is unique in that it must accommodate five separate features, as well as take up to 3000 lbf in bending. The five features are as follows:

Catchplate Mate - the crossbar has two drilled and tapped holes on its extreme end to accept hardware to mount the latch striker/catchplate.

Latching Interface - The crossbar will have an "L" shaped cutout in its end, which mates into the "L" pocket feature on the square vertical bar. This latching interface distributes the load between the horizontal plate and the vertical post.

Actuator Mounting Provisions - The crossbar will have a through hole machined in its center in order to act as a pass-through for the actuator rod. It will also have four 5/8" through holes that match the mounting pattern on the Exlar actuator unit. These holes will accept 5/8" bolts that hold the Exlar unit to the frame.

Bearing Interface - The other extreme end of the crossbar will have a machined pocket that will accept

a standard ball bearing, allowing the crossbar to rotate around the inner shaft surface of the round vertical post. The pocket will also have a through-hole so that it can be slid onto the circular post. *Support Bracket Interface* – The horizontal crossbar will have two drilled and tapped holes in its underside to accommodate bolts that will fasten the horizontal crossbar to the lower bearing support bracket.

The horizontal crossbar will be manufactured on a vertical CNC mill.

4. Actuator Unit

Our actuator unit is a Tritex T2M/X090 electromechanical linear actuator, manufactured by Exlar Corporation of Chanhassen, Minnesota. We carefully selected and spec'd this unit so that it meets or exceeds all our design requirements. Full details can be found in Chapter 4, Section 5. In short, our actuator unit can exert up to 3175 pounds of peak force, and 1587 pounds of continuous force. "Continuous" force represents the amount of force the actuator can exert indefinitely ("continuously") without overheating. "Peak" force represents the amount of force the actuator can exert for short periods of time. According to Exlar engineers, the amount of time that an actuator can spend pressing in the peak region is a function of motor heat dissipation, and cannot be accurately determined without testing in a specific application. Again, according to Exlar engineers, for every minute the actuator spends above the "continuous" threshold, it must spend an equivalent amount of time below the continuous threshold to cool. Because our actuation cycle will be relatively short (<10 seconds) and the rest time between cycles is relatively long (> 5 minutes), operating in the peak region should not be a problem. In addition, any material bolted to the actuator acts as a heat sink and promotes cooling; our actuator bolts to a ¾" thick steel plate, greatly aiding heat dissipation.

Our actuator has a front flange mount that bolts to the horizontal crossbar with four 5/8" bolts. The actuator rod end has 6" of linear travel (enough to accommodate different height clutches and release bearings), and has a female threaded end that accepts our male-threaded load cell. It also has an internal position sensor that is accurate to 0.002".

5. Load Cell

The load cell we selected is a Futek unit. It can measure up to 3500 lb in both tension and compression. Although our test cycle is only concerned with compression, a threaded load cell can accommodate the light tension load that our release bearing adaptor's weight will put on it when hanging freely. This eliminates the need for separate fastening provisions to hold the release bearing adaptor when it is unloaded and hanging freely. Both ends of the load cell have 1/2-20 UNF 2A external threads that will thread into the 1/2-20 UNF 2B female internal threads on both the actuator rod end and the release bearing adaptor plate. The load cell has a 2mV/V analog output that can be routed to our data acquisition system. Although the Exlar actuator has built-in force sensing capability, it measures force through motor torque, and is only accurate to +/- 10%.

6. Release Bearing Adaptor

Our release bearing adaptor is made from 4140 steel round stock. It was designed to mimic Tilton's hydraulic release bearing housings, and has a deep circular groove cut into the bottom of it to accept any of Tilton's stock release bearings. The bearings are held in by friction provided by a stock Tilton orange wiper seal that sits in a machined groove. The top side of the release bearing adaptor has a blind tapped ½-20 2B UNF female thread that accepts the end of the threaded load cell. The release bearing adaptor will be manufactured on a CNC vertical mill.

7. Support Bracket

The support bracket serves the purpose of distributing the moment on the bearings when the frame is left open. Instead of distributing all the load into a single bearing/joint interface, our support bracket divides the force in two – allowing the bottom bearing to react the force-couple created by the top bearing. This interface should drastically reduce slop in the rotating assembly over time, especially if the unit is left open overnight.

8. Round Vertical Post and Collars

The right vertical post is made up of a rigid bar and collar support system. The rigid bar is in place so that the horizontal cross member can rotate out of the way of the operator while changing clutches. This rotary motion will be facilitated by two heavy load-double sealed ball bearings. These bearings are not designed to take axial loading so we designed a collar system that will take all axial loads during operation. The collar system is made up of tubes that will act as sleeves over the rigid bar support. The system consists of a cap, an intermediate collar (between the horizontal bar and the support bracket), and a lower support. Between the horizontal cross member and the collar supports is a set of thrust bearings. The bearings are the interface between the collars and cross members to ensure smooth rotary motion when pivoting around the rigid support. These bearing are rated up to 3800 lb of thrust (axial) load. The collar system will be torqued down by a prescribed amount with a bolt through the top cap to reduce slop and ensure all load is taken by the collars.

3.3 Analysis Results

Most of our analysis was centered not on strength but on strain. This is because we want the machine to accurately measure displacement and to do that, the frame must not deflect under our applied loads. After finding all the strains which can be seen in Appendix E, we found that the largest deflection by far was due to the horizontal cross beam that holds the actuator. This deflection was 0.0268" under a 3,000 lb load while the stress in this member was 26,142 psi which is well under the 60,000 psi yield strength of 4140 steel. Once we had the deflection values for all the structural components, we found the deflection as a percent of overall clutch travel. This value was 7.075% which is higher than our design specification. However, the loading scenario we analyzed was for the 3/4" thick horizontal crossbar *alone*. In our design, the horizontal beam will have the flange mount for the Exlar actuator bolted to it. The flange mount is a 0.44" steel plate which will greatly increase the second moment of area which will lower the percent deflection to within our specification of 7.5% of overall clutch travel.

3.4 - Cost Break Down

NOTE: Cost ledger does NOT include the following:

- Hookup wire and small electronic equipment (op-amps, resistors, etc) as these items were not finalized at the time of writing (6/13/13)

- Shipping, handling, or sales tax

- Raw material stock (most sourced and provided internally by Tilton)

- Labor costs of any kind, including CNC machining done by Tilton, Cal Poly, or outside sources

INSTRUMENTS/ELECTRONICS

Item	Manufacturer (if known)	Distributor	Part Number	Subtotal	Qty Used	Total
Load Cell	Futek	Futek	LCM350 - FSH00673	525.00	1	525.00
DAQ Card	Futek	Futek	USB210 - FSH03221	500.00	1	500.00
Load Cell Calibration	Futek	Futek	SLC00007	150.00	1	150.00
Linear Actuator	Exlar	Minarek	T2M090-0601-GFF-IE-238-40-230-SIO	4055.00	1	4055.00
Actuator USB Cable	Exlar	Minarek	CBL-T2USB485-M8-015	150.00	1	150.00
Latch	Protex	Protex	TLH-UBAB-041-080	17.05	1	17.05
Latch Catchplate	Protex	Protex	TLC-UBCP-020-024	2.26	1	2.26
PNP Proximity Sensor		McMaster-Carr	McMaster 7674K912	69.20	1	69.20
Actuator Cable Glands M20 x 1.5		McMaster-Carr	McMaster 9448K33	11.82	2	23.64
Shielded 14 AWG Power Cable		McMaster-Carr	McMaster 9936K75	7.66	12 ft	91.92
Shielded 18 AWG I/O Cable		McMaster-Carr	McMaster 7673K46	6.23	5 ft	31.15
Touch Pad Switch		McMaster-Carr	McMaster 7692K4	17.72	1	17.72
E-Stop Corrosion-Resistant Enclosure Switch Turn to Reset	Baco	McMaster-Carr	Baco-LBX17301,McMaster-6785K23	43.86	1	43.86
Steel Disconnect Switch, Fusible, Indoor, DPST, 3-Wire, 30 Amps at 240V AC	Siemens	McMaster-Carr	McMaster 7524K21	45.10	1	45.10
K5 Fuse 250 VAC, 15 Amps		McMaster-Carr	McMaster 7072K104	3.70	2	7.40
DB25 Parallel Male/Dual Female Y-Splitter Printer Cable		CablesOnline.com	CablesOnline YS-005	12.99	1	12.99
DB-25 - Female / Female Gender Changer		CablesOnline.com	CablesOnline GC-008	2.99	1	2.99
DB-25 – Male/Male Gender Changer		CablesOnline.com	CablesOnline GC-007	2.99	1	2.99
24 VDC Power Supply	Omron	McMaster-Carr	Omron S8JX-G05024C, McMaster 7010K46	83.48	1	83.48
					INSTRUMENTS TOTAL	5831.75

HARDWARE/FASTENERS

Item	McMaster-Carr P/N	Subtotal	Qty Purchased	Total
Grade 8 Alloy Steel Hex Head Cap Screw, Zinc Yellow Plated, 1/2"-20 Thread, 3-1/2" L, Fully Thread	92620A751	7.70	1 Pack	7.70
Button Head Socket Cap Screw, 1/4"-20 Thread, 1-1/2" Length	91255A546	7.70	1 Pack	7.70
Serrated Belleville Washer, 1/4"/M6 Screw Size, .38" OD, .03" Thick	93501A029	8.50	1 Pack	8.50
Nylon-Insert Hex Locknut, Zinc-Yellow Plated, 5/8"-18 Thread Size	97135A275	4.53	1 Pack	4.53
.032" Thick Washer for 1-3/4" Shaft Diameter, Steel Thrust Needle-Roller Bearing	5909K55	2.06	Qty 2	4.12
Cage Assembly for 1-3/4" Shaft Diameter, 2-1/2" OD, Steel Thrust Needle-Roller Bearing	5909K42	4.45	Qty 1	4.45
.032" Thick Washer for 1-1/8" Shaft Diameter, Steel Thrust Needle-Roller Bearing	5909K51	1.53	Qty 6	9.18
Cage Assembly for 1-1/8" Shaft Diameter, 1-3/4" OD, Steel Thrust Needle-Roller Bearing	5909K37	3.09	Qty 3	9.27
High-Load Steel Ball Bearing Double Sealed, for Shaft Diameter 3/4" X 1-5/8" OD X 1/2" W	2780T63	17.85	Qty 2	35.70
Pillow-Block Linear Bearing, Closed, for 3/8" Shaft Diameter	6255K32	42.02	Qty 1	42.02
Grade 8 Alloy Steel Hex Head Cap Screw, Zinc Yellow Plated, 9/16"-18 Thread, 2" L, Fully Thread	92620A782	13.30	1 Pack	13.30
Serrated Belleville Washer, 9/16"/M14 Screw Size	93501A034	12.00	1 Pack	12.00
Socket Head Cap Screw, 10-32 Thread, 1/2" Length	91251A342	11.34	1 Pack	11.34
Socket Head Cap Screw, 1/4"-28 Thread, 1" Length	91251A442	10.82	1 Pack	10.82
Serrated Belleville Washer, No. 10	93501A027	8.00	1 Pack	8.00

Serrated Belleville Washer, 1/2"	93501A033	11.56	1 Pack	11.56
Grade 8 Steel Flat Washer, SAE, 9/16"	98023A034	7.05	1 Pack	7.05
Grade 8 Steel Hex Nut, 9/16"-18 Thread Size	94895A830	8.15	1 Pack	8.15
Hex Head Cap Screw, Zinc Yellow Plated, 1/2"-13 Thread, 3-1/2" L, Fully Thread	92620A726	3.85	Qty 1	3.85
Socket Head Cap Screw, 10-24 Thread, 1-1/2" Length	91251A251	9.61	1 Pack	9.61
Shaft Collar, Type 303 Stainless Steel, 1/4" Bore	6435K32	3.40	Qty 1	3.40
			HARDWARE TOTAL	**$232.25**

TRAVEL

Travel Date	Destination	Driver	Total Mileage	Mileage Rate	Total Cost
10/4/12	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
2/14/13	Tilton Engineering, Buellton CA	Ryan Bylard	128.0	$0.50/mile	64.00
5/14/13	Tilton Engineering, Buellton CA	Ryan Bylard	128.0	$0.50/mile	64.00
6/6/13	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
6/11/13	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
				TRAVEL TOTAL	**$320.00**

PROJECT TOTAL	**$6384.00**

3.5 - Material, Geometry, and Component Selection

Actuator Selection

The actuator was by far the most thoroughly researched component of this project. Because our test machine required linear motion, it became quickly apparent that we would need to spec and select a linear actuator for our application. Tilton communicated to us that their current clutches require release loads up to about 900 lb, but that they would like to have the ability to test stiffer clutch springs in the future that could require up to 3000 lb of release load. This number gave us a load target for both our frame and our actuator unit. Soon after we began looking at linear actuators that could meet this 3000 lb push force requirement, it became apparent that the actuator would be the most expensive, most complex component in our test machine.

Using the internet as our primary search tool, we began selecting viable actuator options. In addition to a 3000 lb push force, we let the following three attributes drive our actuator selection process:

1. Integration of all necessary components into a single unit

2. Cost

3. Ease of precise position control.

We quickly found that linear actuators come in one of two configurations: electromechanical or hydraulic. Hydraulic actuators use fluid pressurized buy a pump to move their actuator rod, while electromechanical actuators use electric servo motors to create rotary motion, which is converted to linear motion using a threaded-screw interface or similar. Our findings and conclusions on the two different actuator types are as follows:

Hydraulic

In general, hydraulic cylinders are cost-effective and can produce a high level of push force for their size. We found many hydraulic actuators (also called "hydraulic cylinders") capable of our 3000 lbf push force. However, our findings showed that hydraulic actuators, on their own, are relatively "dumb" interfaces: run the hydraulic pump and they extend, turn it off and they retract. To achieve the level of fine position and force accuracy that we require, a hydraulic actuator would require mounting *many* external components: an LVDT for linear position monitoring, a load cell for force measurement, a pump and lines to supply the necessary fluid pressure, a controller to receive signals from the position and force devices and translate them into a hydraulic pump duty cycle, as well as a made-from-scratch closed-loop control program. While there exist such things as "Smart Hydraulic Cylinders", these simply contain an internally-mounted LVDT that gives position feedback. There would still be many other components necessary to make such a system work. Hydraulic cylinders also have a high friction rod seal that causes stiction, causing noise in force/displacement plot data.

Electromechanical

Compared to hydraulic actuators, electric actuators are generally much more expensive. When compared to a similar hydraulic unit, electric units deliver significantly less push force per dollar. While we were able to find a handful of electric actuators that met our force requirement, choices were few and far between. When exploring a company's electric actuator options, we usually had to look to their biggest, most expensive models to reach our 3000 lb push force requirement. It became apparent that going with an electric actuator would cost between $4000 and $5000, over half of our budget ceiling.

However, what electric actuators give up in cost and push force, they make up for with high levels of positioning precision, nearly plug-and-play integration, cleanliness and low levels of maintenance. Because their seals only serve to keep dust and debris *out* of the actuator and don't have to keep hydraulic fluid *in*, they are far less prone to friction/stiction. Also, because they require no fluids whatsoever, they are clean and require little to no maintenance.

The electric actuators we found used one of two methods to convert rotary motion to linear: ball screw, or roller screw.

After considering all of the above factors, we found three actuators that fit our criteria.

1. Exlar Tritex T2M X090 - $4610. This electric actuator uses a roller screw. Of the three actuators we considered, this one is the most compete and integrated solution. It's also the most expensive. It comes with the actuator, motor, digital position sensor, and servo drive built-in to the unit. These built-in features *may* eliminate the need for external force and position instruments. It comes with programming/control software. The model we chose can exert a peak force of 3175 lbf and a continuous force of 1587 lbf. It runs off either 120 V or 240 V power.

2. Tolomatic IMA44 5mm lead - $4200 This electric actuator uses a ball screw. This actuator is *almost* a fully integrated unit. However, it does not have a built in servo drive, so that is something we'd have to source, spec, and price separately. This unit includes the actuator, motor, and digital positioner built-in to the unit. The model we chose can exert a peak force of 2000 lbf and a continuous force of 1750 lbf. Higher-force units are available, but their prices reach into the $6000 range.

3. Parker EHA Compact Hydraulic HY22-3101D - $500 This actuator is the least expensive option. It's the only hydraulic unit of the three, but the motor/pump is integrated into the actuator, so there will be no hydraulic lines draped off the machine. It runs off DC power, so we'd need to buy a converter to plug it into wall power. It comes as a relatively "dumb" interface, with no provisions for force or position control. To achieve the desired position and force control we want, we would need to externally mount position and force instruments and build a control system from scratch. (We may or may not have to do that with the above two options anyways). This model can exert ~4000 lbf of force. It's base price is far cheaper than the other two, but it will require buying more external equipment to make it work for our application. Even so it will likely end up being the cheapest option of the three (although not the ~$4100 cheaper that the base prices initially suggest).

After reviewing each of these options, we decided that because each one met our requirements, with enough work, we could make any of the three actuators perform the necessary functions. However, it became apparent that the more expensive electric options would be far easier to program and set up. With this, we presented Tilton engineering with our findings and asked which unit they preferred, given the above advantages/disadvantages. Tilton expressed their favor for the Exlar unit, provided it fit our budget constraints.

After communicating with Tilton and each of the three actuator suppliers, we ended up going with the Exlar unit for the following reasons:

- Their customer support and communication was excellent. They were very good about answering our calls and emails. Tilton felt this level of support would prove advantageous should the actuator need servicing in the future.

- The Tritex unit has an internal position sensor that is accurate to +/- 0.002" inch. We can use this for both programming and data output purposes, eliminating the need for an externally mounted LVDT.

- The Tritex unit was very nearly a fully-integrated, plug-and-play option. It contains the actuator, motor, servo drive, and controller all in one self-contained unit, eliminating the need to spec and program other components.

We felt that the above factors made the Exlar actuator the unit that was best suited for our application and would give us the best chance of fulfilling Tilton's expectations and finishing the project on time.

Load Cell Selection

The load cell selection process occurred after we decided on using the Exlar actuator unit. Although the Exlar unit has built in force-sensing capability, it derives push force mathematically by monitoring motor torque output. According to Exlar representatives, this method of force sensing

is only accurate to +/- 10% of overall force output. For a 1000 lb-force clutch, this equates to an error of +/- 100 pounds - not accurate enough for our purposes. Due to our need for very accurate force output, we anticipated the need to mount an external load cell to any one of the actuator units we would have chosen.

We researched the different types of load cells available, considering the force values we anticipated seeing (up to 3000 lbf) and the load direction (compression only). Button load cells are designed for this exact purpose, and their small size made them easy to integrate into our design. However, although our load cell needed only to measure compression, it also did need to act in slight tension when the machine was not operating to keep the bearing holder from falling off. It was for this reason that we looked into "threaded rod load cells" which contain a threaded screw protruding from both their top and bottom surfaces. These threaded screws allow the load cell to be loaded in tension *or* compression. We found that we could order our Exlar actuator with a 1/2-20 female threaded rod end, so we narrowed our load cell search to threaded rod load cells that had 1/2-20 threaded rods and could take up to 3000 lb in compression. We ended up finding two:

Futek LCM 350 FSH00673 $525

Omega LCM202-20KN $570

Both these load cells were very similar in price and features. The Omega load cell was slightly more expensive, and had a 2-week lead time as opposed to the Futek which was available immediately. Also, our sponsor expressed that he had used Futek load cells in the past, and found their performance and customer service to be exceptional. It was for these reasons that we decided to go with the Futek load cell.

Latch

We felt it was necessary to include a latch in our mechanism to preload the frame and take any slop or play out of the system before running the actuation cycle. Very early in the project our sponsor expressed his past experience with Protex latches. Upon looking through Protex's latch options, we

found that a "draw action toggle clamp" was the type of latch most suitable for our application, due to its vertical mounting capability, large ergonomic handle and draw force capability. From there, packaging was the biggest challenge in our latch selection process: most of the latches Protex offered were much too large to mount to our 1.75" by 1.75" inch square bar. However, we found the Protex TLH-UBAB-041-080-MS latch met our packaging requirements.

Left Square Vertical Post

We decided to design this piece to be a solid piece of steel bar. We chose steel over other metals due to its low cost, high stiffness, resistance to fatigue loading, and widespread availability. We decided to use a solid steel bar instead of a tube or box structure due to the complex latch catch geometry that needed to be machined into the top end. Because weight is not much of a concern for the vertical posts, solid steel bar was the obvious choice. When deciding on an alloy, we let strength, cost, machinability, and availability drive our selection. We looked primarily at online suppliers McMaster-Carr and OnlineMetals, and found that they offered three different steels in the size stock we were looking for -

Option 1: Low-Carbon Steel
Option 2: 1045 Steel
Option 3: 4140 Steel

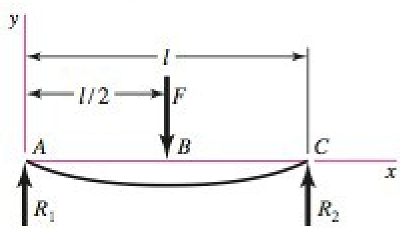
Between these three options, we first eliminated low-carbon steel because it had the lowest yield strength (50,000 psi). Although low-carbon steel exceeded our stress requirements in simple beam tension, other parts of the beam - such as the threads in the bottom for the bolt, and the latch interface machined in the top - would see much higher localized stresses. (See attached calculations for greater detail). While low-carbon steel *still* met our strength requirements for these higher-stress areas, its factor of safety was significantly lower that of other two. Given the fact that we had not yet finalized the latch catch geometry (and our final design might have greater stress than the currently calculated value), and the fact that the stronger steels were so similar in price to low- carbon, we decided to eliminate low-carbon steel as an option.

Between 1045 and 4140, the decision came down to price and past experience. The modulus, yield, ultimate, and stiffness values for the two are extremely similar. Our team members have considerable experience machining 4140 steel. Given these factors, combined with the fact that it was cheaper, we decided to choose 4140 steel for our left post.

Horizontal Crossbar

Once again, we decided to design this piece out of a piece of solid steel plate. It acts as a latch interface with a cutout that mates with the square vertical post, it acts as a mounting plate for the actuator unit, it captures a bearing for interfacing with the round vertical post. During actuator cycling, it acts like a simply supported beam in bending with a point center load.

5 Simple supports—center load



$$y_{max} = -\frac{Fl^3}{48EI}$$

Using the beam deflection formula to find ymax coupled with an "average" modulus for steel (29E6 psi), we found that the beam would have a deflection of 0.029" under 3000 lb load (our max design load), and 0.009" under a 950 lb load (Tilton's current highest release load). Assuming a 0.375" total overall spring travel, the machine deflection due to beam bending will be 7.7% of total spring travel under the 3000 lbf load, and 2.45% under the 950 lbf load. This configuration allows Tilton to run up to 1940 lbf while still staying under our deflection target of 5% of total loaded travel. In reality, the actual beam deflection should be *less* than we specify here, because the Tritex actuator unit has a thick front flange mounting plate that will bolt to the horizontal crossbar and add significantly to the I-value of the beam at its center.

Another major constrain for this horizontal crossbar is the mounting plate for the actuator. The Exlar unit uses a front flange mount that is 3.54 inches wide; therefore the horizontal crossbar must

be 3.54 inches as well. A 3.54 inch mounting plate accommodates the bolt hole pattern (2.36" center-to-center), and also prevents any of the corners/edges of the Tritex mounting plate from hanging off the horizontal crossbar. The Exlar actuator unit mounting plate bolts to the top of the crossbar - mounting it to the bottom would require cutting a much larger opening in the beam, and dismantling the actuator unit before mounting it. The Exlar unit fastens to the steel crossbar with four 5/8” bolts.

We went about material selection for the crossbar in much the same way as we did for the square vertical post. As before, high stiffness and the ability to machine in complex geometry were very important, so solid steel was chosen again. We needed a stock size that was 3.54 inches wide to accommodate the mounting plate for the Exlar actuator, and thick enough to resist a 3000 lb center load with minimal deflection. After looking at packaging constraints and beam deflection calculations, we concluded that a 3/4" thick by 3.54" wide steel plate would work best, accommodating all the features we would need to machine while being thick enough to resist the applied load with minimal deflection.

Angled Support Bar

The angled support bar is constructed of the same 4140 steel bar used for the horizontal crossbar. It is constructed from two separate pieces: one is attached to the circular vertical post and holds a captured bearing, the other is an angled piece that connects to the horizontal support bar. The support bar-to bearing holder interface will be welded, the support bar to horizontal crossbar will be a bolted joint that threads into blind tapped holes in the crossbar.

Bearings

There are two different bearings being used in the final assembly. The first bearing we chose is a heavy load-double sealed steel ball bearing. This bearing was selected to assist in the rotary motion of the horizontal cross member about the rigid support. Steel ball bearings give allow for very smooth rotation and can be press-fit onto a shaft and into a hole. The other bearing we selected is

thrust bearing that can take up to 3800 lb of axial loading. The trust bearings are a key component in the design of the collar system. Without these bearings there would be metal to metal contact between the collar system and horizontal cross members. This portion of the machine may have up to 1500 lb of axial load. The thrust bearings are designed for this loading case; this is specifically why we chose them.

Vertical Circular Post/Collar System

The vertical circular post and collar system serve two of the machine's main functions. We decided early on that whatever we placed above the CT 2000 would need to be capable of moving away from the device so that the operator would be able to interchange clutches with ease. The circular post enables the horizontal cross member to swing out and away from the operator. Unfortunately in order to get smooth rotary action we needed to use a bearing interface. Smooth action ball bearings do not allow for the kind of loads that we would see on the assembly. In order to take the loads off the bearing we designed a collar support system. The collar system encompasses the rigid shaft and bearings so that any load transferred from the horizontal cross member will be transferred to the outer collars, not the bearings themselves.

3.6 - Flow Chart, Schematics, Pseudo Code, Wiring Diagrams

Our actuator is the Tritex T2M90 which is an AC electric linear actuator that has 3,000 lbs of push force. It has 8 digital inputs that allow us to control its motions with limit switches and the existing load cell on the CT2000. It uses a proprietary software program to interface with the computer that give us the ability to take data and create the move profile that starts and stops with minimal operator input. This can be seen in Figure 3.1. The basic move program starts when the operator pushes momentary move 1 on the program. This tells the actuator to move down until it senses load by using a measurement of current in the actuator. Once this current limit is reached, the actuator backs up until it is 0.004" off the top of the clutch. It is now ready to start the measurement cycle. The operator pushes move 2 to begin this cycle. The actuator then moves down at 0.01" per second while taking displacement measurements every 0.039 seconds. This data cycle starts when it senses load for the second time. The actuator continues to move down until it senses zero load on the CT2000 load cell. This means that the clutch is fully released. This data comes from a comparator that takes the analog load cell voltage and compares it to the released state voltage. This level has been preprogrammed into the comparator. Once it determines that there is no load, its output changes from 0 to 12 volts. This is the signal that tells the actuator to stop moving down so it won't damage the clutch. The operator then pushes move 0 to move the actuator to its home position and the data is saved to a CSV Excel file.

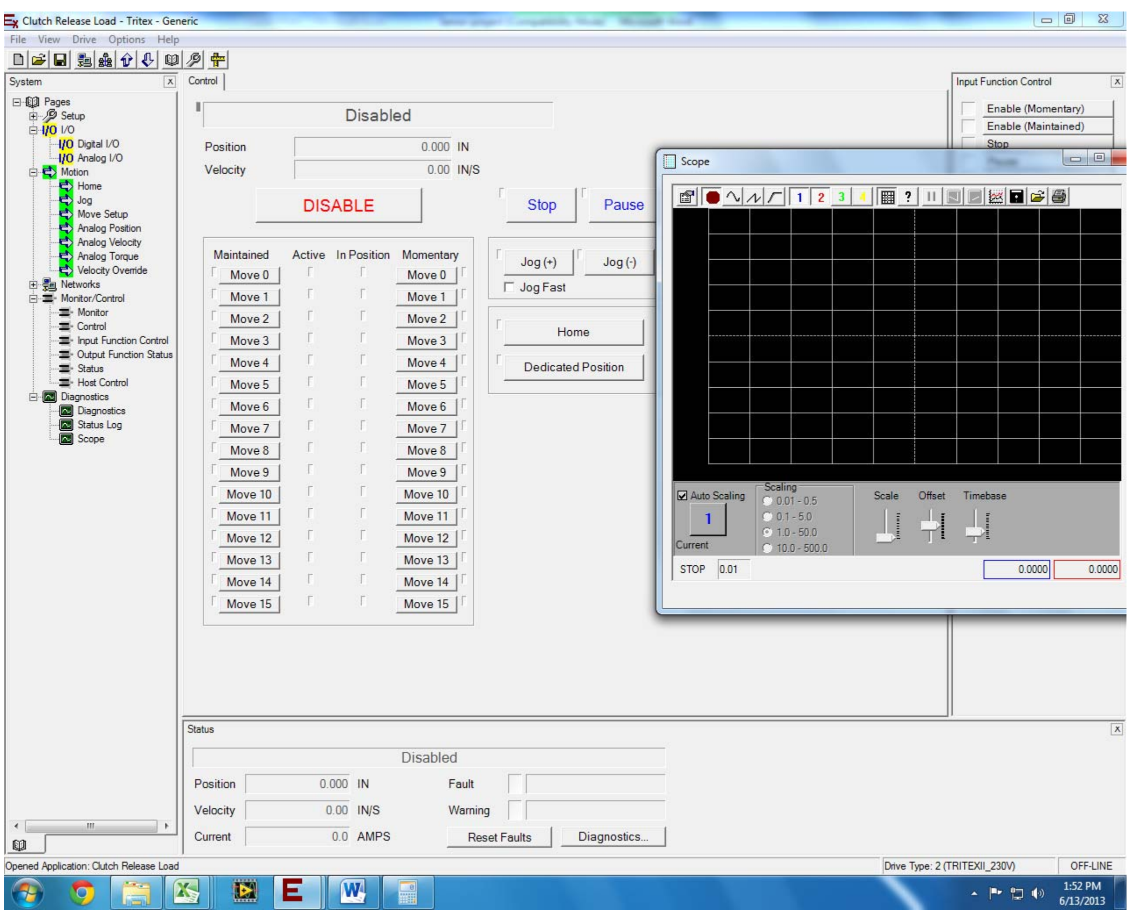


Figure 3.1 Actuator control page

Digital Inputs

Our actuator has 4 digital inputs that control its motion and prevent it from breaking clutches or hurting people. These inputs are: CT2000 load cell which is turned into a digital signal by a comparator, an emergency stop button, a proximity sensor that determines if the gate is closed, and touch pad that defines the home condition for the actuator.

CT2000 Load Cell

This load cell is underneath the clutch and measures the clamp force in the clutch plates. The amplified signal is tapped and put into a comparator which compares the analog voltage to a predetermined voltage that represents the load cell output when the clutch is released. When the load cell voltage is determined to be equal or lower than the predetermined value, the comparator switches its output from approximately 100 mV to 12 volts. This is read by the actuator as "on" and it stops its actuation. Without this digital input, the actuator would have to be told what clutch is being tested and the travel length to release it. Using this input however, we can automate the process and no information about the clutch is necessary. This is extremely helpful and simplifies the process of taking data because every model of clutch can be measured with the same program.

Emergency Stop

This is necessary because OSHA requires that every piece of equipment have a button that can immediately stop the machine in case of an emergency or an injury. Our E-Stop button is a digital input that outputs a constant 24 V to the actuator until it is pressed. It then stops sending the 24 V and the actuator responds by rapidly stopping and returning to the home position. It then cannot be moved until the E-Stop button is twisted to release it. Once released the actuator will not continue its previous movement but instead will wait for a new command.

Proximity Sensor

The proximity sensor is a magnetic material sensor that is designed to determine if the gate is closed. It is mounted to the gate near the latch end and will only output 24 volts if the sensor is touching vertical post with the latch on it. Theoretically, this will not sense if the gate is actually locked, however, the sensor must be touching metal to send a

signal to the actuator and if the actuator is moving, the gate will swing open slightly if not latched. This cuts off the sensor signal and the actuator responds by stopping at its current position until the gate is closed again. This insures that the gate will always be locked when the actuator has load on it, preventing it from bending the fixture or breaking a clutch. The sensor we used is a PNP type magnetic material sensor that is highly accurate and has no moving parts which means that it will not wear out with repeated use.

Touch Pad

The touch pad is used to define where the actuator calls "home." Home is the zero point for all measurements. This is necessary because our thick top plate does not allow the piston to ever fully retreat into the actuator housing; therefore we must define a zero value that is approximately 0.5" out. By using a touch pad, we can tell the actuator to move up until it receives 24 V from the touch pad meaning that it has reached its highest allowable point. This takes all the guess work out of homing the actuator and gives very accurate results without risking that the actuator rod will pull the load cell into the top cross beam which would possibly damage the load cell.

Comparator

This circuit was designed out of necessity. We had originally planned to program different moves for every series of clutch, however, this would have violated one of our design requirements which was to have a simple system that took a minimum amount of operator input and time between tests. The comparator allows us to automate the measurement process by having the actuator stop when the load reads zero. Since zero load is the same value for all clutches, the circuit compares the voltage output from the CT2000 to a calibrated measurement of voltage when the clutch is released using a potentiometer. When the two voltage values are equal, the circuit switches on, telling the actuator that it has released the clutch and to stop moving. This prevents over-actuation and possible damage to the clutch being tested as well as simplifying the actuator programming by allowing a single program to run all the clutches. This circuit can be seen below in Figure 3.2 and 3.3.

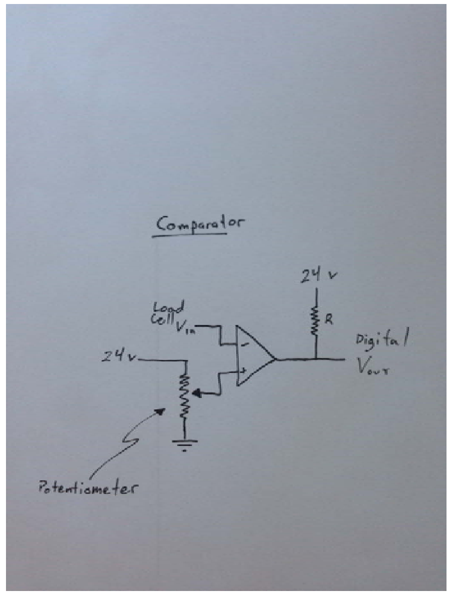


Figure 3.2 Comparator circuit schematic

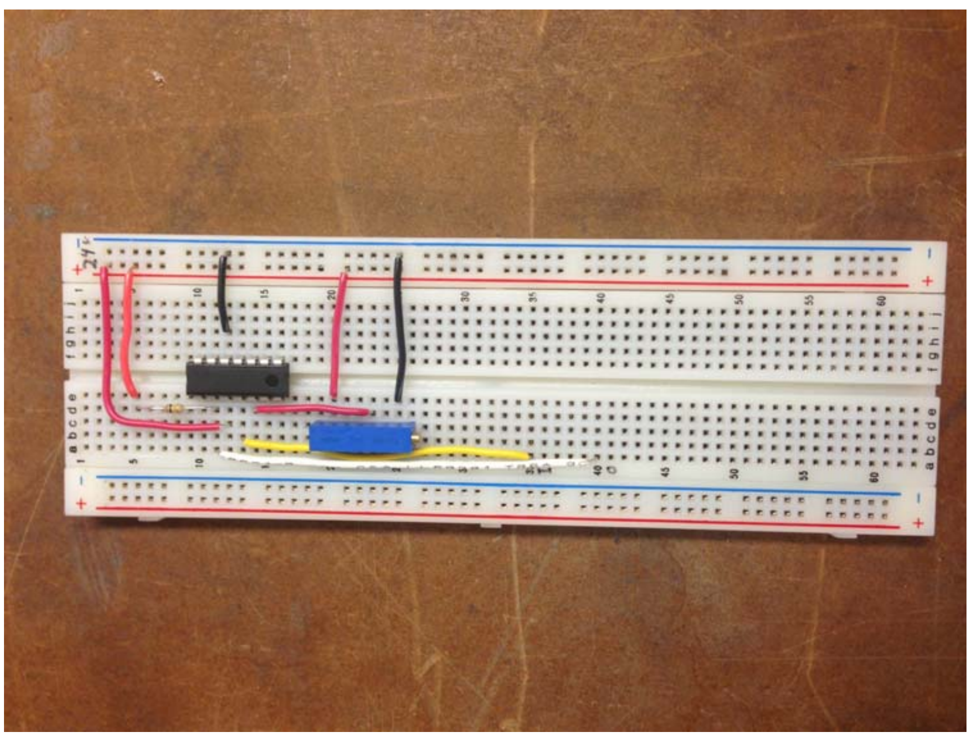


Figure 3.3 Picture of comparator

Load Cell

Our load cell is a Futek LCM350 which has a range of 4000 lbs in both tension and compression. For our design, we are only using the compression side, however the tension ability is needed because there is some weight hanging from the load cell and this would possibly throw it out of calibration if it were not designed to allow a tensile load. The load cell is connected to a Futek USB DAQ system that amplifies and digitizes the reading so that the computer can read it. This load cell has a resolution of approximately 0.5 lbs, however this small value is rarely used because our acquisition rate forces the resolution to about 15 lbs. This gives an error of approximately 1.8% which is more than acceptable, because the data points are plotted with a smooth line connection which adequately represents the clutch load vs. displacement.

DAQ System

Our data acquisition system uses LabVIEW to take the data from the Futek DAQ and move it into an Excel file. One large issue we ran into was that Futek does not make a driver to work with LabVIEW. This meant that there was no way to communicate with the DAQ card. This problem was overcome by reading a string variable from the DAQ and turning that into an array. This was turned into a Dynamic Data Link (DDL) file type which is what LabVIEW can plot, manipulate and eventually turn into an Excel file to be plotted with the position data from the actuator. The LabVIEW block diagram can be seen in Figure 3.4 and the front panel can be seen in Figure 3.5. Once in the DDL format, the reading is calibrated to read -0.7 lbs. This is the total weight of the throw-out bearing which hangs from underneath the load cell. Another feature we programmed in was an automatic start to data acquisition. This occurs when the load reaches 0.0. This signals LabVIEW that the actuator has touched the clutch springs and that it is time to start measuring the release load. This further simplifies the program for the operator by getting rid of another button to press. Once the actuator stops, the operator presses the stop button and LabVIEW automatically saves the data to a CSV file which can be opened in Excel and the data plotted against displacement. One issue that has changed the way we take data is the fact that the DAQ cannot be told what speed to take data. It takes it at .39 seconds per sample which is much slower than we had hoped. Since this cannot be changed using LabVIEW, we had to change the sample rate of the actuator to be exactly 10 time faster. Once in Excel, every 10 samples are averaged and this smaller data set perfectly lines up with the force data from the load cell. This means that the data must be taken slowly so that we don't get any aliasing, however, the total measurement time is 27 seconds which is still inside the range of our design requirements.

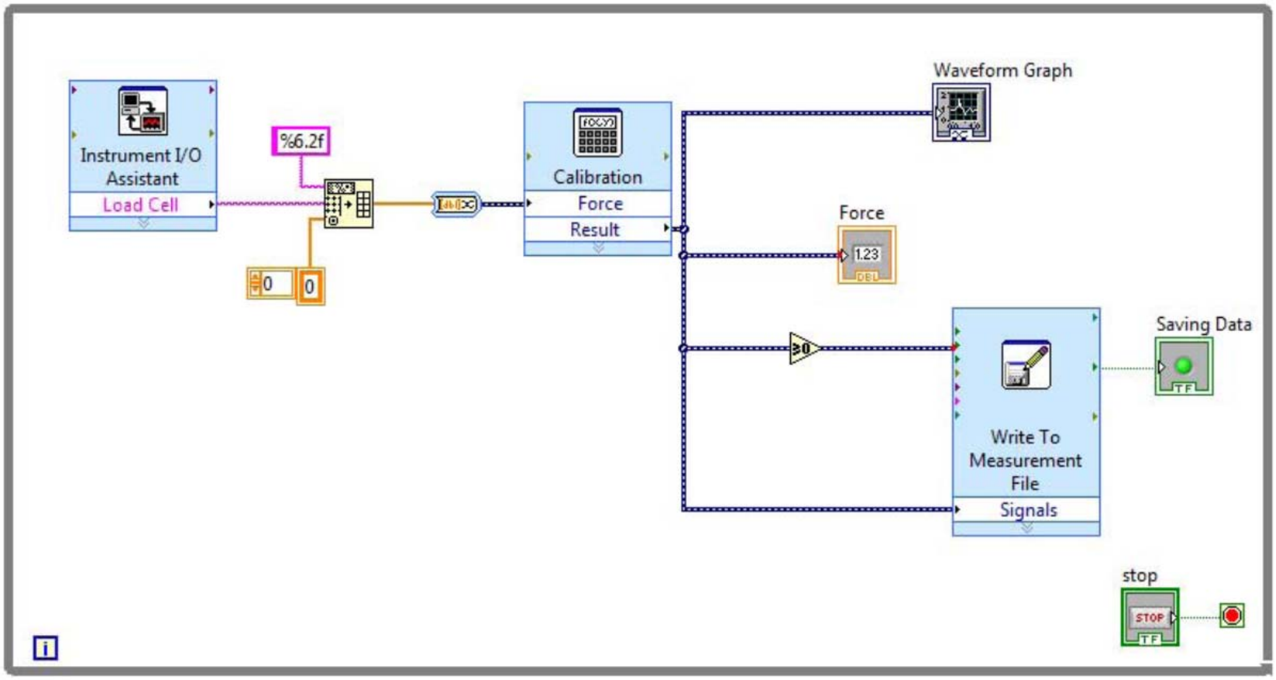


Figure 3.4 LabVIEW block diagram

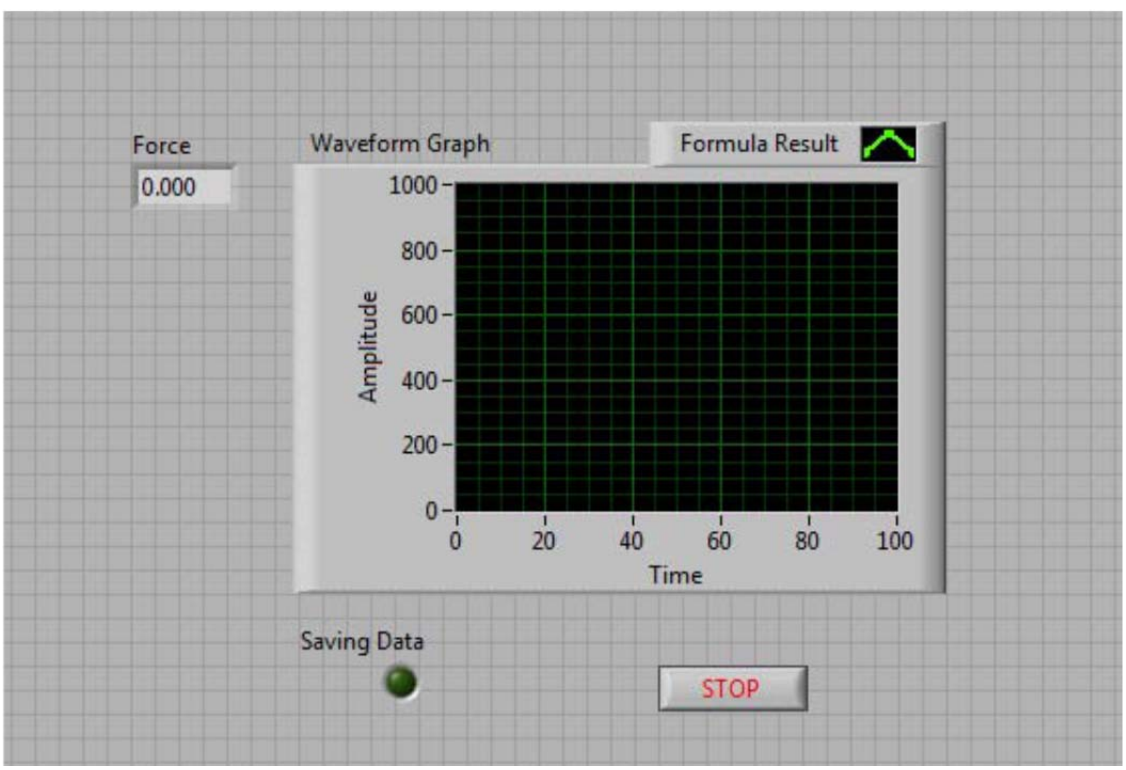


Figure 3.5 LabVIEW front panel

Excel Plotting

We are taking data with two separate programs and using Microsoft Excel to combine the data and plot the results. Once the measurement cycle has been completed, the operator must open both CSV files in Excel and copy the load and displacement data into the "Clutch Plots" Excel file. This file automatically reduces the displacement data by a factor of 10 and then turns absolute actuator displacement into clutch displacement. This is then plotted against the load data and a graph showing clamp load vs. displacement is automatically produced. This program can be seen pre-data addition in Figure 3.6 and post-data addition in Figure 3.7 where the blue force column is where the force data is copied, the green displacement column is where the displacement data is copied and the formatted chart is displayed on the right. All cells are locked except the colored tab columns and the chart. This is to prevent accidental changes to the program. This Excel program is a necessary complication to an otherwise automated program. The reason for this extra step is that the displacement data cannot be read by LabVIEW and therefore we must combine load and displacement data in another program. One fix to this issue would be to have an LVDT take the displacement data and add that, and the load cell data into LabVIEW using a National Instruments DAQ module. This would allow us to take much faster measurements with the same accuracy and plot them together in LabVIEW, eliminating the need for Excel altogether. However, to lower cost we decided to use the internal position data from the Tritex linear actuator which meant that we needed two programs to take data, and a third to combine it and analyze it.

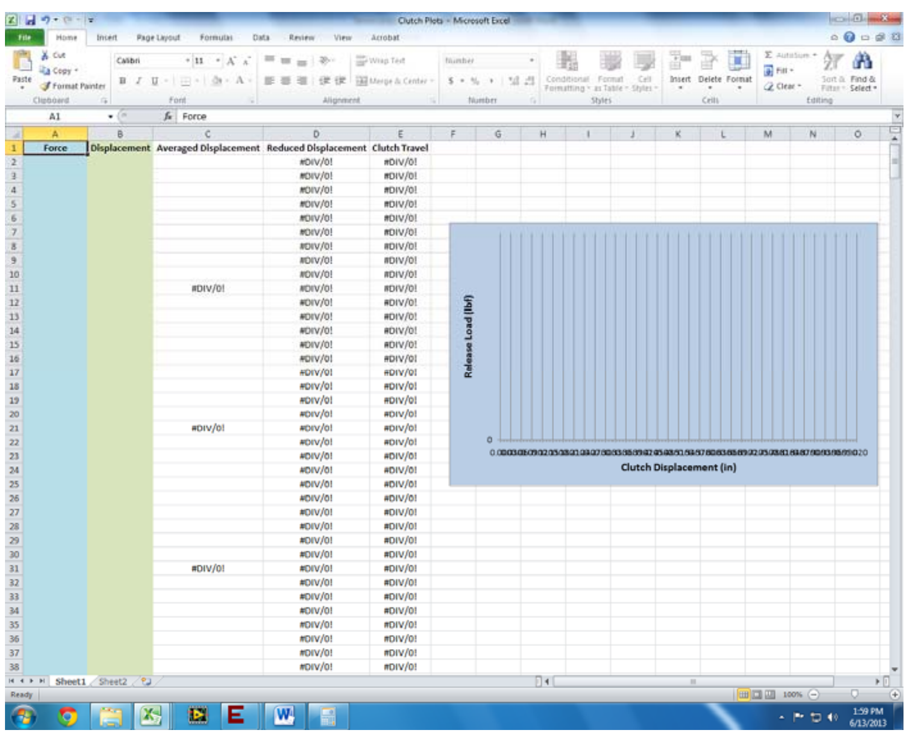


Figure 3.6 Pre-data addition Excel program

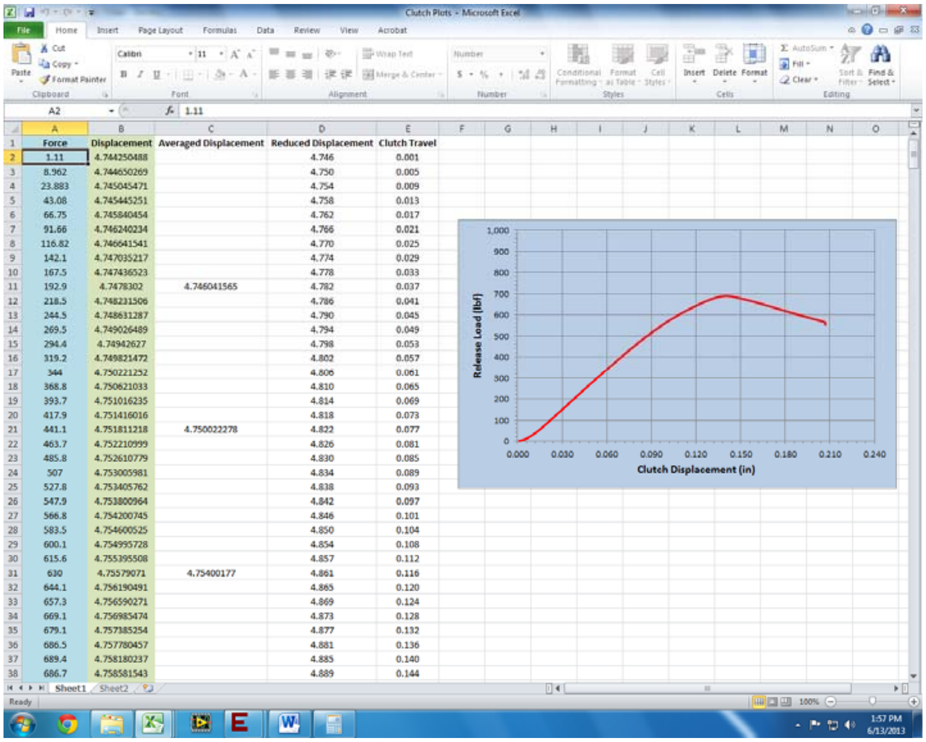
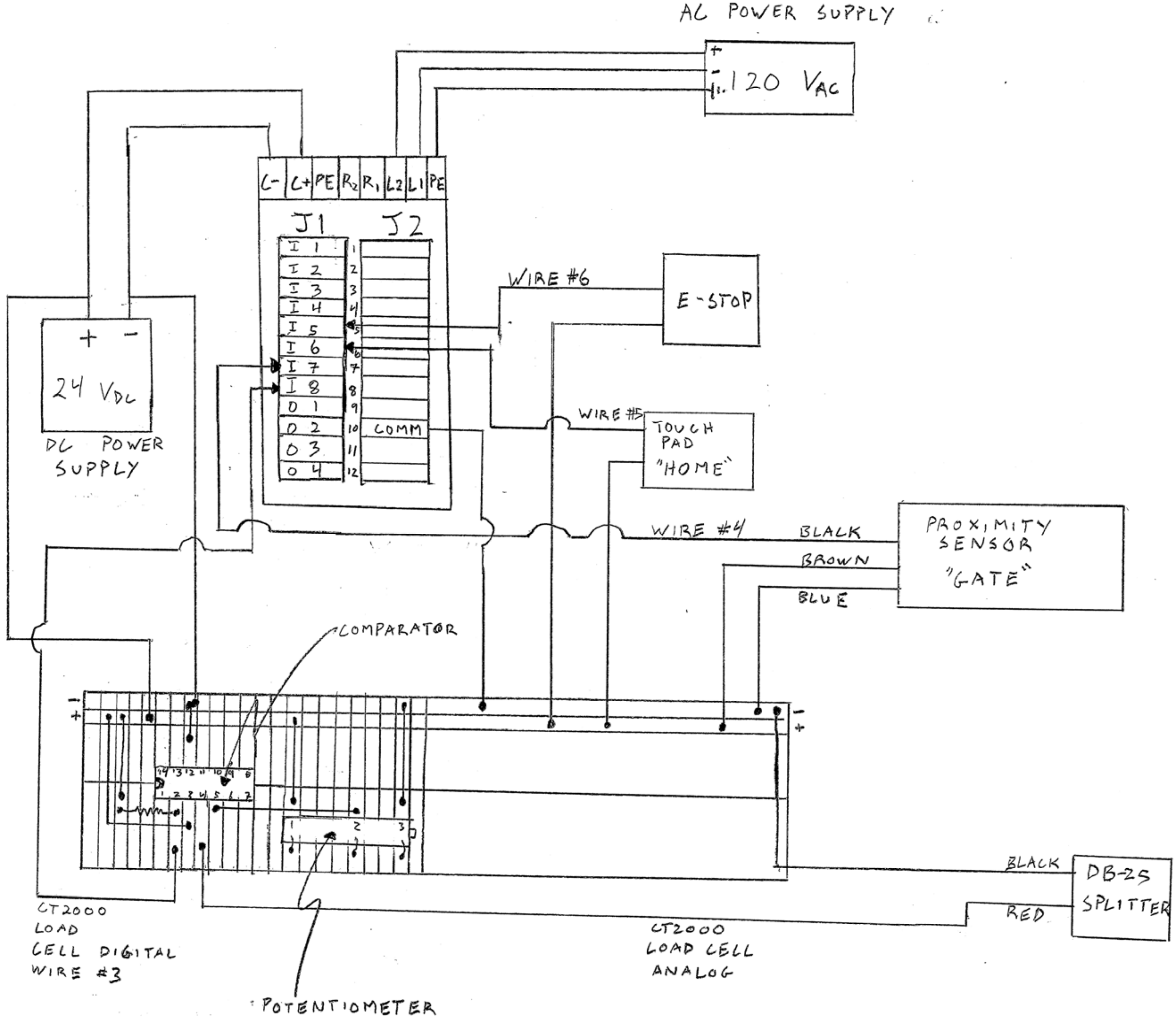


Figure 3.7 Post-data addition Excel program

WIRING DIAGRAM



3.7 Maintenance/Repair Considerations

We have designed and spec'd our load testing machine to be easily maintained and serviced in the unlikely event of component failure. The bearings will be friction-fit onto their shaft and can be removed relatively easily if need be. All other components are easily accessed and removable for maintenance or replacement.

The Tritex linear actuator does not have a preloaded follower which allows it to be serviced in house when the time comes to grease the planetary gear screws. This means it can be serviced on-site by an Exlar repair technician, or by Tilton. From the Exlar website:

"Products are warranted for two years from date of manufacture as determined by the serial number on the product label."

Although the Futek load cell does not specify a calibration interval, it is possible that after years of use it will need to be re-calibrated. According to Futek's website,

"We offer full system calibration for sensors with displays and/or amplifiers and use calibration procedures that are in compliance with A2LA standards. Our Full Services includes:

- *- Calibration of FUTEK Sensors as well as other brands through extensive qualification, verification, & validation of sensors, materials, and fasteners.*
- *- Full NIST Traceable calibration services of load cells and torque sensors with precision dead weigh calibration capabilities ranging from 1mg to 10K lb. We also perform hydraulic calibration up to 2 million lbs.*
- *- System Calibration*

We also offer Field Calibration Services where we come to you."

We plan to include replacement bearings upon delivery of the device to Tilton, as well as any other components we deem normal-wear items. No other maintenance should be necessary.

Chapter 4 - Manufacturing

4.1 Manufacturing Considerations and Processes

Manufacturing of the 13 major components used in the device was split between Tilton Engineering's facility in Buellton, the Cal Poly Senior Project Lab in San Luis Obispo, and an outside machine shop contracted by Tilton. Below is the breakdown of what was machined and where.

Tilton Engineering – Horizontal crossmember, lower pivot plate

Cal Poly ME SPL - Angled support piece, anti-rotate arm

Contracted Machine Shop – Circular vertical post, support block, latch block, piston load cell adapter, vertical pivot post, collar cap, collar adapters (qty 2), middle collar.

Machining was split due to time constraints. Although all of the above parts could have conceivably been machined by any of these three shops, machine and operator availability made it necessary to split machining as shown.

When considering our design requirements and Tilton's needs, it quickly became apparent that a high level of part accuracy with very high tolerances would be necessary. Precise locating and low deflection were critical in achieving accurate outputs from our measurement instruments. This made CNC machining the obvious choice for manufacturing almost all of our components.

3-Axis CNC: Horizontal crossmember, lower pivot plate, angled support piece (difficult, used angled vise), anti-rotate arm, support block, latch block

CNC Lathe: Circular vertical post (finished on mill), vertical pivot post, middle collar

Unknown (could have been made on CNC Lathe or mill): Piston load cell adapter, collar cap, collar adapter.

4.2: Recommendations for Future MFG or Replacement Parts

Should a replacement part need to me made, any of the above parts could be machined relatively easily by any competent machine shop. See Appendix B for final part drawings, or refer to electronic CAD files to generate CNC code.

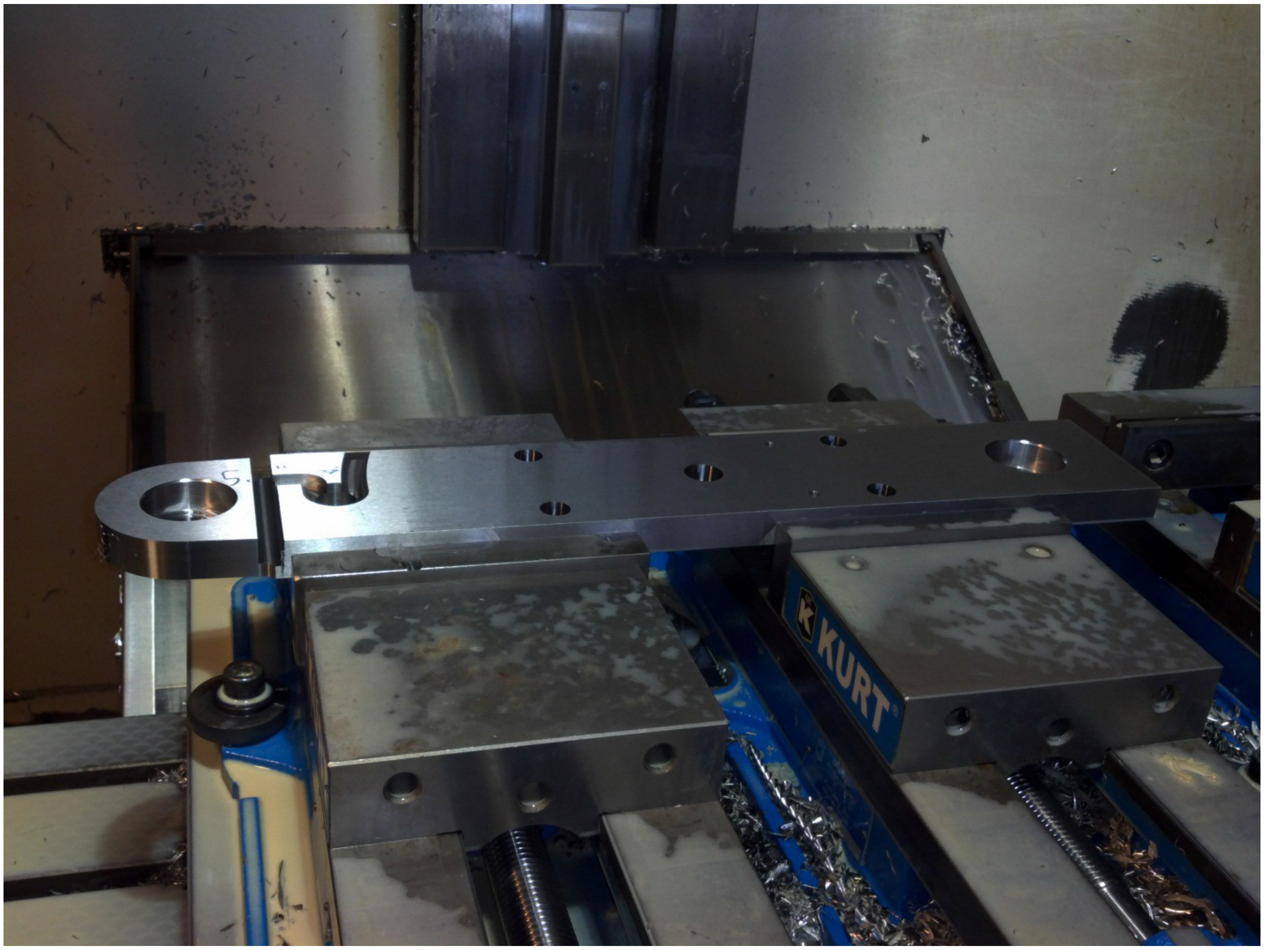


Figure 4.1. Horizontal crossbar being machined at Tilton.

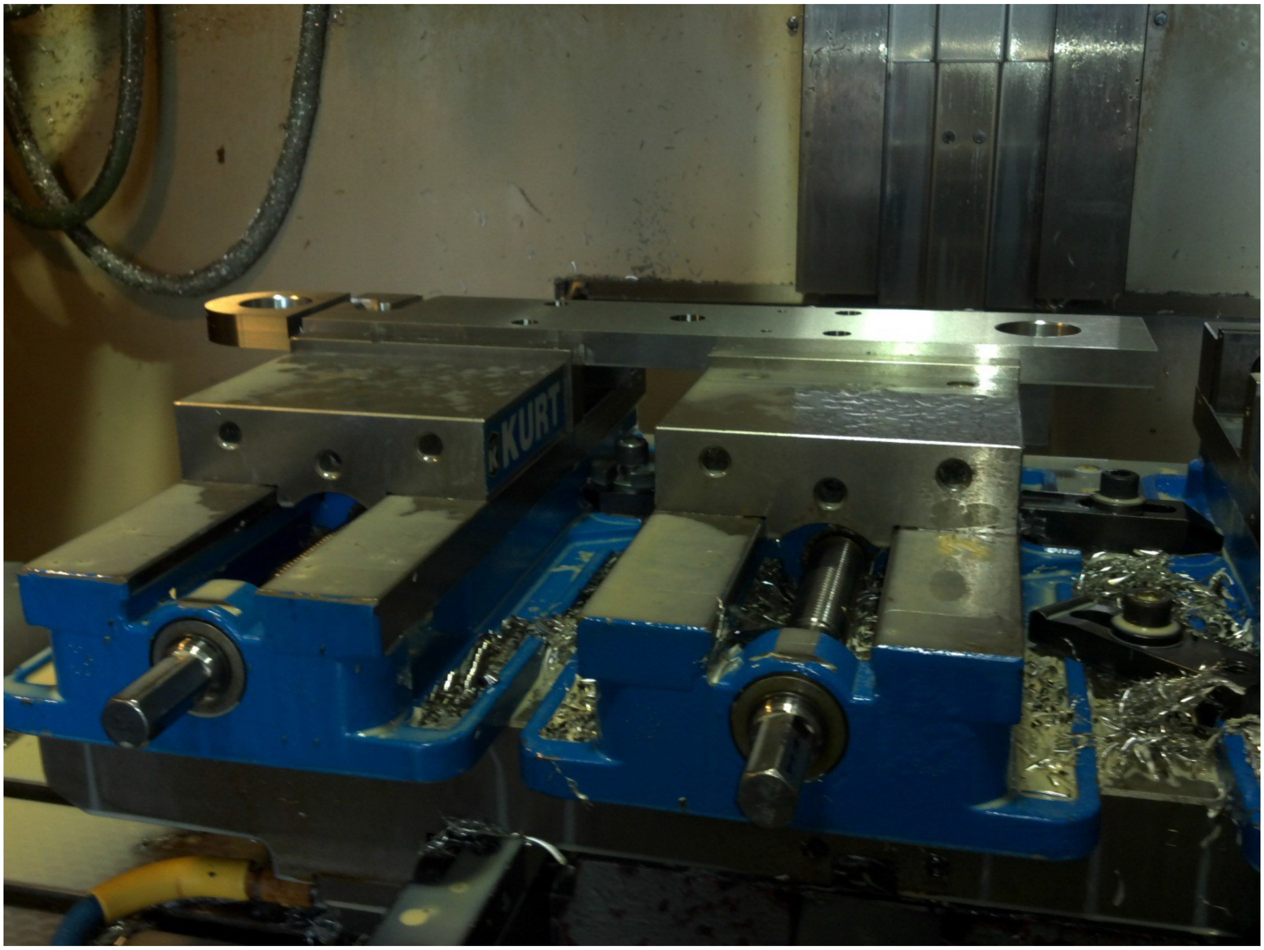


Figure 4.2. Horizontal crossbar being machined at Tilton.

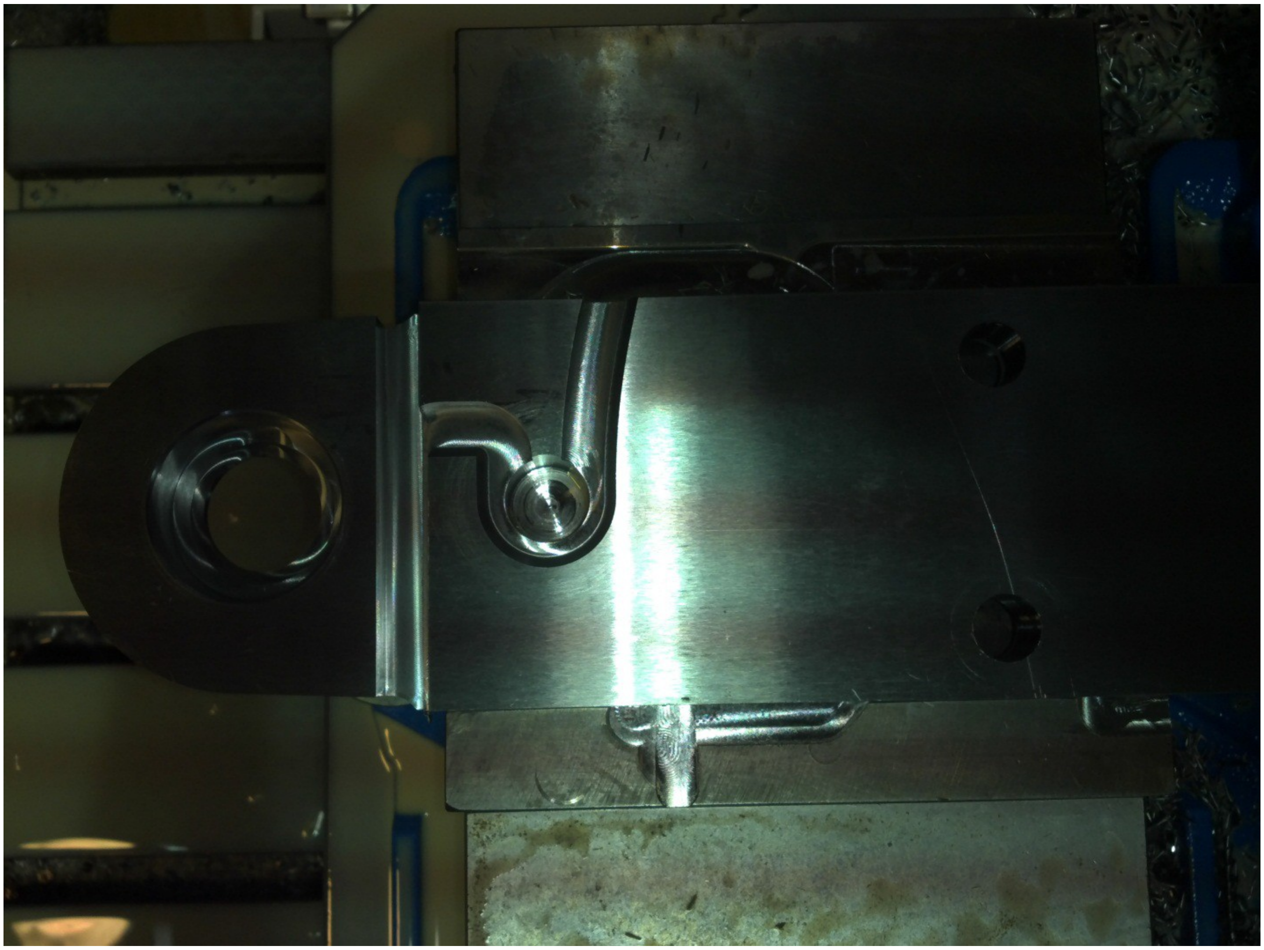


Figure 4.3. Horizontal Crossbar being machined at Tilton Engineering.

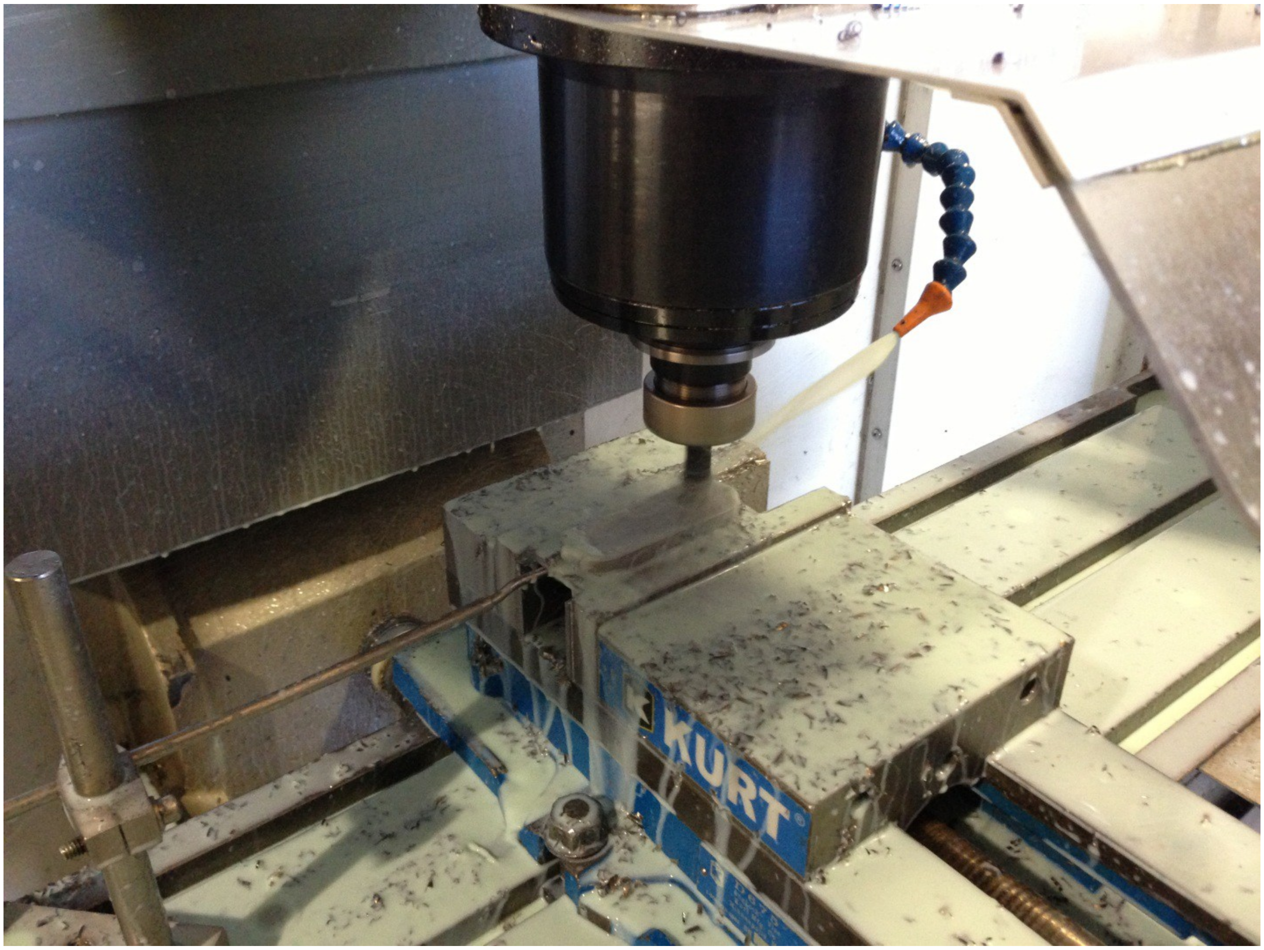


Figure 4.4. Anti-rotate arm on 3-Axis CNC at Cal Poly ME SPL

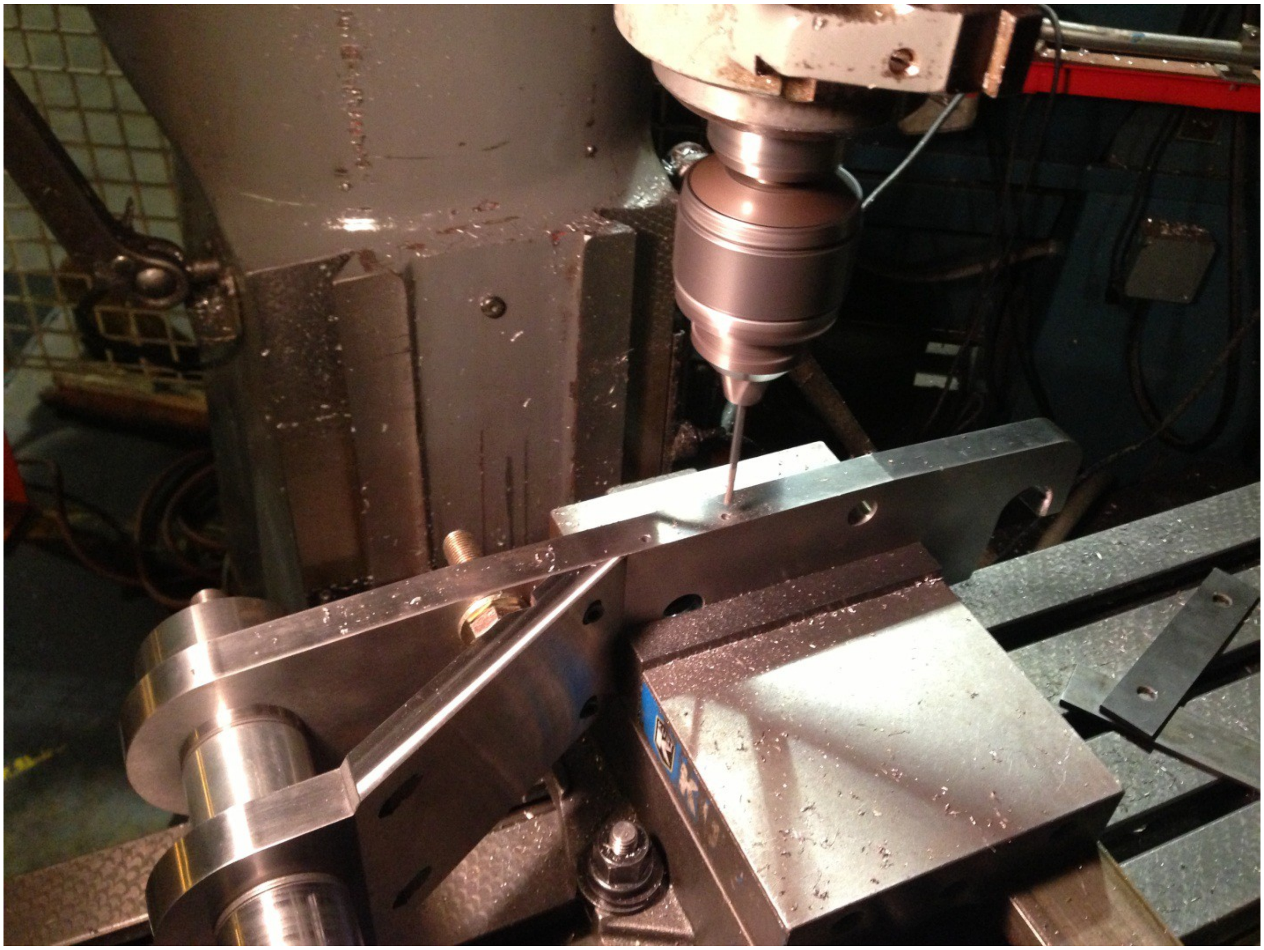


Figure 4.5. Drilling horizontal crossbar for tapped holes on a manual mill at Cal Poly ME SPL.

5.1 - Clutch Release Load Tester Test Procedures:

Background

The Clutch Release Load Tester will be used for product development for rebuilt and new clutches. The clutch will be mounted to the CT2000 test machine. The CRL3000 test machine will then load the clutch until the clutch has been fully released. A linear actuator loads the clutch from above. During this process the machine frame is put in a state of tension.

Purpose

The purpose of the test is to determine if the total displacement of the frame under load is within the predetermined appropriate limit of 5% of total clutch travel. Clutch travel is defined as the amount of travel from when the clutch springs are first contacted to when the clutch is fully released.

Procedure

Over all deflection will be measured using a of dial gauge. The dial gauge should be located on the test fixture and frame according to the Dial Gauge Procedures attached.

Tests will be preformed using the Instron testing Machine in 192-135. Instron Tensile Test Procedure written by Professor Mello, with minor changes for running the test without an extensometer will be used to run the test, and is cited.

Instron Tensile Test Procedure

This procedure outlines the steps for testing materials and small structures using the Instron servo-hydraulic load frame and associated NI/LabView data acquisition system (DAS).

Note: Instron Manual should be consulted with questions to the load frame and 8500 controllers. The 8500 front panel controls all the test parameters. DAS and labview questions can be answered via the on-line help menus associated with the software.

Instron Set-up

Safety Note: One person should load the specimens and operate the tests. This will preclude starting a test while hands are in the test area.

1. Make sure that the water line to the hydraulic pump is open. It should be cracked open already.
2. Turn on the Instron Controller. (May have to "unlatch" the oil light safety)
3. Using the OUTPUTS button on the front panel make sure the following:

    Load is going out channel A.

    Position is going out B.

Then select each (load, position, and extensometer) and note the data/voltage relationship, e.g. load channel may output 2.0kips/volt. The DAS must have corresponding relationships to convert the voltage into appropriate units. Make sure each channel is in the track mode as well. Make sure extensometer gage length set-up corresponds to the current configuration.

4. Calibrate the load cell. The set-up light is flashing. Press this then CAL, CAL, AUTO, GO. The cell is calibrated when the light stops flashing.
5. Turn on the hydraulic pump. (Note sometimes the circuit breaker may need to be reset. It is near the Autoclave. Get a technician or Instructor to help in this case.)
6. Install on the grips the specimen alignment blocks. These control the alignment off the specimen.
7. Install the specimen by clamping it in the upper grips only by holding it against the alignment tooling. Keep away from the hydraulic jaws during this procedure.
8. Install the extensometer via elastic bands or o-rings. Remove the safety pin and calibrate the extensometer in the same fashion as the load cell.

LabView DAS Setup

9. Double-Click the Labview VI file **2g-ext.vi**. This file acquires load, extensometer, and longitudinal

and transverse strain gages.

10. Check that the voltage relationships correspond with the Instron outputs.

11. Manually balance the strain bridges if input voltages are excessive.

12. Set the strain gage factors and shunt calibrate the gage circuits. You must run the vi by clicking the start arrow to perform this operation. Verify that the extensometer and load values correspond with Instron front panel displays. You may need to press display buttons on front panel to view strain rather than displacement.

13. Note the ASCII data file name and folder or location. This file should be saved after each test.

Run Test

14. Press WAVEFORM corresponding to position control on the Instron front panel. Lower display entries should be: "ramps", "S RAMP", .5in, .001in/sec (i.e. the actuator will move down 0.5 in at a rate of 0.001 in/sec; this waveform works well for composite tests but may be modified as desired.

15. Close the Lower grip. Note the jaw action may result in load on the specimen at this point. The operator can manually, carefully fine adjust the crosshead manually to remove jaw induced tensile or compressive loads.

16. Start the data acquisition process by clicking the start arrow on the labview VI.

17. Press START on the Instron controller to start the test, the lower grip will move down.

18. It is necessary to remove the extensometer prior to specimen failure to avoid possible damage to the extensometer: Press HOLD on the controller at an appropriate strain level to stop the actuator; cut the lower rubber band on the extensometer, reinstall the pin to fix the lower knife edge, and then cut the upper rubber band on the extensometer.

19. Press START to resume the test waveform.20. After failure of the specimen press HOLD.

21. The lower portion of the fractured specimen may be removed by opening the lower grip.

22. End the test by pressing RESET which will move the actuator to its position at the start of the test.

23. Remove the upper portion of the specimen from the upper grip.

System Shut Down

24. The system may be shut down as follows: A) turn off actuator by pressing LOW, then OFF, B) turn off hydraulics, C) turn off controller, D) Exit VI and shutdown the DAS computer.

Dial Gauge Procedures

One Dial Gauge will be used to test the overall deflection of the fixture. The gauge will be placed on the bottom of the right hand support beam using a magnetic base. The gauge itself will rest on the underside of the horizontal cross member. Detailed procedures as follows.

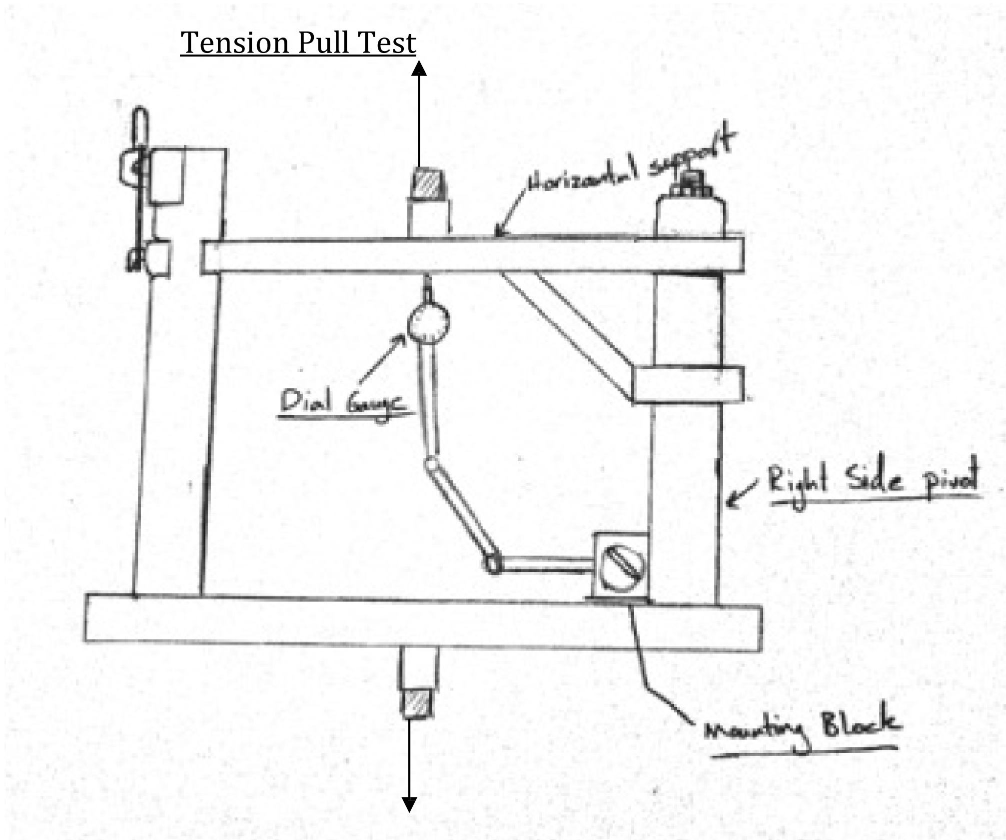


Figure 5.1 Dial Gauge Setup.

Dial Gauge Setup

1. Mount magnetic base to right side pivot as shown in schematic
2. Place Dial Gauge tip on underside of horizontal support member and secure all pivot points
3. Check the gauge is perpendicular to the horizontal cross member
4. Check that gauge point is in center of the beam being measured.

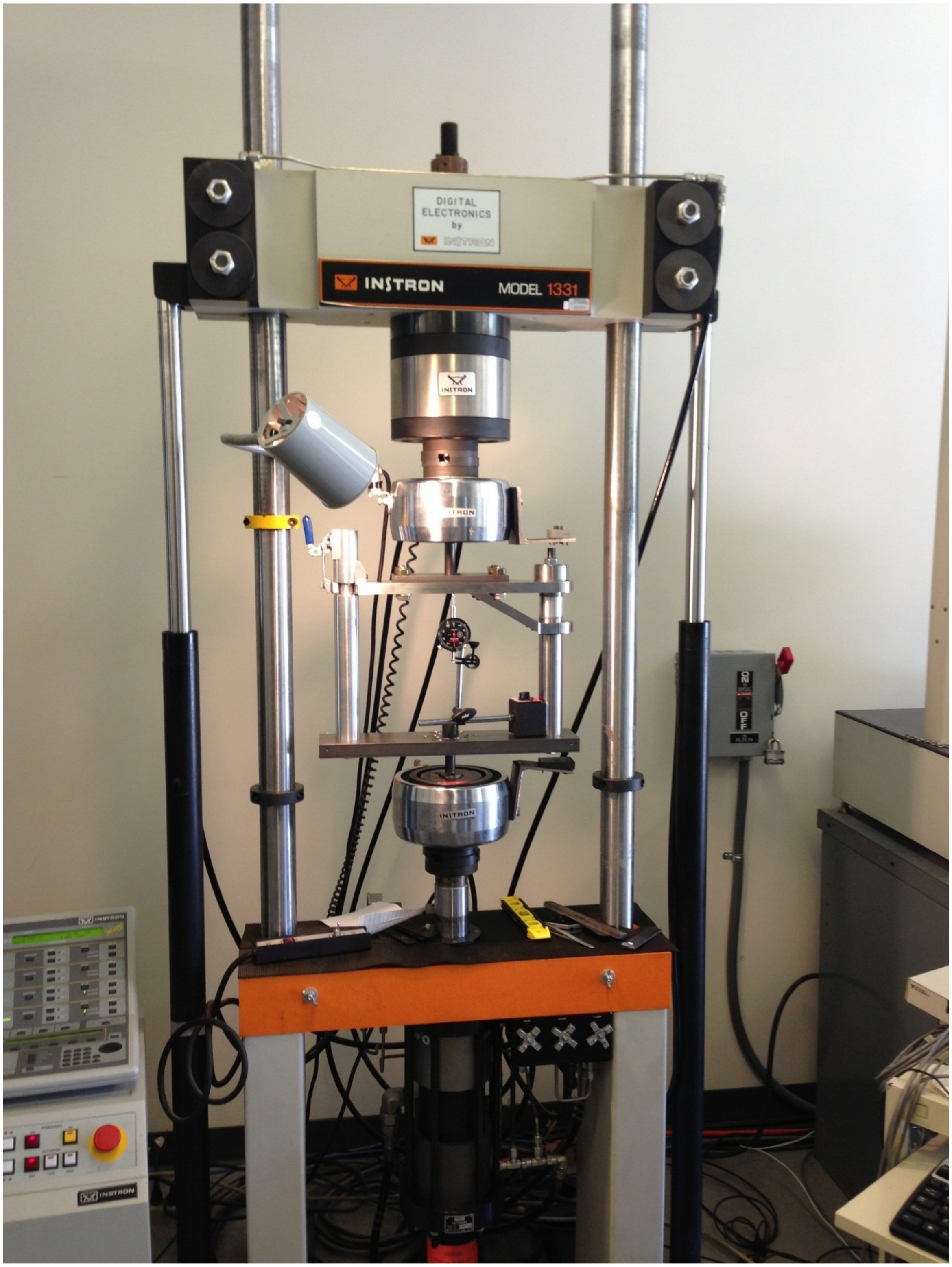
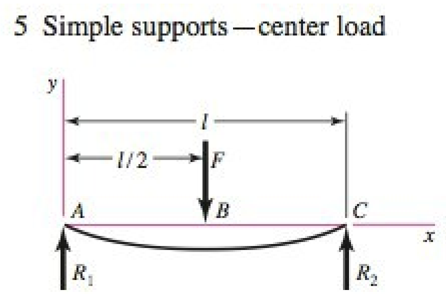


Figure 5.2 Test Setup

5.2 - Results:

The maximum bending deflection calculation (shown below) was used to determine the max design deflection based on material and dimensions of the frame. From the schematic above in Figure 5.1 we can see that the total deflection will be contributed to by the two vertical supports as well. However, we found that they only added about 0.001 in to the overall deflection because of their large cross-sectional areas so we based the design primarily from the calculation below.



At 3000 lbf loading we calculated the beam deflection to be 0.053 in.

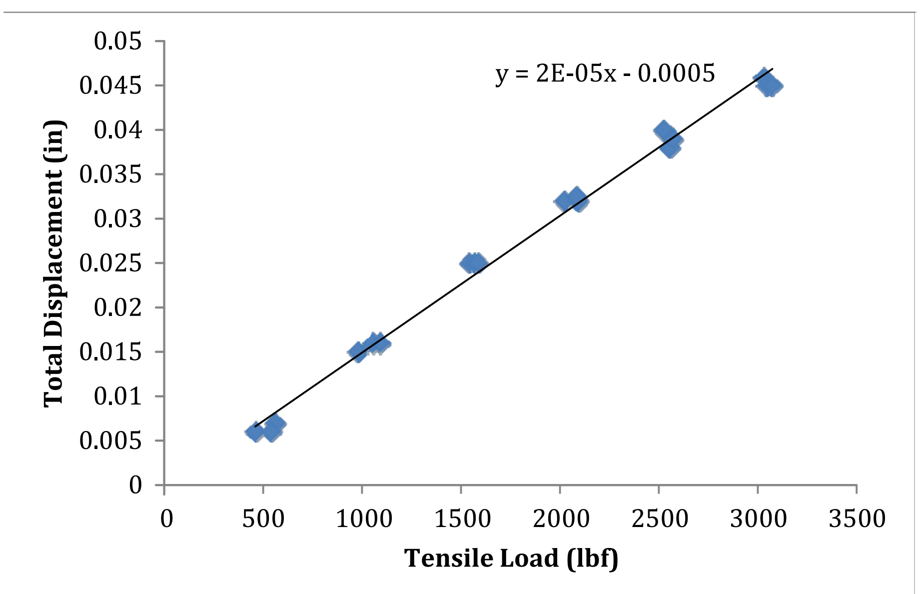


Figure 5.3 Frame Deflection as a Function of Load.

Figure 5.2 above depict the results of loading the frame in 3000 lbf of tension. We ran the test three times to ensure that the data was not somehow being altered by the testing conditions. It is a linear slope for the deflection at each increasing load telling us that we are in the elastic deformation range. The Maximum deflection that was seen during the test was about 0.045 in.

5.3 – Specification Verification

A standard clutch that Tilton currently produces has a total clutch travel of about 0.4 in at a load of 1500 lbf. The verification that we set was to have a frame deflection of no more than 7.5% of the total clutch travel. This would give us a desired deflection of 0.03 in. From FigureXX above, at 1500 lbf we have a total deflection of about 0.02125 in. This is consistent with the design specification

6.1: Conclusions and Recommendations

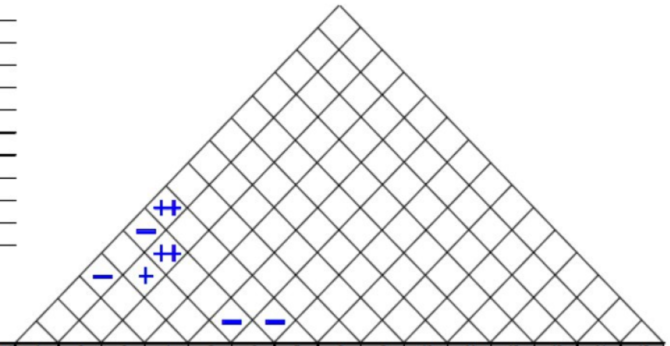
Below is a list of items to look into, improvements to be made, and recommendations to be considered as this project grows and evolves in the future.

1. Redo control system so that entire process can be entirely automated and can be initiated with minimal user input. LabView could potentially handle all data acquisition from CT2000 and release load tester simultaneously.
2. It proved *very* difficult to get our load cell to output to LabView and then Excel. Much of this was due to the fact that we purchased a Futek DAQ (USB210 device). Using a LabView DAQ system along with LabView software would provide a much better solution and would bypass the need to merge different sets of data from different DAQ programs (Tritex and LabView) into Excel.
3. Another possibility is to look into using Futek Sensit software for load cell data acquisition. May provide better interface and more options with Futek load cell than LabView, but has the drawback that it could not handle multiple inputs like LabView can.
4. Consider using an externally-mounted LVDT for position output instead of the Tritex's internal position sensor. It proved difficult to get the sample rate and output rate of the Tritex position data to interface with load data.
5. If not using recommendations 1-4, adjust actuator and load cell sample rates so that both compression and return stroke graphs are more accurate. Because we had to use two separate programs for data acquisition, it proved very difficult to line up these two data sets with respect to time. Sample rates did not match up.
6. Implement tester frame deflection data curve into Excel macro so that data output automatically compensates for frame deflection.
7. Look into a different load cell on CT2000 that has better resolution at tested loads. This would provide the actuator unit with a more accurate signal of when to reverse direction (clutch fully released).
8. Apply threadlocker to all blind tapped holes upon final assembly.
9. Get parts anodized and Melonite finished to prevent corrosion.
10. Permanently bond touchpad switch to underside of crossbar after Melonite finish for final assembly. Recommend using strong epoxy of fasteners with a mounting bracket.

11. Machine a custom set of bearing snouts that are all identical lengths. Then set a max travel limit in the Exlar program to ensure that the actuator rod can never run into the top of the CT2000.
12. Inspect and clean up all wiring connections after final assembly and final integration with CT2000 and new table is complete.
13. Put both clamp load and release load on the same graph for customer printout.
14. Redo setup inside beige computer case.
15. Hardwire fuse box to wall and mount.

Appendix A: QFD

Title: Tilton Test Machine
Author: Ryan Bylard, Kevin Campbell, Trevor Hebbel
Date: 10/9/2012
Notes: 5 = Highest Priority



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Detection less than 5% of overall travel	No More Than 4 Commands	Minimize Failure Prone Electronics i.e. Sensors	Wont Overtravel Maximum Clutch Displacement	Plots Data Aquired	Additional Setup Time Less than 30 seconds	Design for Infinite Fatigue Life									Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	x	x	▼	▲														
1	9	14.3	4.0	Integrate With Existing Equipment	▲		▲	○		⊙	○														
2	9	10.7	3.0	Quick to Setup	▲	⊙				⊙															
3	9	3.6	1.0	Data Acquisition			○		⊙																
4	9	7.1	2.0	Automated		⊙	○	⊙		○															
5	9	16.1	4.5	Max Travel for Safety	▲			⊙			▲														
6	9	17.9	5.0	Measure Load and Travel Accuratey	⊙		⊙				○														
7	9	7.1	2.0	Plots Load vs Travel					⊙																
8	9	8.9	2.5	Simple User Interface / NO GUI		⊙																			
9	9	14.3	4.0	Ridgid to Provide Accurate Measurement	⊙						⊙														
10																									
				Target or Limit Value	5%	4	minimal	Saftey	yes	30 sec	Infinity														
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	5	2	5	3	2															
				Max Relationship Value in Column	9	9	9	9	9	9	9														
				Weight / Importance	330.4	241.1	207.1	251.8	96.4	245.4	241.1														
				Relative Weight	20.5	14.9	12.8	15.6	6.0	15.3	14.9														

Competitive Analysis (0=Worst …)

Legend

⊙	9
○	3
▲	1
++	
+	
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x	

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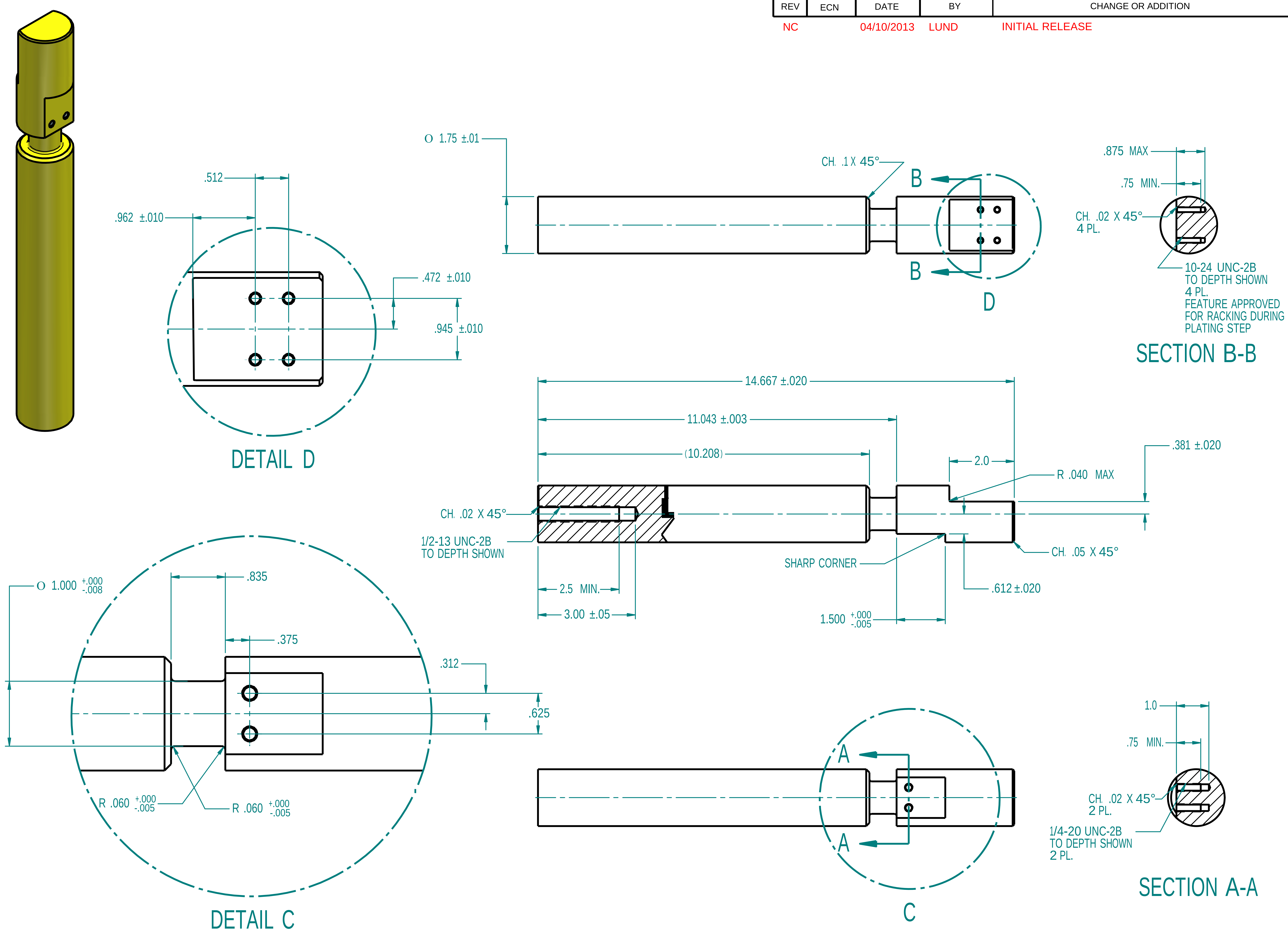

NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.
4. ANODIZE PER MIL-A 8625F, TYPE II, CLASS 2, BLACK.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC(TIR)	.005

DRILL HOLES

.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L SPEC	ALUMINUM 6061 PER ASTM B211-12e1
COND HARD	T6
FINISH SPEC	ANODIZE SEE NOTES

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, CIRCULAR VERTICAL POST**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 1:2	SIZE C	DWG 5804	REV NC
P/N 97-090	DATE 04/10/2013	SHEET 1 OF 1			

tilton ENGINEERING INC

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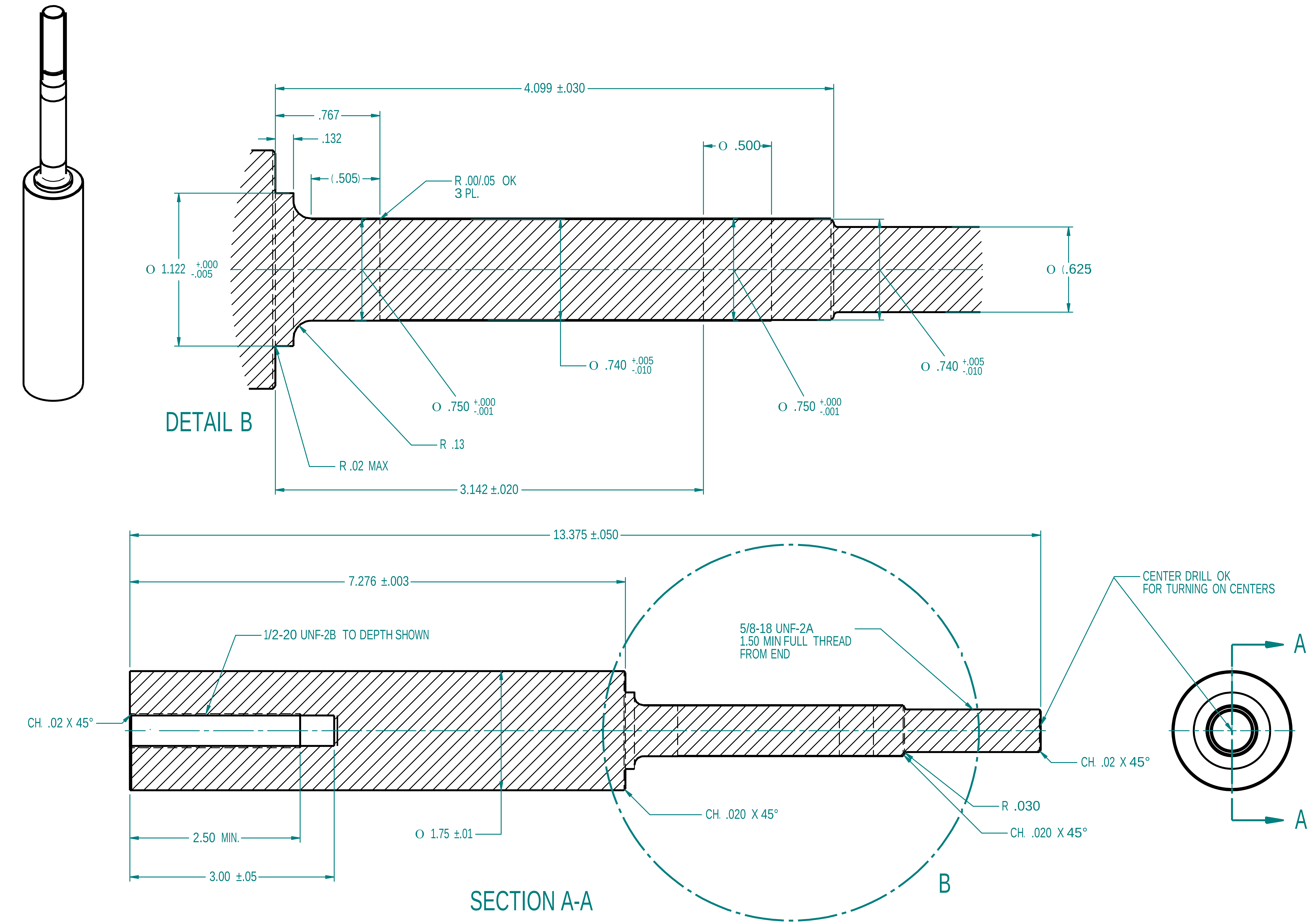

NOTES:

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3. BREAK SHARP EDGES .005-.010.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC(TIR)	.005

DRILL HOLES

.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L SPEC	STEEL 4140 PER ASTM A108-07
COND HARD	Q & T Rc 25 - 35
FINISH SPEC	MELONITE

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, CIRCULAR PIVOT POST**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 1 : 1	SIZE C	DWG 5805	REV NC
P/N 97-091	DATE 04/10/2013	SHEET 1 OF 1			

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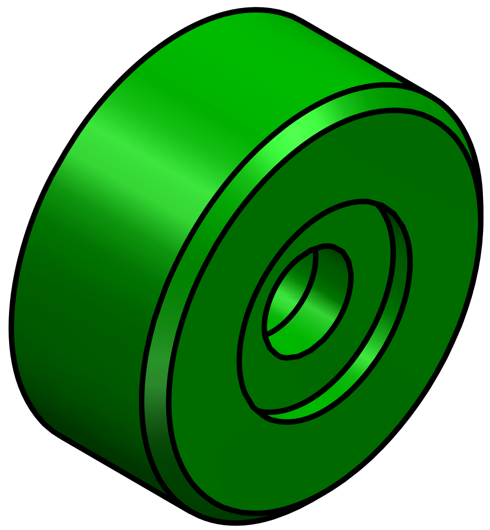
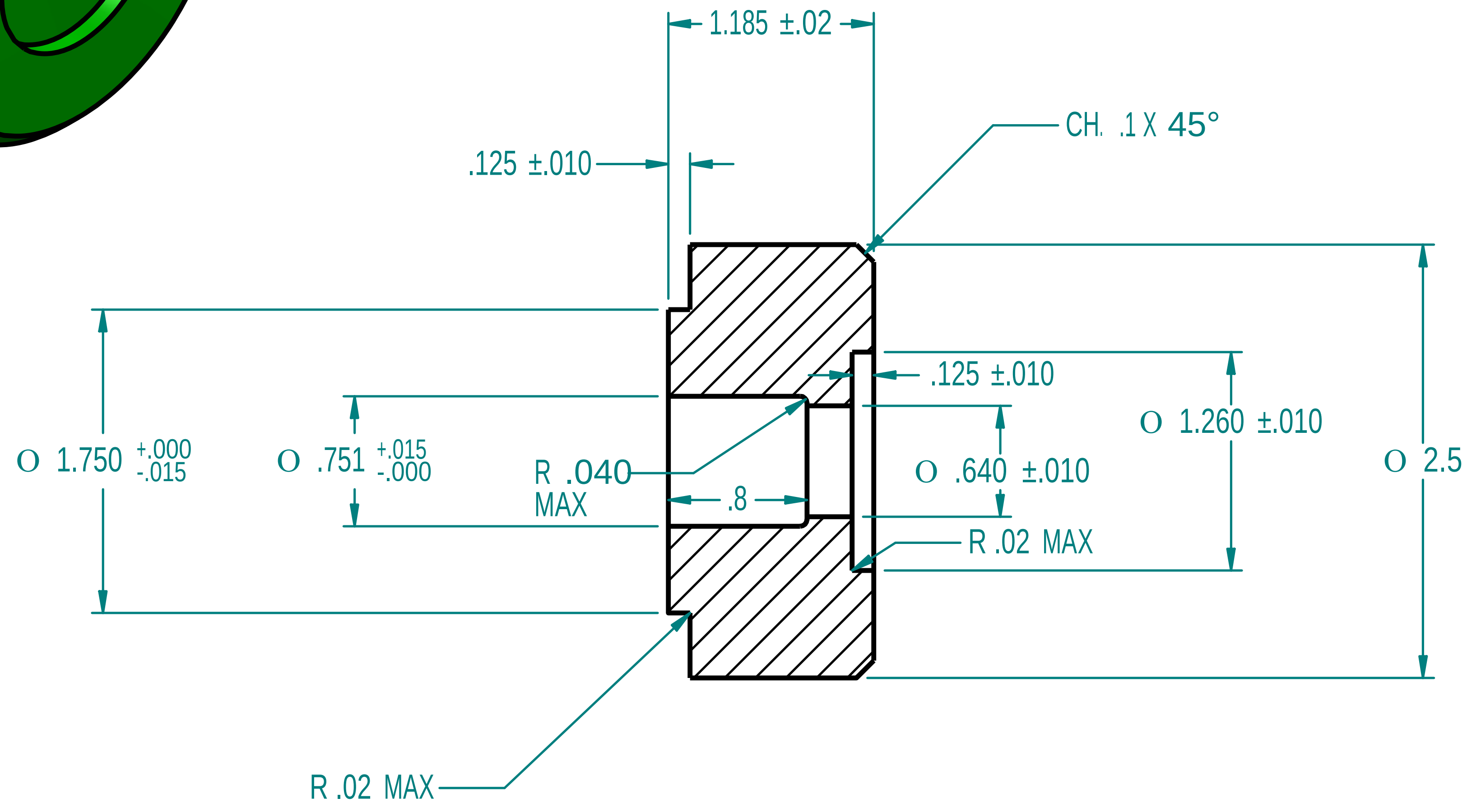
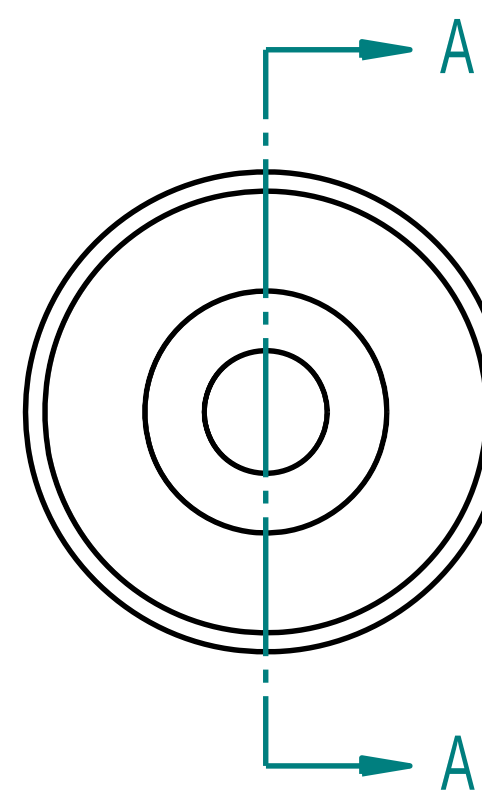




SECTION A-A



NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC	.005

DRILL HOLES	
.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L	STEEL
SPEC	4140 PER ASTM A108-07
COND	Q & T
HARD	Rc 25 - 35
FINISH SPEC	MELONITE

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, COLLAR CAP**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 1 : 1	SIZE B	DWG 5806	REV NC
P/N 97-092	DATE 04/05/13	SHEET 1 OF 1			

tilton ENGINEERING INC ®

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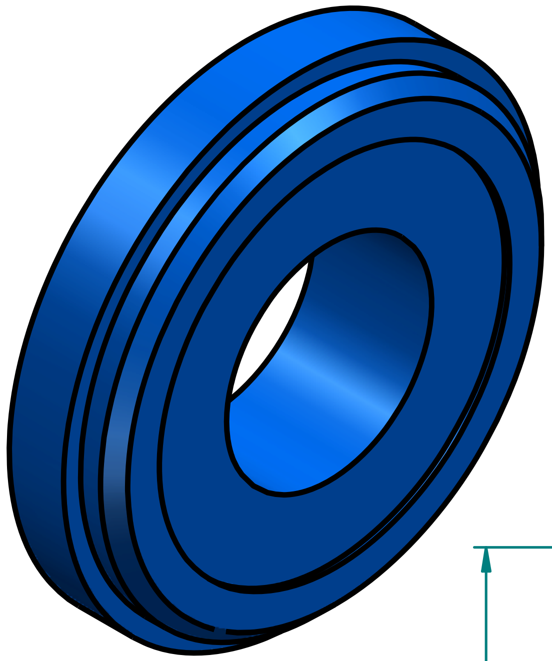

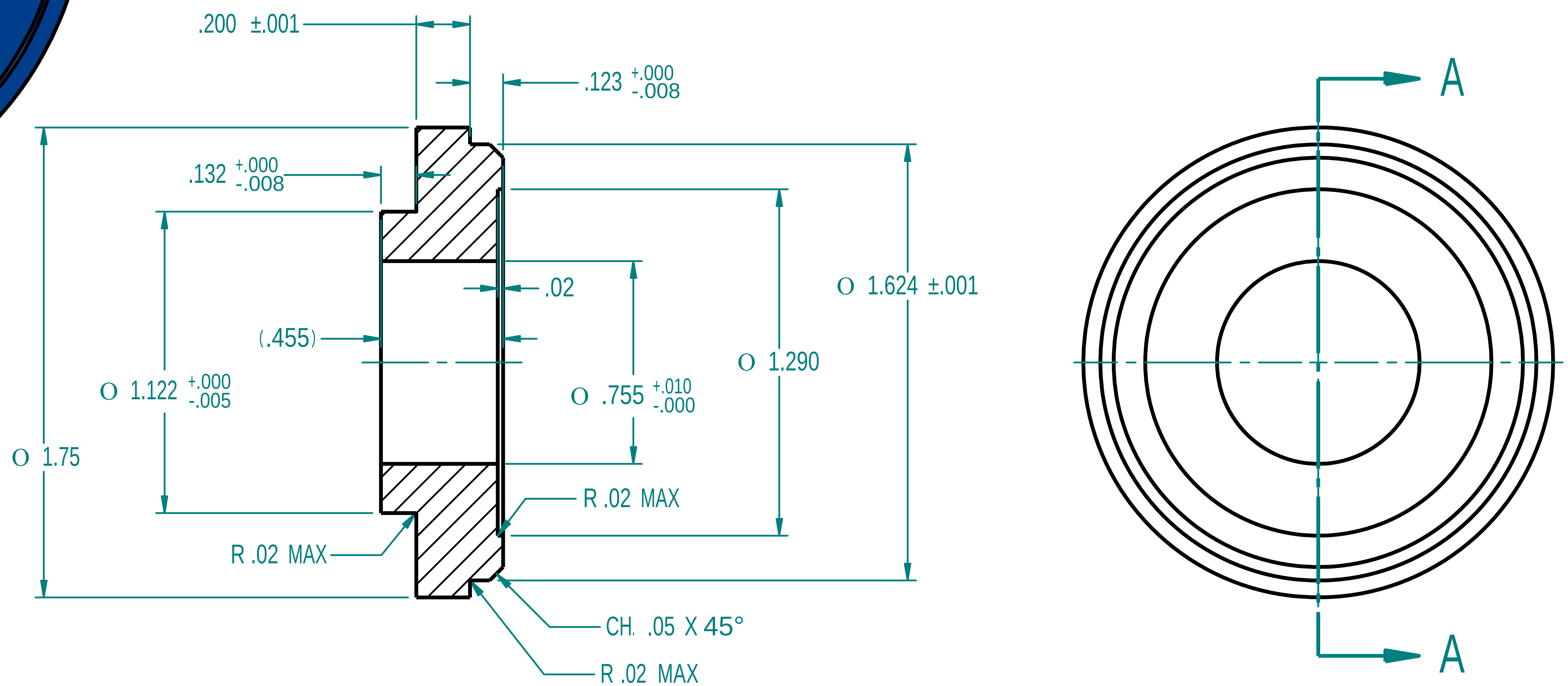

SECTION A-A

NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC	.005

DRILL HOLES	
.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L SPEC	STEEL 4140 PER ASTM A108-07
COND	Q & T
HARD	Rc 25 - 35
FINISH SPEC	MELONITE

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, COLLAR ADAPTOR**
CLUTCH RELEASE LOAD TESTER

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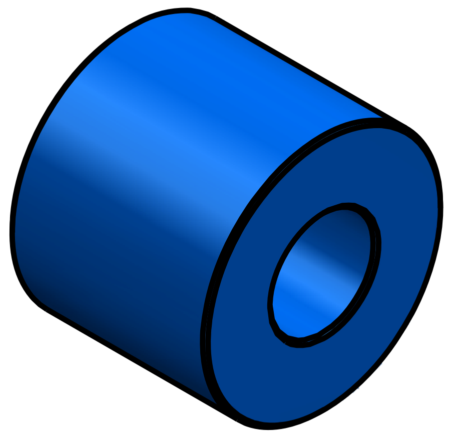
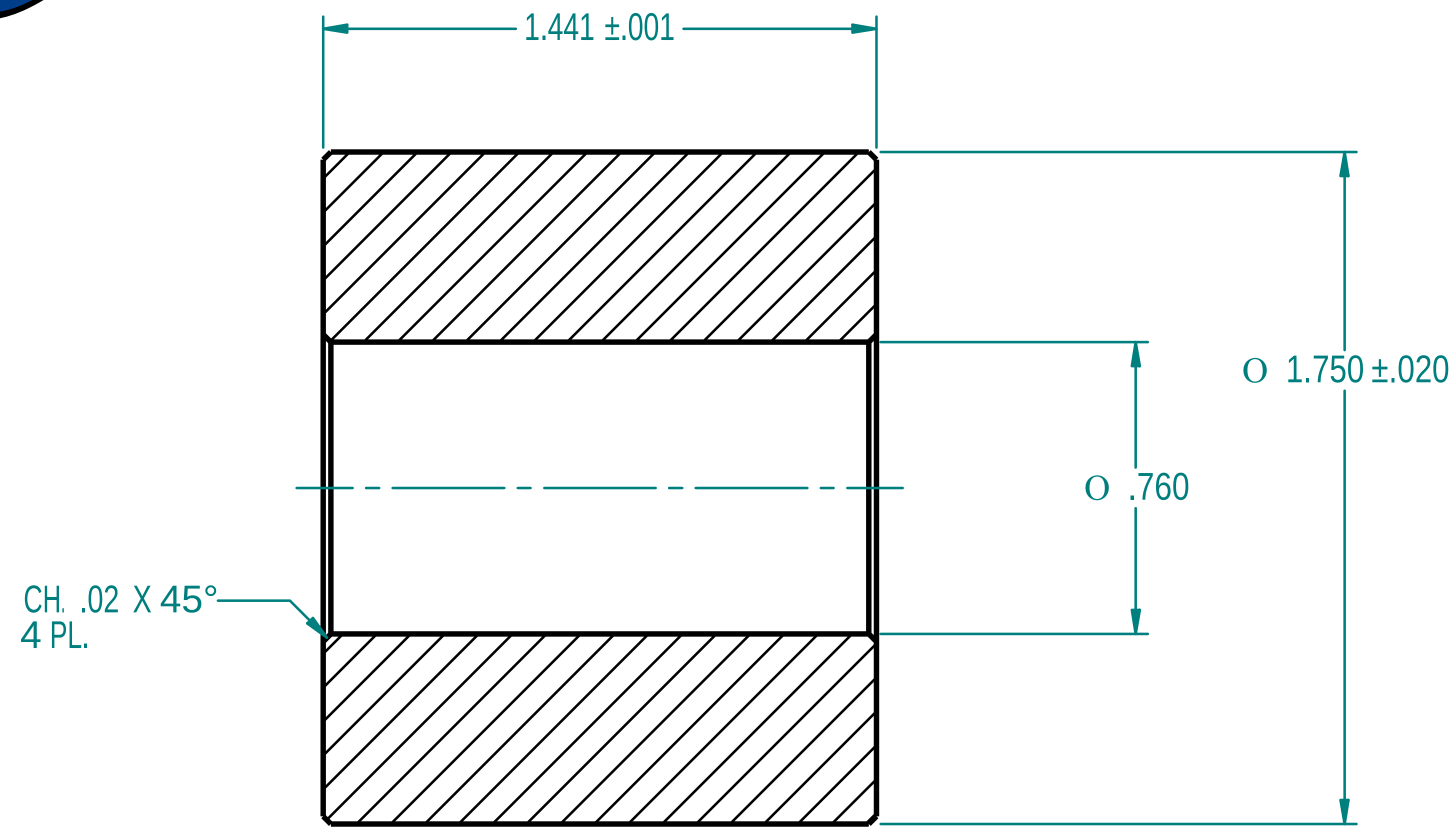
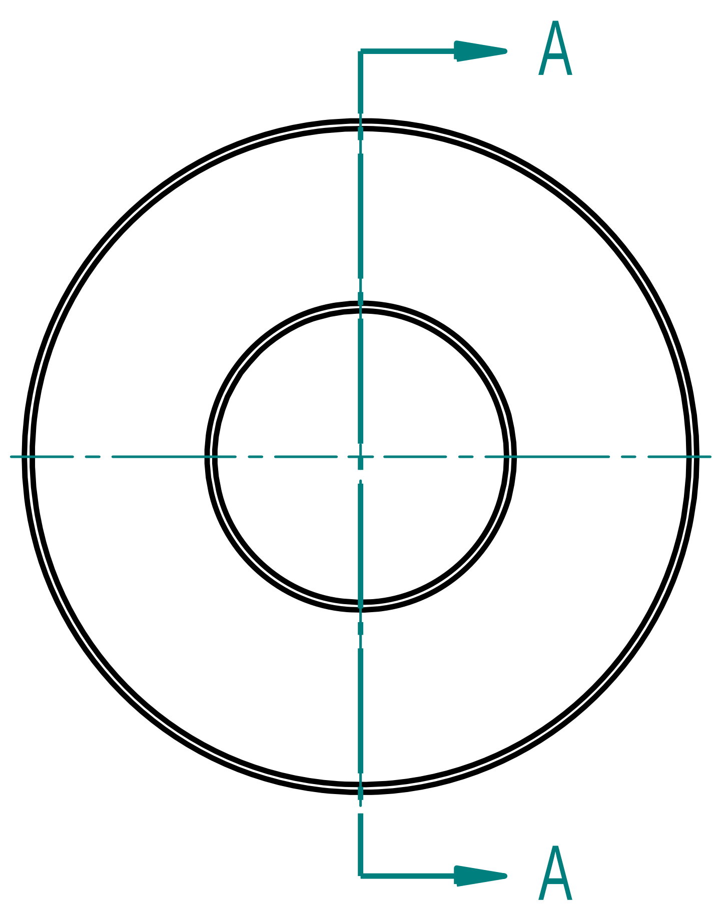




SECTION A-A



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2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.
4. ANODIZE PER MIL-A 8625F, TYPE II, CLASS 2, BLACK.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC	.005

DRILL HOLES	
.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

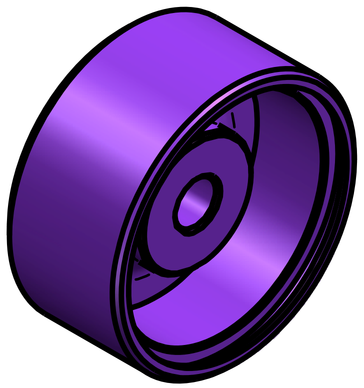
MAT'L SPEC COND HARD	ALUMINUM 6061 PER ASTM B211-12e1 T6
FINISH SPEC	ANODIZE SEE NOTES

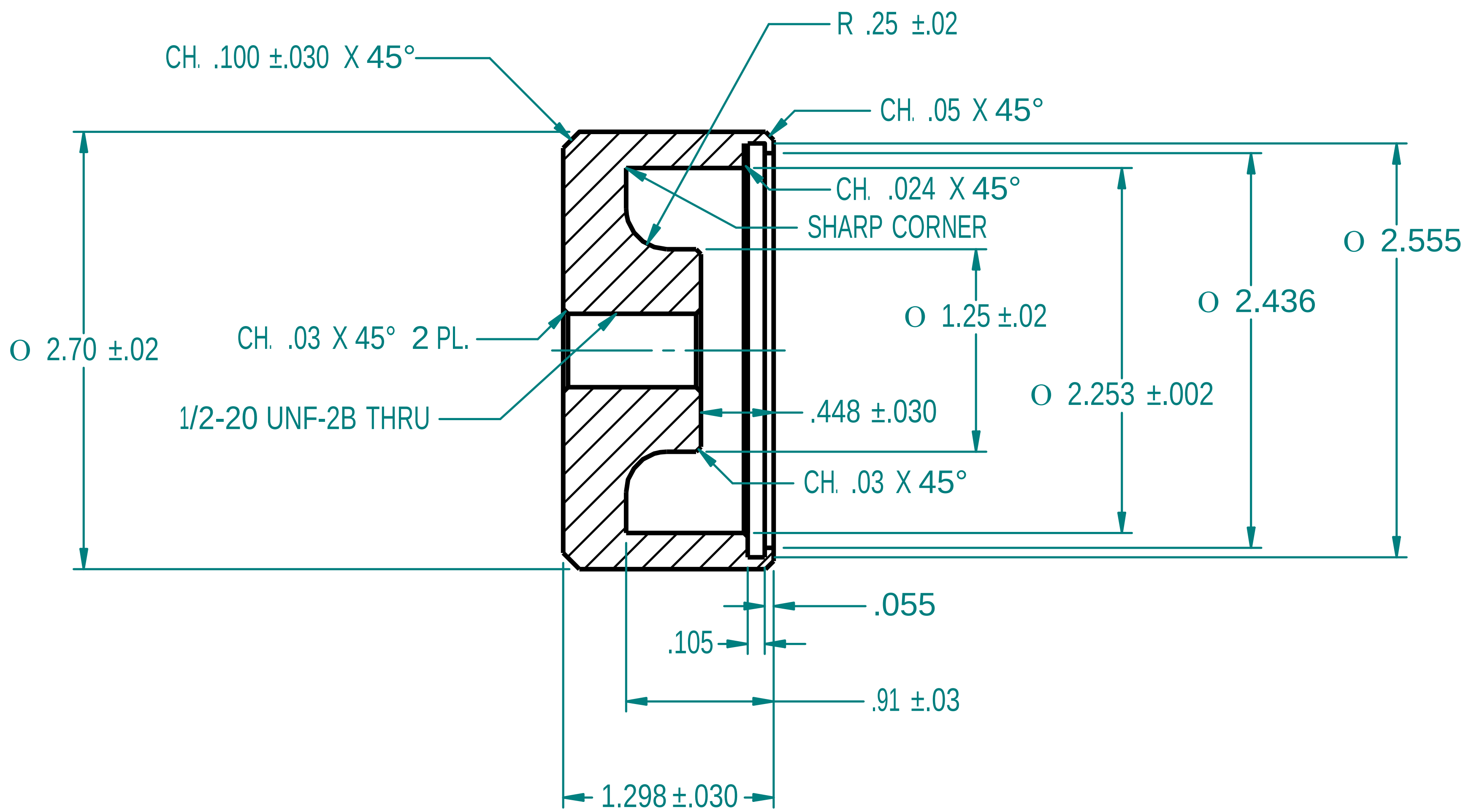
TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, MIDDLE COLLAR**
CLUTCH RELEASE LOAD TESTER

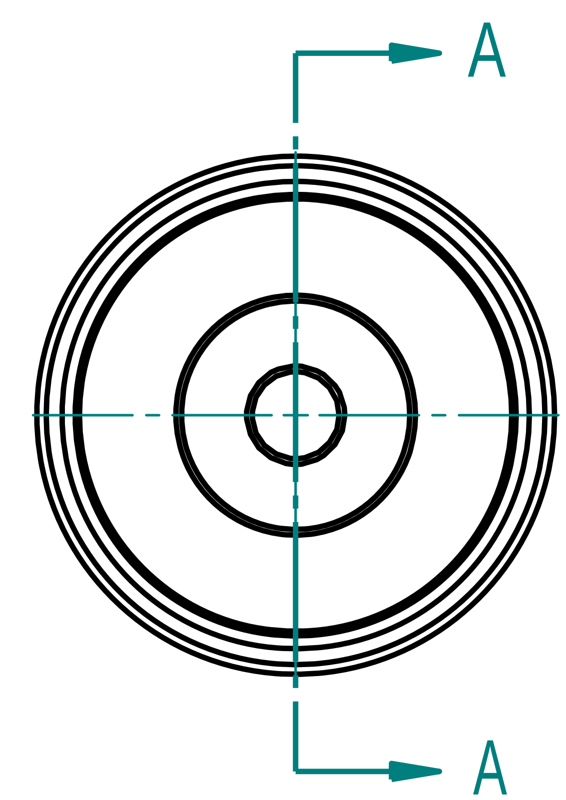
DRAWN BY LUND	CHKD WAHL	SCALE 1 : 1	SIZE B	DWG 5808	REV NC
P/N 97-094	DATE 04/10/13	SHEET 1 OF 1			

REV	ECN	DATE	BY	CHANGE OR ADDITION
NC		04/10/2013	LUND	INITIAL RELEASE





SECTION A-A



NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.

TOLERANCES: UNLESS SPECIFIED OTHERWISE

		DRILL HOLES	
.X ±	.020	.013-.040:	+.001/-.001
.XX ±	.010	.041-.130:	+.002/-.001
.XXX ±	.005	.131-.229:	+.003/-.001
FRACT ±	1/32	.230-.500:	+.004/-.001
ANGLE ±	1/2°	.501-.750:	+.005/-.001
CONC	.005	.751-1.000:	+.007/-.001

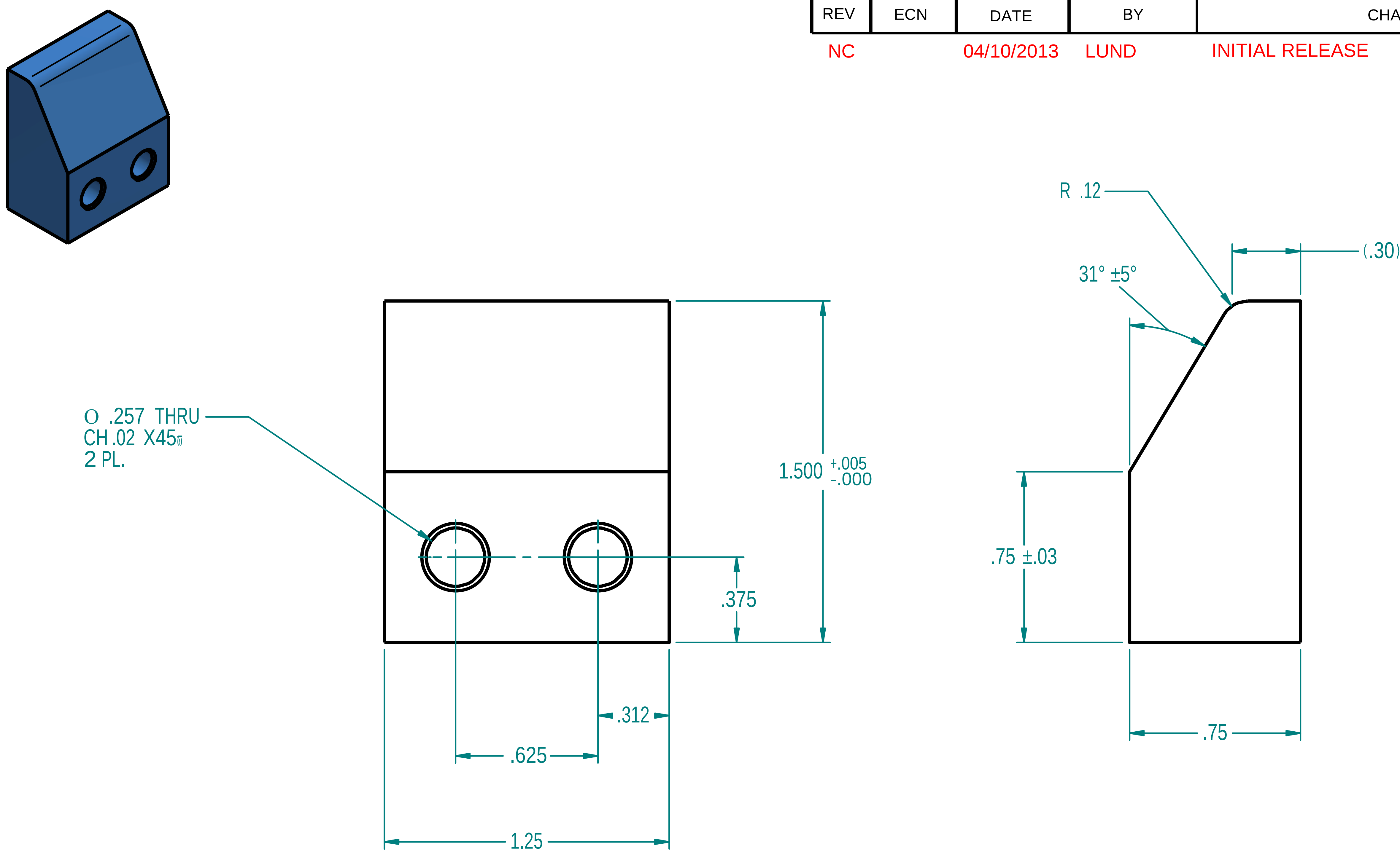
MAT'L SPEC	STEEL 4140 PER ASTM A108-07
COND	Q & T
HARD	Rc 25 - 35
FINISH SPEC	MELONITE

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, PISTON LOAD CELL ADAPTOR**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 1 : 1	SIZE B	DWG 5809	REV NC
P/N 97-095	DATE 04/10/2013	SHEET 1 OF 1			

REV	ECN	DATE	BY	CHANGE OR ADDITION
NC		04/10/2013	LUND	INITIAL RELEASE



NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.
4. ANODIZE PER MIL-A-8625F, TYPE II, CLASS 2, BLACK

TOLERANCES: UNLESS SPECIFIED OTHERWISE

		DRILL HOLES	
.X ±	.020	.013-.040:	+.001/-.001
.XX ±	.010	.041-.130:	+.002/-.001
.XXX ±	.005	.131-.229:	+.003/-.001
FRACT ±	1/32	.230-.500:	+.004/-.001
ANGLE ±	1/2°	.501-.750:	+.005/-.001
CONC	.005	.751-1.000:	+.007/-.001

MAT'L SPEC	ALUMINUM 6061-T6 PER ASTM B209-10
COND HARD	T6
FINISH SPEC	ANODIZE BLACK SEE NOTES

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

TITLE: **TOOL, SUPPORT BLOCK**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 2 : 1	SIZE B	DWG 5810	REV NC
P/N 97-097	DATE 04/10/2013	SHEET 1 OF 1			

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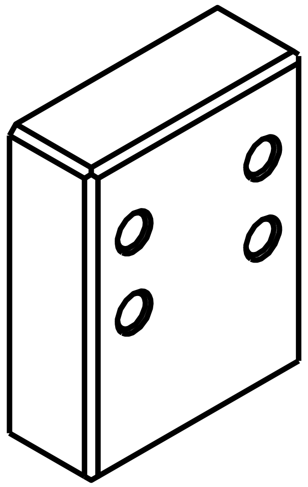
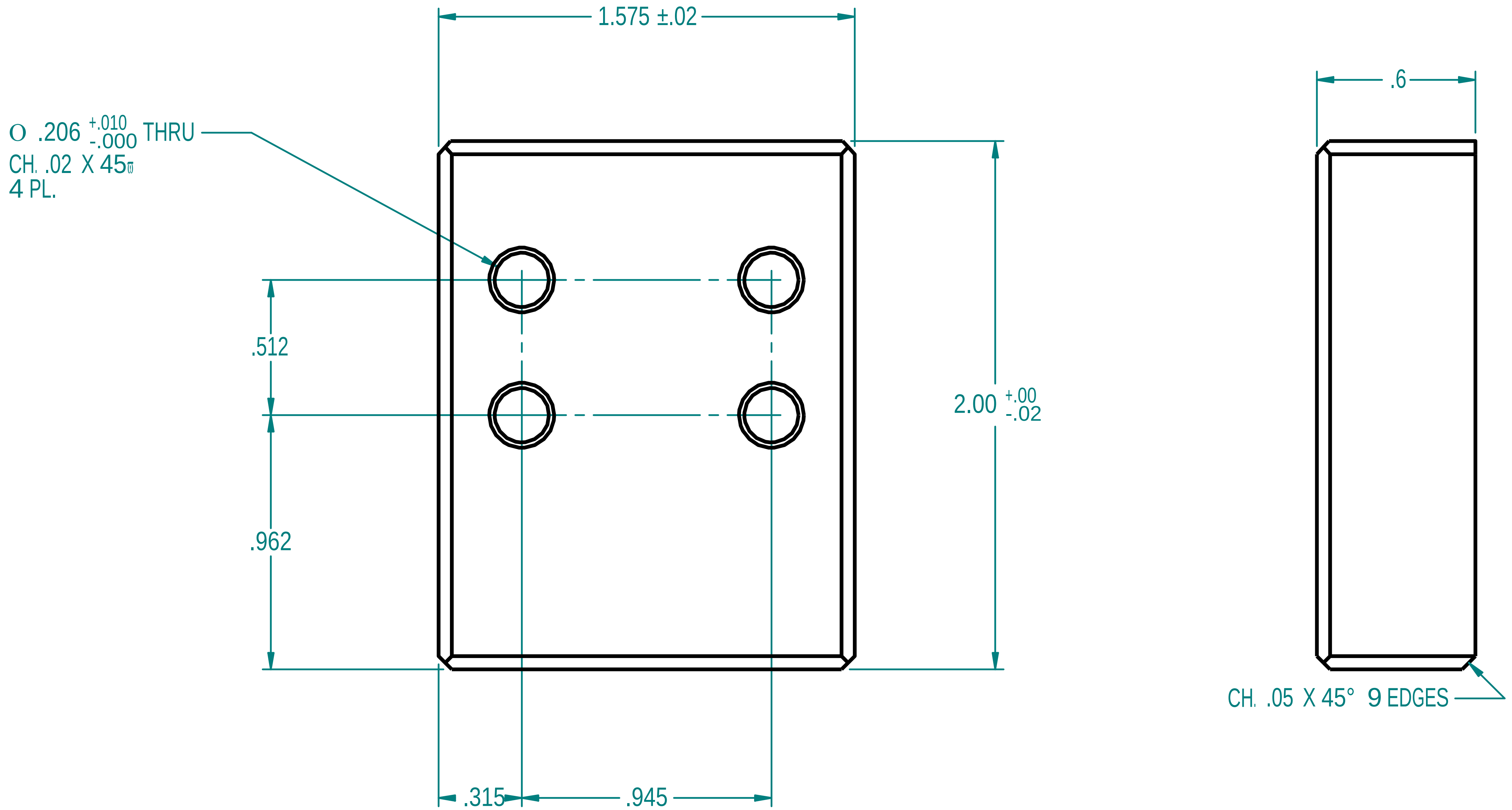
REV	ECN	DATE	BY	CHANGE OR ADDITION
NC		04/10/13	LUND	INITIAL RELEASE





NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2009
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. BREAK SHARP EDGES .005-.010.
4. ANODIZE PER MIL-A-8625F, TYPE II, CLASS 2, BLACK

TOLERANCES: UNLESS SPECIFIED OTHERWISE

		DRILL HOLES	
.X ±	.020	.013-.040:	+.001/-.001
.XX ±	.010	.041-.130:	+.002/-.001
.XXX ±	.005	.131-.229:	+.003/-.001
FRACT ±	1/32	.230-.500:	+.004/-.001
ANGLE ±	1/2°	.501-.750:	+.005/-.001
CONC	.005	.751-1.000:	+.007/-.001

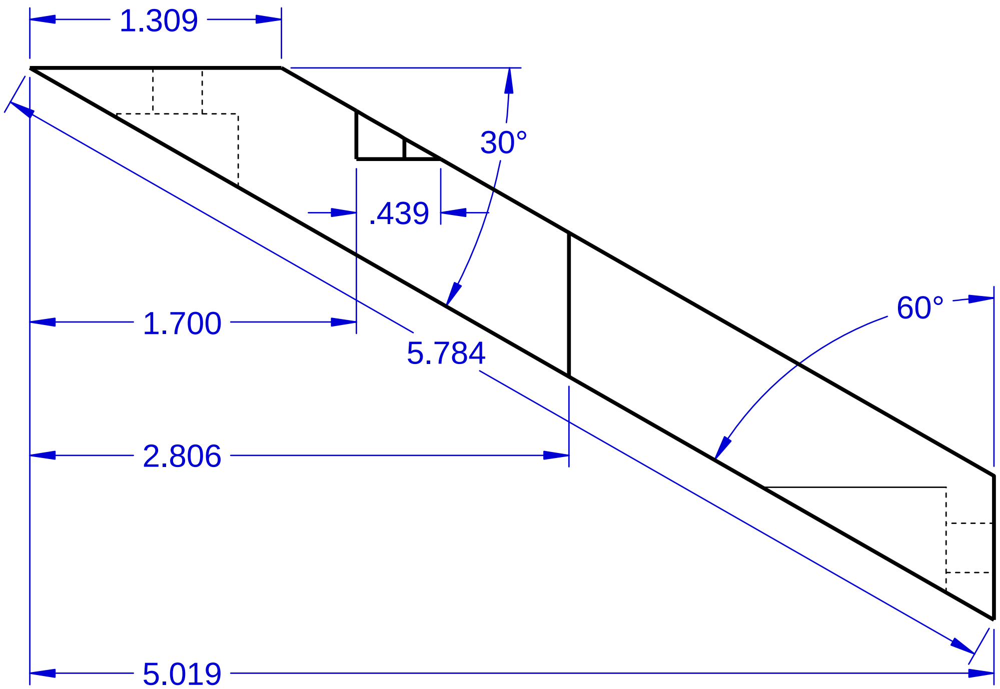
MAT'L SPEC COND HARD	ALUMINUM 6061-T6 PER ASTM B209-10 T6
FINISH SPEC	ANODIZE BLACK SEE NOTES

TILTON ENGINEERING, INC. FAX 805/688-2745
25 EASY STREET, P.O. BOX 1787, BUELLTON, CA 93427 805/688-2353

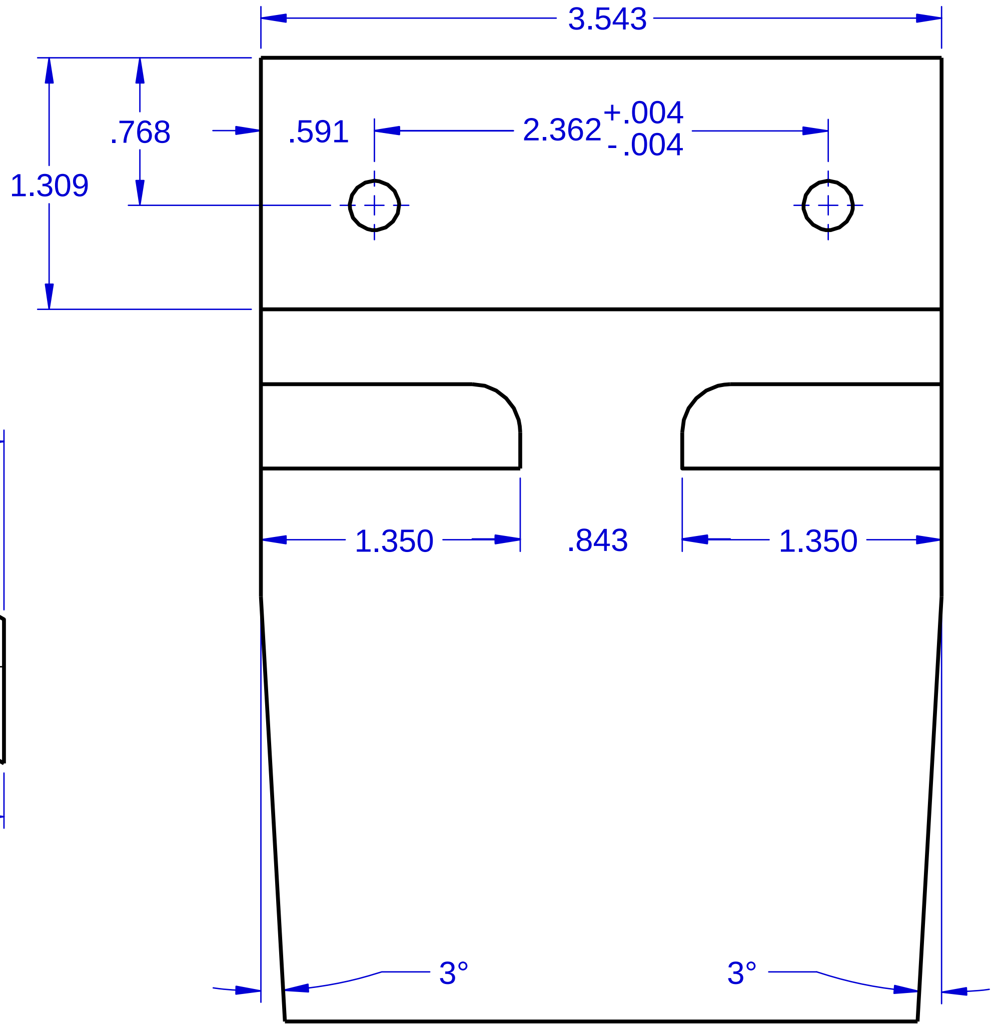
TITLE: **TOOL, LATCH BLOCK**
CLUTCH RELEASE LOAD TESTER

DRAWN BY LUND	CHKD WAHL	SCALE 1 : 1	SIZE B	DWG 5811	REV NC
P/N 97-097	DATE 04/10/2013	SHEET 1 OF 1			

tilton ENGINEERING INC ®



LEFT VIEW



TOP VIEW

CAL POLY Mechanical Engineering

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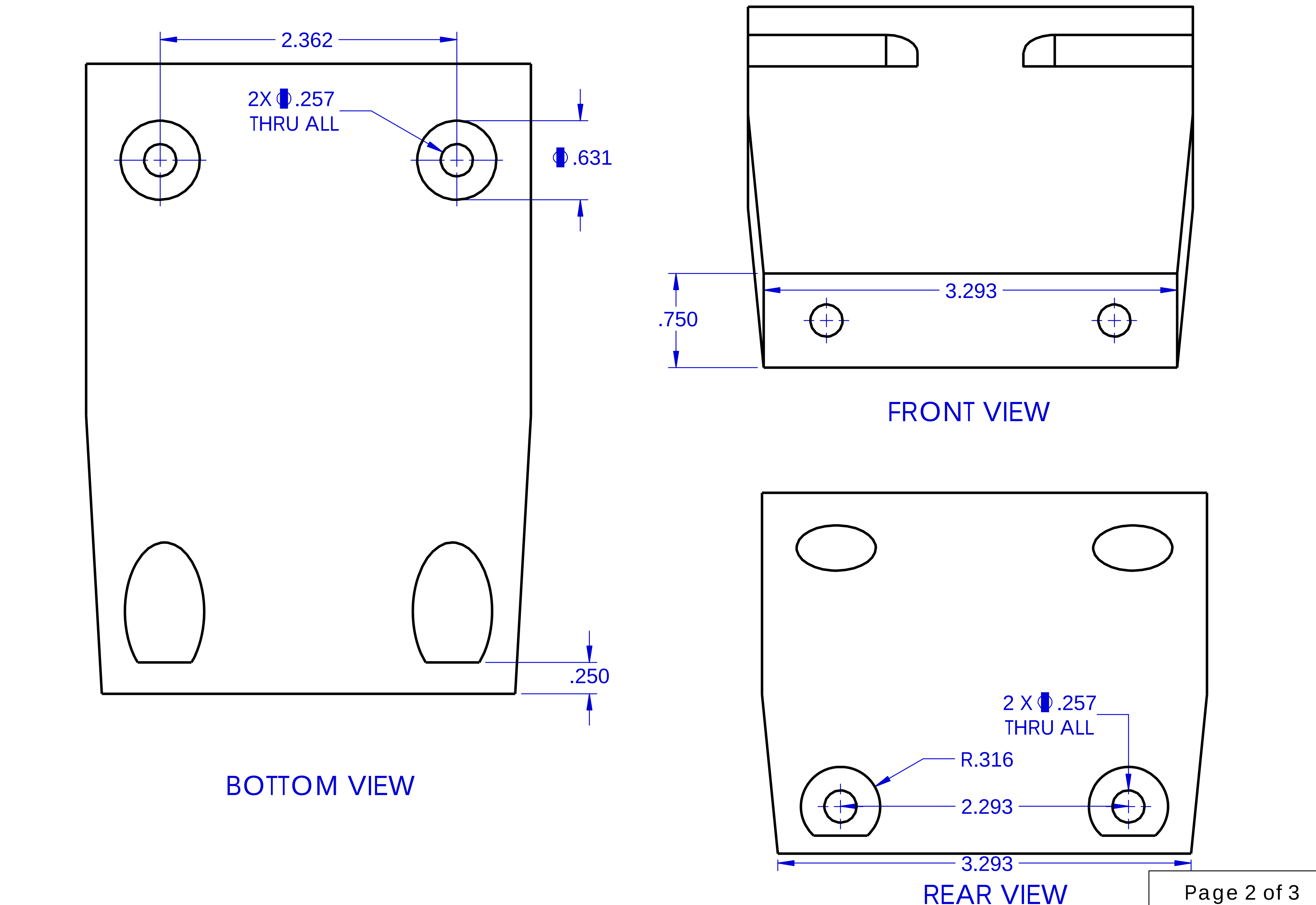
TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X±	.020
.XX±	.010
.XXX±	.005
FRACT±	1/32
ANGLE±	1/2°
CONC±	.005

DRILL HOLES

.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L: STEEL 1045	DRAWN: CAMPBELL	TITLE: **ANGLED SUPPORT PLATE**
FINISH: MELONITE	CHKD: BYLARD	DATE: 4/7/13 / SCALE: 1:1



CAL POLY Mechanical Engineering

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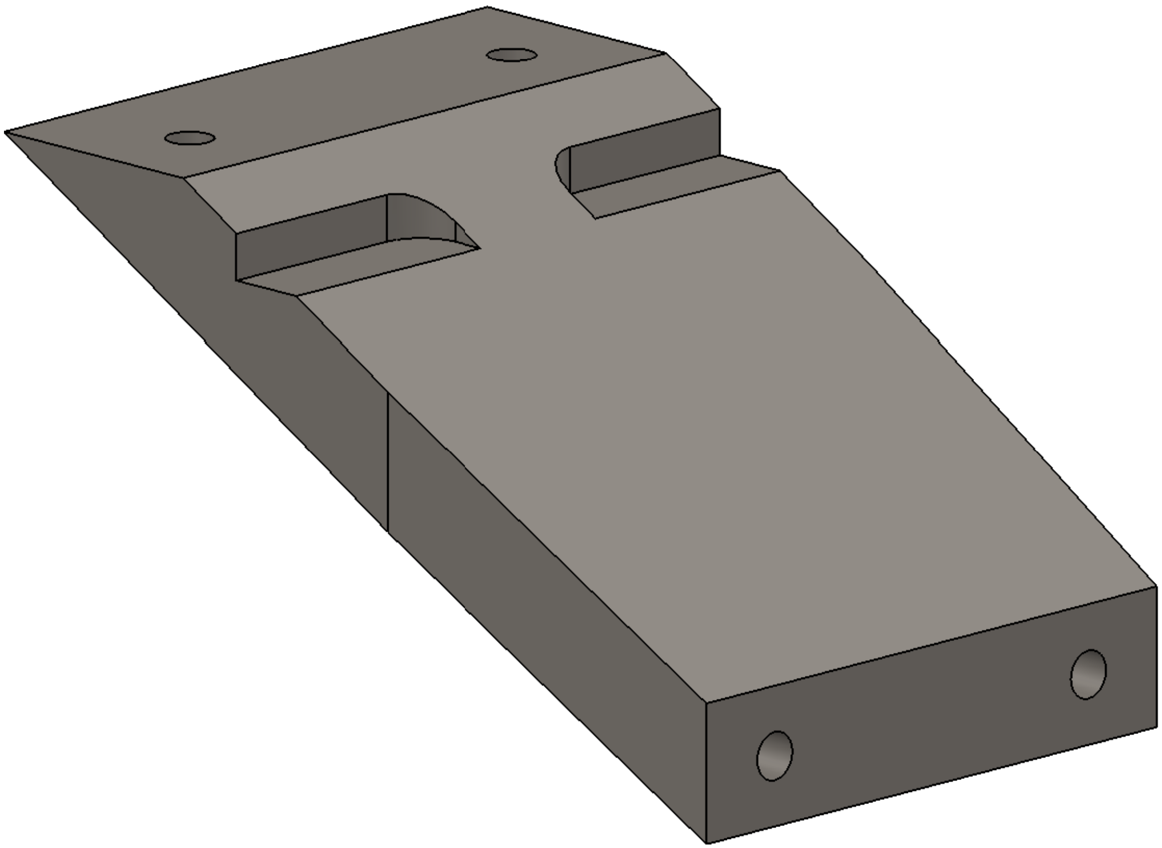
TOLERANCES: UNLESS SPECIFIED OTHERWISE

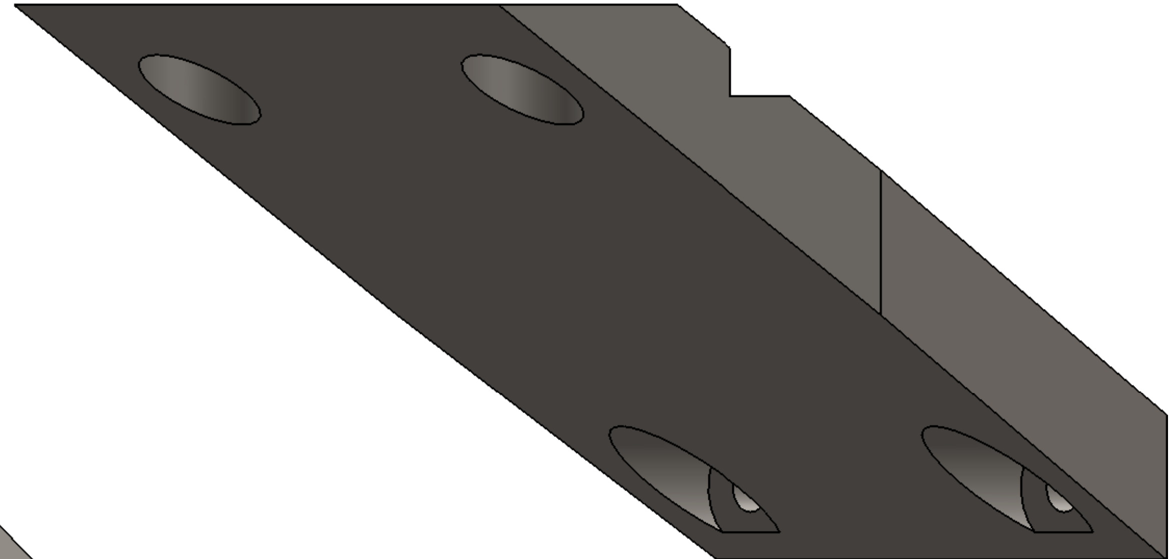
.X±	.020
.XX±	.010
.XXX±	.005
FRACT±	1/32
ANGLE±	1/2°
CONC±	.005

DRILL HOLES

.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

MAT'L: STEEL 1045	DRAWN: CAMPBELL	TITLE: **ANGLED SUPPORT PLATE**	
FINISH: MELONITE	CHKD: BYLARD	DATE: 4/7/13	SCALE: 1:1

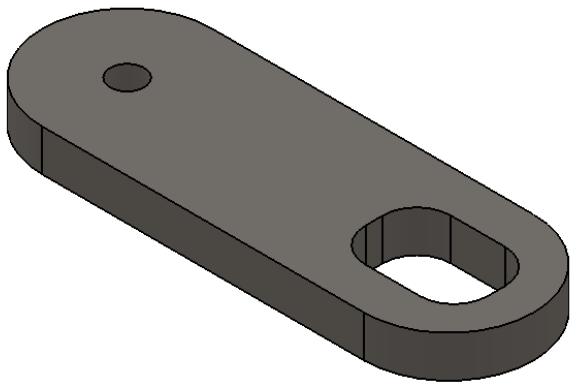


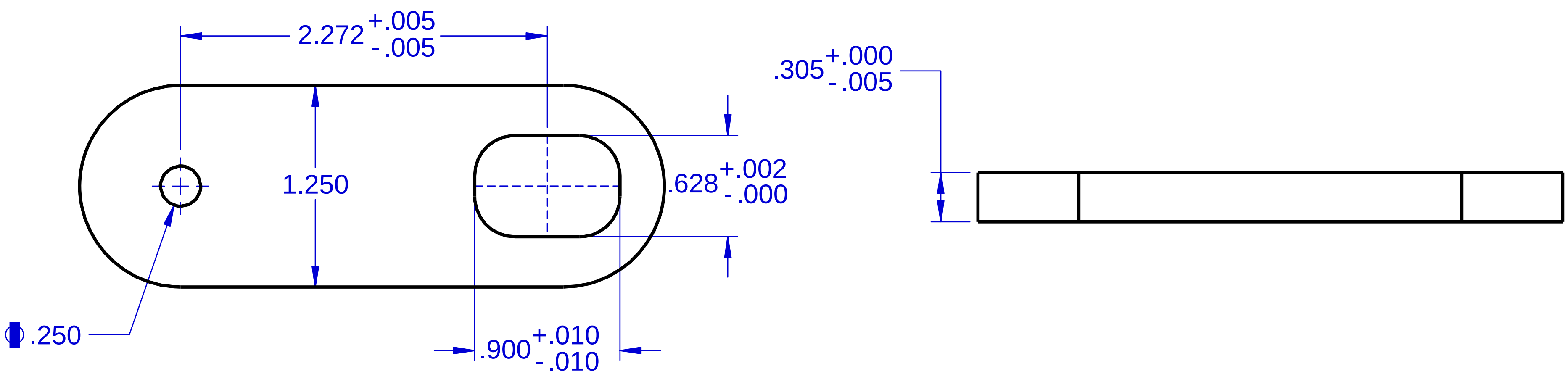


CAL POLY Mechanical Engineering

TOLERANCES: UHfstSHCflf[)<)!HEt'WU		DRILL HOLES	
.X::!:	J)20	013-.040:	+.001(·.001
.XX:!:	.010	041-.130:	+.002(-.001
.XXX±	.005	.131-.229:	+.003(-.001
FRACT±	1/32	23:1-.500:	+.004(-.001
ANGLE±	1/2°	501-.750:	+.005(-.001
CONC+	.005	751-1000:	+.007(-.001

MAll: STEEL 1045	DRAWN: CAMPBELL	TITLE: **ANGLED SUPPORT PLATE**
FINISH: MELONITE	CHKD: BYLARD	DATE: 4/7/13 SCALE: 1:1





CAL POLY Mechanical Engineering

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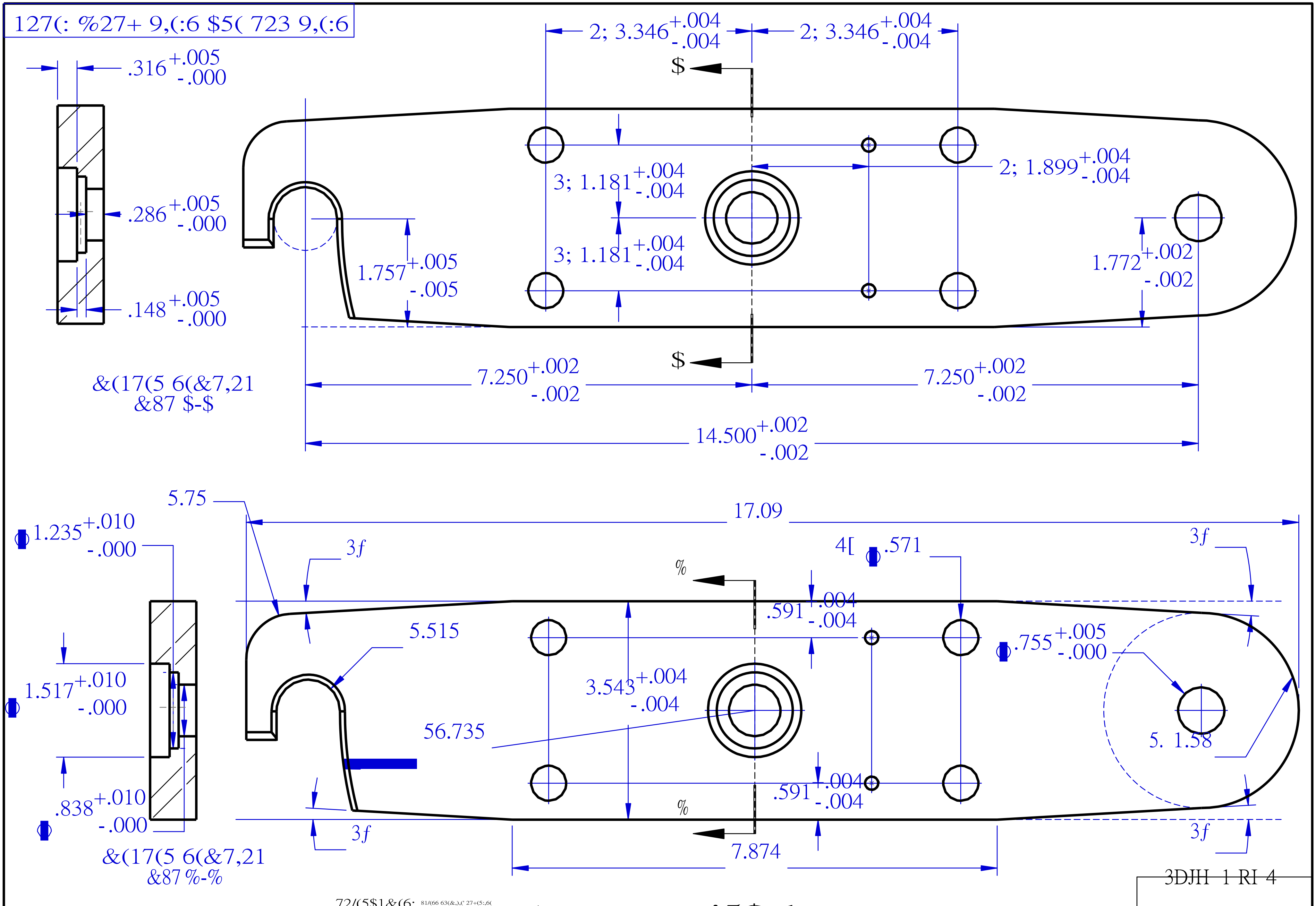
TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X ±	.020
.XX ±	.010
.XXX ±	.005
FRACT ±	1/32
ANGLE ±	1/2°
CONC ±	.005

DRILL HOLES

.013-.040:	+.001/-.001
.041-.130:	+.002/-.001
.131-.229:	+.003/-.001
.230-.500:	+.004/-.001
.501-.750:	+.005/-.001
.751-1.000:	+.007/-.001

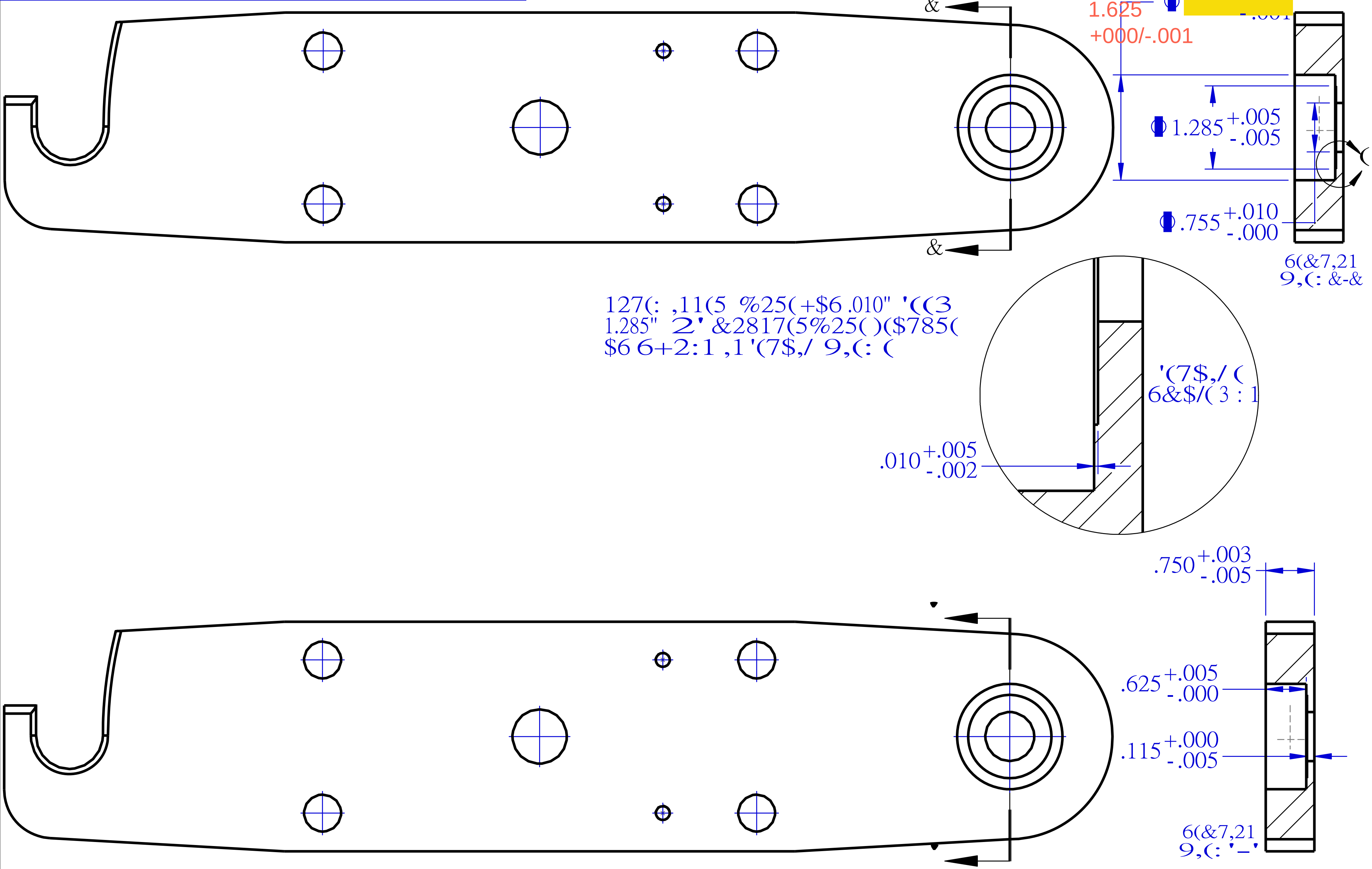
MAT'L: STEEL 1018	DRAWN: CAMPBELL	TITLE: ANIT-ROTATE ARM
FINISH: MELONITE	CHKD: BYLARD	DATE: 5/25/13 SCALE: 1:1



CAL POLY Mechanical Engineering / tilton ENGINEERING	72/(5$1&(6: 81/(66 63(&,),(' 27+(5:,6(	0$7'/: 67((/ 1045	'5$:1: &$03%(//
	'5,// +2/(6	),1,6+: 0(/21,7(	&+.'.: %</$5'
		7,7/(: +25,=217$/ &52660(0%(5	'$7(: 4/7/13
			6&$/(: 1:2

.; ±	.020	.013-.040:	+.001/-.001
.;; ±	.010	.041-.130:	+.002/-.001
.;;; ±	.005	.131-.229:	+.003/-.001
)5$&7±	1/32	.230-.500:	+.004/-.001
$1*/(±	1/2°	.501-.750:	+.005/-.001
&21&±	.005	.751-1.000:	+.007/-.001

127(: %27+ 9,(:6 $5(,'(17,&$/ %27720 9,(:6



3DJH 2 RI 4

CAL POLY Mechanical Engineering	72/(5$1&(6: ; ± .020; .; ± .010; .;; ± .005;)5$&7± 1/32; $1*/(± 1/2°; &21&± .005	81/(66 63(&,),(' 27+(5:,6('5,// +2/(6: .013-.040: +.001/-.001; .041-.130: +.002/-.001; .131-.229: +.003/-.001; .230-.500: +.004/-.001; .501-.750: +.005/-.001; .751-1.000: +.007/-.001	0$7'/: 67((/ 1045	'5$:1: &$03%(//
tilton ENGINEERING			),1,6+: 0(/21,7(	&+.'. %<1$5'
			7,7/(: +25,=217$/ &52660(0%(5	'$7(: 4/7/13
				6&$/(: 1:2

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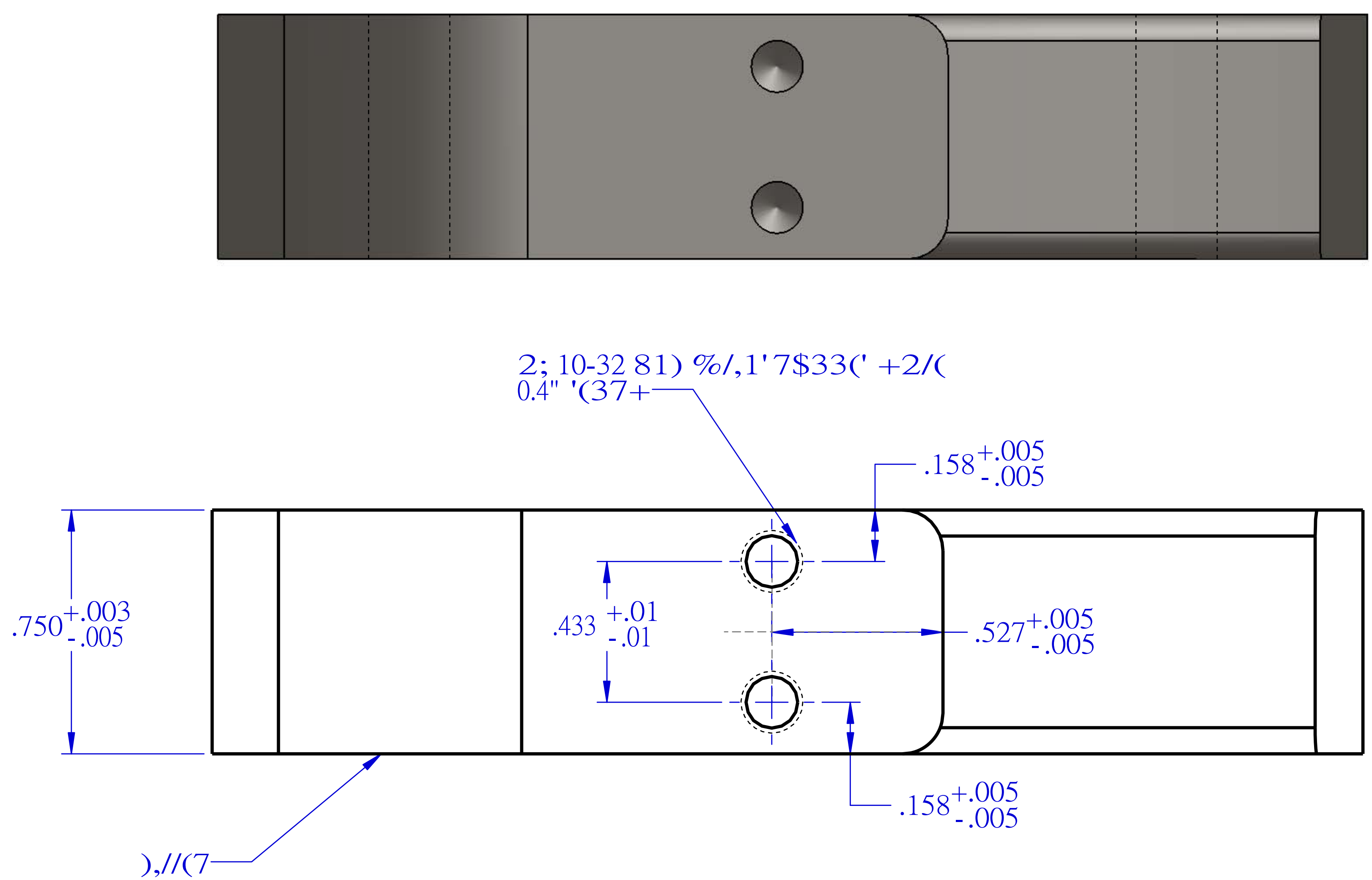
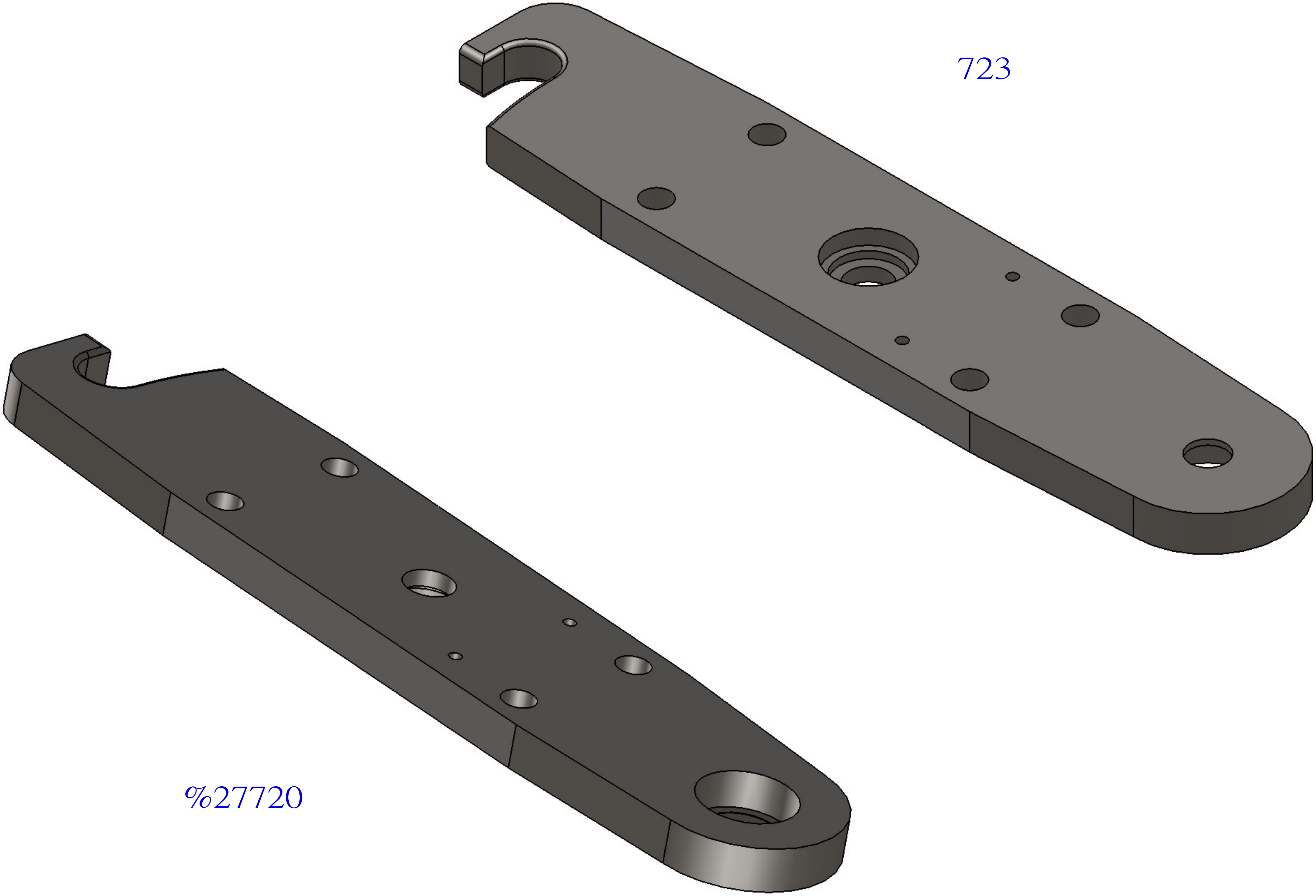


3DJH 3 RI 4

CAL POLY Mechanical Engineering

titan ENGINEERING

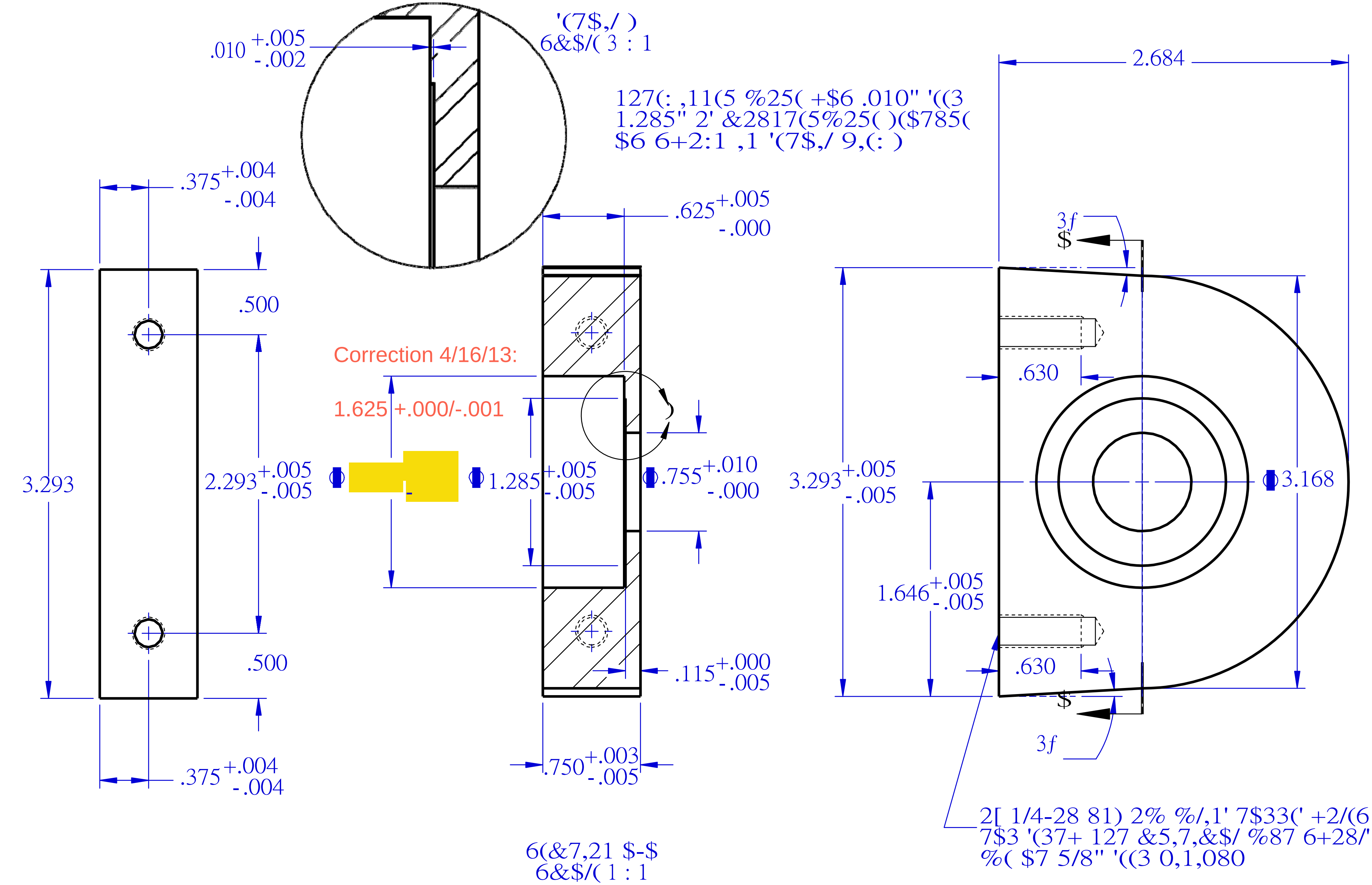
72/(5$1&(6: .;± .020 / .;;± .010 / .;;;± .005 /)5$&7± 1/32 / $1*/(± 1/2° / &21&± .005	'5,// +2/(6: .013-.040: +.001/-.001 / .041-.130: +.002/-.001 / .131-.229: +.003/-.001 / .230-.500: +.004/-.001 / .501-.750: +.005/-.001 / .751-1.000: +.007/-.001	0$7'/: 67((/ 1045	'5$:1: &$03%(//	7,7/(: +25,=217$/ &52660(0%(5
		),1,6+: 0(/21,7(	&+.'': %</$5'	'$7(: 4/7/13 / 6&$/(: 2:1



3DJH 4 RI 4

CAL POLY Mechanical Engineering	72/(5$1&(6:	0$7'/: 67((/ 1045	'5$:1: &$03%(//	7,7/(: +25,=217$/ &52660(0%(5
titan ENGINEERING		),1,6+: 0(/21,7(	&+.': %</$5'	'$7(: 4/7/13
				6&$/(: 1:2

72/(5$1&(6:		81/(66 63(&,),(' 27+(5:,6('5,// +2/(6
.;±	.020	.013-.040: +.001/-.001
.;;±	.010	.041-.130: +.002/-.001
.;;;±	.005	.131-.229: +.003/-.001
)5$&7±	1/32	.230-.500: +.004/-.001
$1*/(±	1/2°	.501-.750: +.005/-.001
&21&±	.005	.751-1.000: +.007/-.001

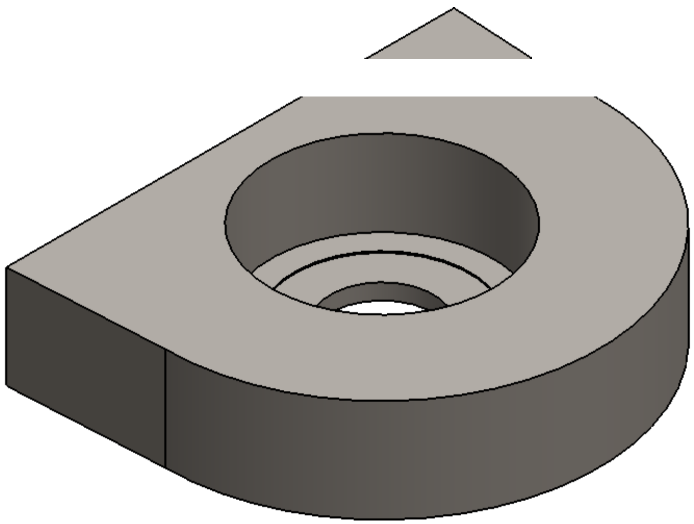


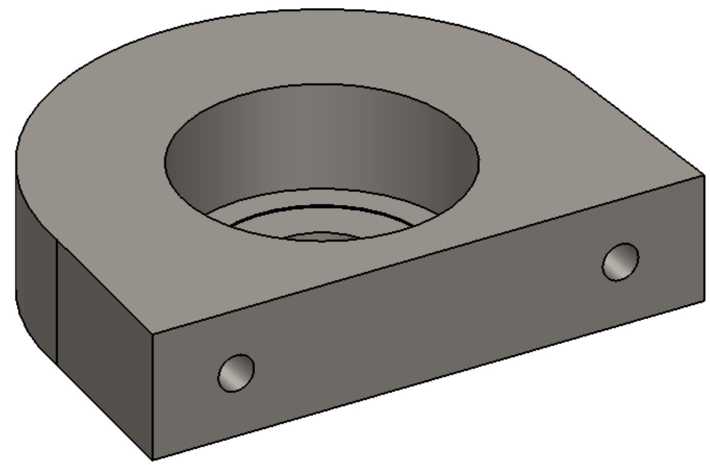
3DJH 1 RI 2

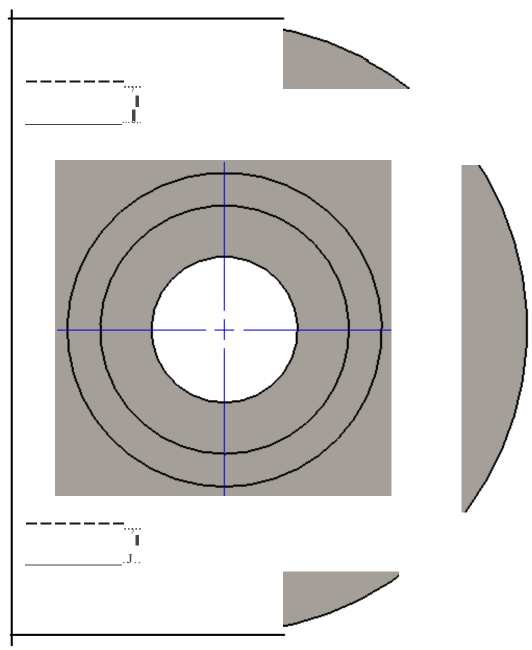
CAL POLY Mechanical Engineering	0$7'/: 67((/ 1045	'5$:1: &$03%(//	7,7/(: /2:(5 3,927 3/$7(
tilton ENGINEERING	),1,6+: 0(/21,7(	&+.'': %</$5'	'$7(: 4/7/13	6&$/(: 1:1

72/(5$1&(6:
.;± .020
.;;± .010
.;;;± .005
)5$&7± 1/32
$1*/(± 1/2°
&21&± .005

81/(66 63(&,),(' 27+(5:,6(
'5,// +2/(6
.013-.040: +.001/-.001
.041-.130: +.002/-.001
.131-.229: +.003/-.001
.230-.500: +.004/-.001
.501-.750: +.005/-.001
.751-1.000: +.007/-.001



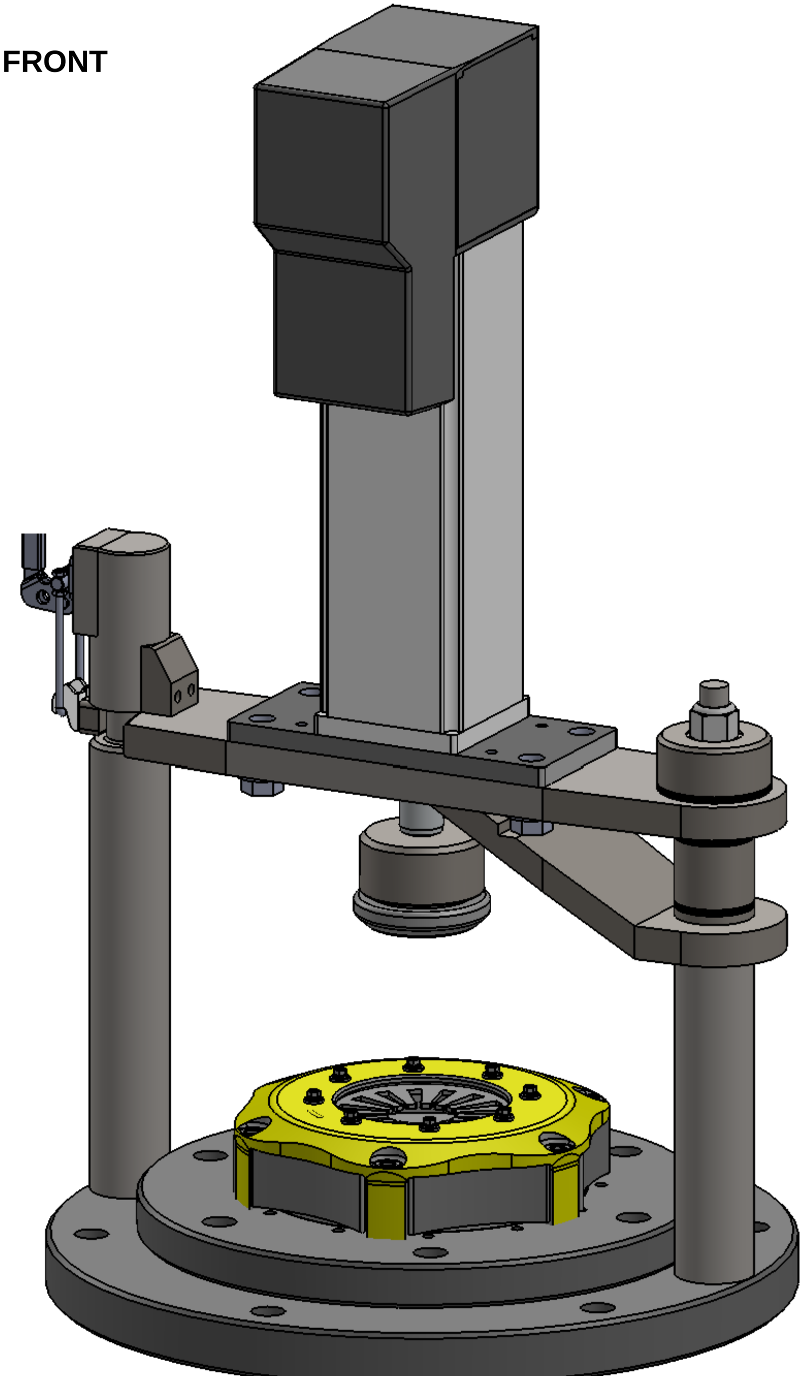




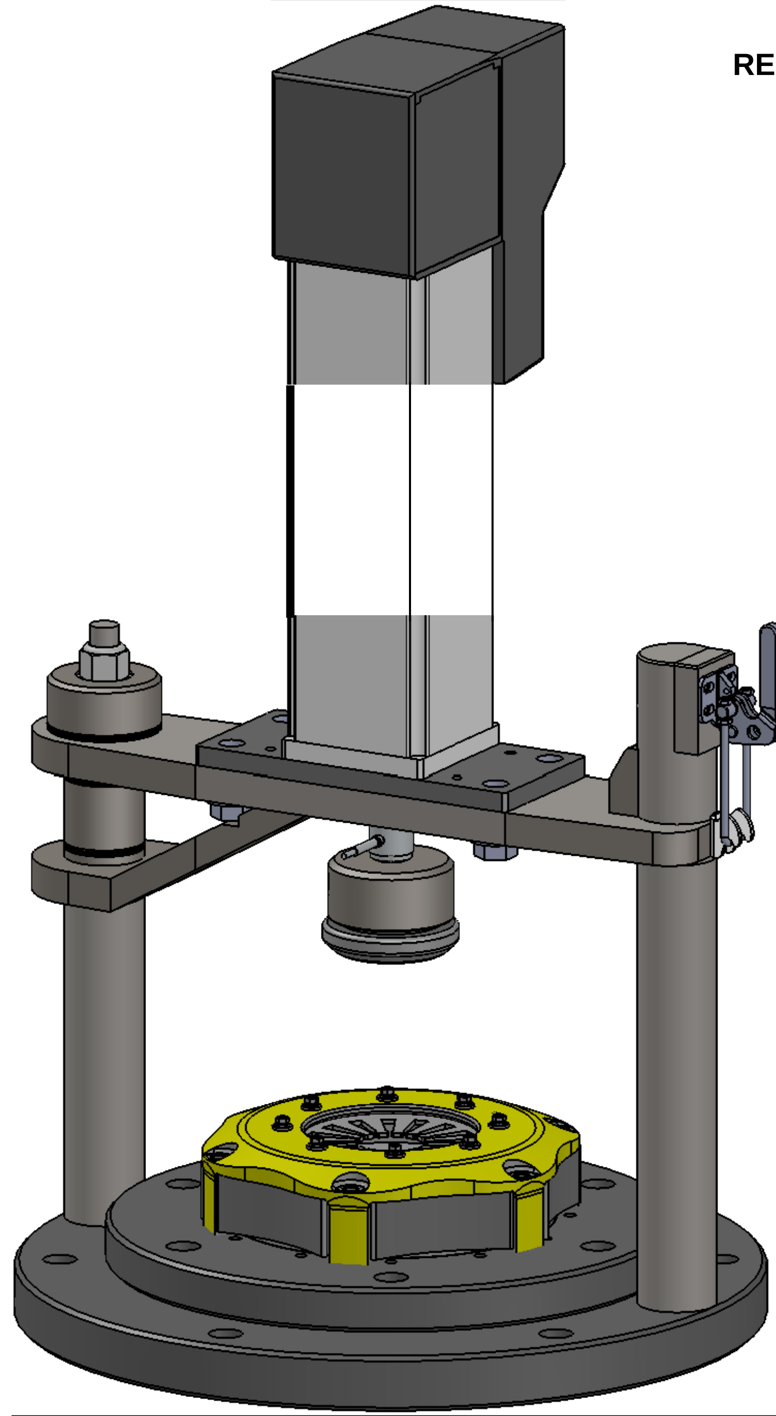
CAL POLY Mechanical Engineering tilton ENGINEERING	TOLERANCES: UHfstSHCflf[)<)!HEt......f .X::!: J)20 .XX::t DIO .XXX± .005 FRACT± 1/32 ANGLE± 1/2° CONC+ .005 DRILL HOLES 013-.040: +.001(·.001 041-.130: +.00'2(·.001 .131-.229: +.003(-.001 23:1-.500: +.004(-.001 501-.750: +.005(-.001 751·1.000: +.007(-.001	MAll: STEEL 1045 FINISH: MELONITE	DRAWN: CAMPBELL CHKD: BYLARD

TITLE:	LOWER PIVOT PLATE
DATE: 4/7/13	SCALE: 1:1

FRONT



REAR



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TOLERANCES: UNLESS SPECIFIED OTHERWISE

.X±	.020
.XX±	.010
.XXX±	.005
FRACT±	1/32
ANGLE±	1/2°
CONC±	.005

DRILLHOLES

013-.040:	+.001(0 01
041-.130:	+.002(-001
.131-.229:	+.003(-.001
2:0-.soo,	-.004i-.001
501-.750:	•.oo.sr-.ool
751-1000:	+.007(-001

MAll:

FINISH•. MELONITE + ANODIZED

DRAWN: CAMPBELL

CHKD: BYLARD

TITLE: CLUTCH RELEASE LOAD TESTER

DATE: 4/8/13

SCALE: 1:4

NOTE: Cost ledger does NOT include the following:

- Hookup wire and small electronic equipment (op-amps, resistors, etc) as these items were not finalized at the time of writing (6/13/13)

- Shipping, handling, or sales tax

- Raw material stock (most sourced and provided internally by Tilton)

- Labor costs of any kind, including CNC machining done by Tilton, Cal Poly, or outside sources

INSTRUMENTS/ELECTRONICS

Item	Manufacturer (if known)	Distributor	Part Number	Subtotal	Qty Used	Total
Load Cell	Futek	Futek	LCM350 - FSH00673	525.00	1	525.00
DAQ Card	Futek	Futek	USB210 - FSH03221	500.00	1	500.00
Load Cell Calibration	Futek	Futek	SLC00007	150.00	1	150.00
Linear Actuator	Exlar	Minarek	T2M090-0601-GFF-IE-238-40-230-SIO	4055.00	1	4055.00
Actuator USB Cable	Exlar	Minarek	CBL-T2USB485-M8-015	150.00	1	150.00
Latch	Protex	Protex	TLH-UBAB-041-080	17.05	1	17.05
Latch Catchplate	Protex	Protex	TLC-UBCP-020-024	2.26	1	2.26
PNP Proximity Sensor		McMaster-Carr	McMaster 7674K912	69.20	1	69.20
Actuator Cable Glands M20 x 1.5		McMaster-Carr	McMaster 9448K33	11.82	2	23.64
Shielded 14 AWG Power Cable		McMaster-Carr	McMaster 9936K75	7.66	12 ft	91.92
Shielded 18 AWG I/O Cable		McMaster-Carr	McMaster 7673K46	6.23	5 ft	31.15
Touch Pad Switch		McMaster-Carr	McMaster 7692K4	17.72	1	17.72
E-Stop Corrosion-Resistant Enclosure Switch Turn to Reset	Baco	McMaster-Carr	Baco-LBX17301,McMaster-6785K23	43.86	1	43.86
Steel Disconnect Switch, Fusible, Indoor, DPST, 3-Wire, 30 Amps at 240V AC	Siemens	McMaster-Carr	McMaster 7524K21	45.10	1	45.10
K5 Fuse 250 VAC, 15 Amps		McMaster-Carr	McMaster 7072K104	3.70	2	7.40
DB25 Parallel Male/Dual Female Y-Splitter Printer Cable		CablesOnline.com	CablesOnline YS-005	12.99	1	12.99
DB-25 - Female / Female Gender Changer		CablesOnline.com	CablesOnline GC-008	2.99	1	2.99
DB-25 – Male/Male Gender Changer		CablesOnline.com	CablesOnline GC-007	2.99	1	2.99
24 VDC Power Supply	Omron	McMaster-Carr	Omron S8JX-G05024C, McMaster 7010K46	83.48	1	83.48
					INSTRUMENTS TOTAL	5831.75

HARDWARE/FASTENERS

Item	McMaster-Carr P/N	Subtotal	Qty Purchased	Total
Grade 8 Alloy Steel Hex Head Cap Screw, Zinc Yellow Plated, 1/2"-20 Thread, 3-1/2" L, Fully Thread	92620A751	7.70	1 Pack	7.70
Button Head Socket Cap Screw, 1/4"-20 Thread, 1-1/2" Length	91255A546	7.70	1 Pack	7.70
Serrated Belleville Washer, 1/4"/M6 Screw Size, .38" OD, .03" Thick	93501A029	8.50	1 Pack	8.50
Nylon-Insert Hex Locknut, Zinc-Yellow Plated, 5/8"-18 Thread Size	97135A275	4.53	1 Pack	4.53
.032" Thick Washer for 1-3/4" Shaft Diameter, Steel Thrust Needle-Roller Bearing	5909K55	2.06	Qty 2	4.12
Cage Assembly for 1-3/4" Shaft Diameter, 2-1/2" OD, Steel Thrust Needle-Roller Bearing	5909K42	4.45	Qty 1	4.45
.032" Thick Washer for 1-1/8" Shaft Diameter, Steel Thrust Needle-Roller Bearing	5909K51	1.53	Qty 6	9.18
Cage Assembly for 1-1/8" Shaft Diameter, 1-3/4" OD, Steel Thrust Needle-Roller Bearing	5909K37	3.09	Qty 3	9.27
High-Load Steel Ball Bearing Double Sealed, for Shaft Diameter 3/4" X 1-5/8" OD X 1/2" W	2780T63	17.85	Qty 2	35.70
Pillow-Block Linear Bearing, Closed, for 3/8" Shaft Diameter	6255K32	42.02	Qty 1	42.02
Grade 8 Alloy Steel Hex Head Cap Screw, Zinc Yellow Plated, 9/16"-18 Thread, 2" L, Fully Thread	92620A782	13.30	1 Pack	13.30
Serrated Belleville Washer, 9/16"/M14 Screw Size	93501A034	12.00	1 Pack	12.00
Socket Head Cap Screw, 10-32 Thread, 1/2" Length	91251A342	11.34	1 Pack	11.34
Socket Head Cap Screw, 1/4"-28 Thread, 1" Length	91251A442	10.82	1 Pack	10.82
Serrated Belleville Washer, No. 10	93501A027	8.00	1 Pack	8.00

Serrated Belleville Washer, 1/2"	93501A033	11.56	1 Pack	11.56
Grade 8 Steel Flat Washer, SAE, 9/16"	98023A034	7.05	1 Pack	7.05
Grade 8 Steel Hex Nut, 9/16"-18 Thread Size	94895A830	8.15	1 Pack	8.15
Hex Head Cap Screw, Zinc Yellow Plated, 1/2"-13 Thread, 3-1/2" L, Fully Thread	92620A726	3.85	Qty 1	3.85
Socket Head Cap Screw, 10-24 Thread, 1-1/2" Length	91251A251	9.61	1 Pack	9.61
Shaft Collar, Type 303 Stainless Steel, 1/4" Bore	6435K32	3.40	Qty 1	3.40
			HARDWARE TOTAL	**$232.25**

TRAVEL

Travel Date	Destination	Driver	Total Mileage	Mileage Rate	Total Cost
10/4/12	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
2/14/13	Tilton Engineering, Buellton CA	Ryan Bylard	128.0	$0.50/mile	64.00
5/14/13	Tilton Engineering, Buellton CA	Ryan Bylard	128.0	$0.50/mile	64.00
6/6/13	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
6/11/13	Tilton Engineering, Buellton CA	Kevin Campbell	128.0	$0.50/mile	64.00
				TRAVEL TOTAL	**$320.00**

PROJECT TOTAL	**$6384.00**

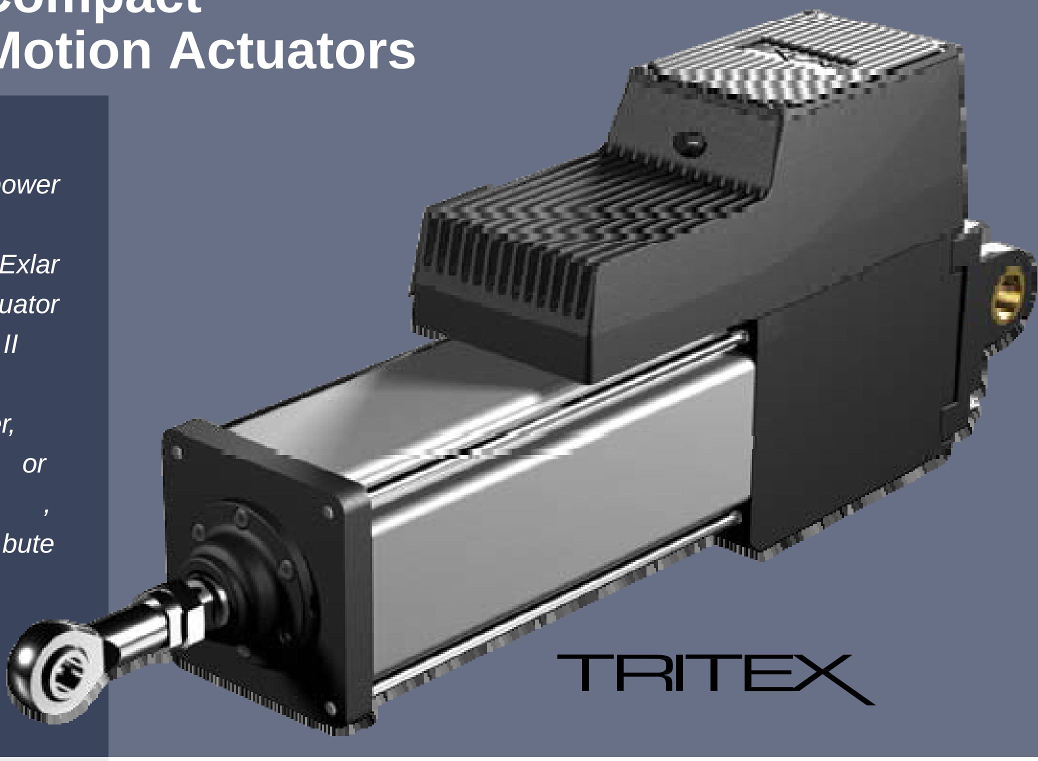
Vendor Spec Sheets

Advanced Linear and Rotary Actuators
with Embedded Electronics

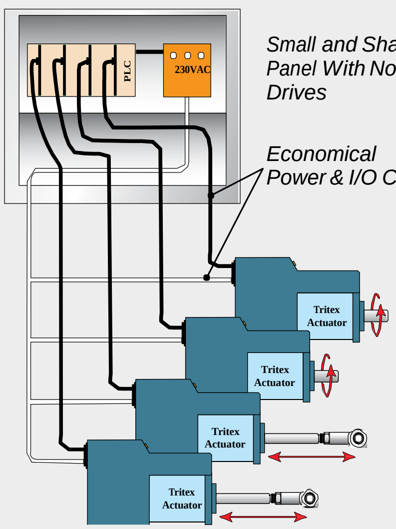
Tritex II™ AC Powered Actuators

Industry's Most Compact
Linear & Rotary Motion Actuators

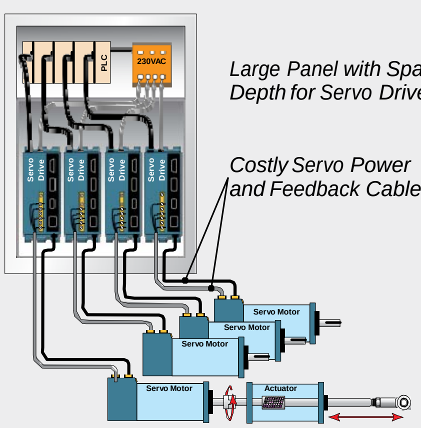
By combining the latest electronic power technology with advanced thermal management modeling technology, Exlar has set a benchmark for electric actuator performance versus size. The Tritex II actuators integrate an AC powered servo drive, digital position controller, brushless motor and line or rotary actuator in one elegant, , sealed package. Now, you can distr bute motion control and solve your application with one integrated device. Simply connect AC power, I/O, communications and go!



Tritex II System



Alternative Systems



Dramatically Reduce Space Requirements

Tritex II actuators are the highest power density, smallest footprint servo drive devices on the market. Finally, you can incorporate a fully electronic solution in the space of your existing hydraulic or pneumatic cylinder. You can also eliminate troublesome ball screw actuators or bulky servo gear reducers. And the space previously consumed by panel mount servo drives and motion controllers is no longer needed. Tritex II actuators may also reduce the size of your machine design while offering significant reliability improvement.

Reduce Costs

Because the AC powered Tritex II unit houses the servo drive, digital positioner and actuator all in one convenient package, you eliminate the labor costs for mounting and wiring the panels. Cable costs are also significantly reduced by eliminating the need for expensive, high-maintenance specialty servo cables. All that is required is an economical standard AC power cord, and standard communication cable for digital and analog I/O.

Also eliminated are the issues associated with power signals and feedback signals traveling long distances from servo drive to servo motor. With the Tritex II, the servo drive and motor are always integrated in the same housing.

No Compromises on Power, Performance or Reliability

With forces to approximately 4000 pounds (18 kN) continuous and 10,000 pounds peak (44 kN), and speeds to 33 in/sec (800 mm/sec), the AC Tritex II linear actuators also offer a benefit that no other integrated product offers - POWER! No longer are you limited to trivial amounts of force, or speeds so slow that many motion applications are not possible. And the Tritex II with AC power electronics operates with maximum reliability over a broad range of ambient temperatures; -40˚C to +65˚C.

The AC powered Tritex II actuators contain a 1.5 kW servo amplifier and a very capable motion controller. With standard features such as analog following for position, compound moves, move chaining and individual force/torque control for each move, the Tritex II Series is the ideal solution for most motion applications.

Applications

Flexible Communications

Multiple feedback types, including absolute feedback, allow you to select the system that is best-suited for your application. Digital and analog I/O plus popular communication networks such as Modbus TCP, Ethernet/IP and ProfiNet (future networks include CANopen and Hart) allow the Tritex II to become an integral part of your control architecture or machine control processes.

Linear Applications

Tritex II linear actuators employ Exlar's patented, inverted roller screw mechanism for converting rotary motion to highly robust and long-life linear motion. These characteristics enable the Tritex actuator to solve applications that previously required pneumatic or hydraulic cylinders. No additional mechanisms (such as acme or ball screws) are necessary to convert the actuator's rotary power into linear motion in order to move the load. Simple to configure, yet powerful interface software allows the Tritex II to perform nearly any motion requirements. Moves can be made to incremental or absolute positions, and also to preset forces or to a switch (input). Moves can be initiated by inputs, by other moves, or by events such as reaching a selected force. The Tritex II linear actuator can be programmed to follow an analog command signal, making it ideal for controlling valves and dampers in process control applications.

Rotary Applications

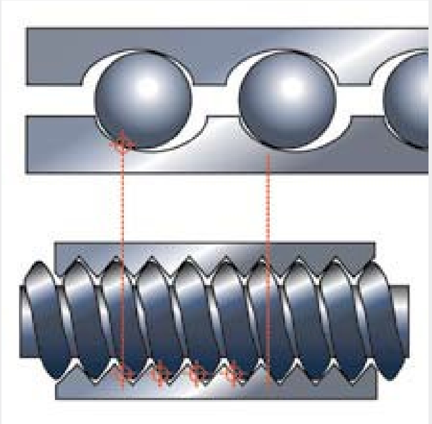
Tritex II rotary motors and gearmotors provide high response and precise control of a rotatable shaft similar to that found in any electric motor. The difference is that with Tritex II you can program (via your PC) the rotational speed and position of the output shaft in response to external commands. For example, the motor can be commanded to rotate at a controlled velocity and precisely stop at a preprogrammed position. You can also program the unit to run at a preset velocity until a switch input is received or a preprogrammed torque level is produced against a load. Alternatively, the rotary Tritex II actuators can be set up to follow an analog signal, either voltage or current, representing your choice of torque, velocity or position. Signals for initiating the preprogrammed velocity and position commands come from optically isolated inputs or via network communications. Likewise, isolated output commands of the status and events allow precise coordination with your sys
or r
ope

Optional Internal Gear Reducer

If the application requires greater torque and less speed than available with the base unit, the Tritex II is available with an integral servo grade planetary gear reducer. Gear ratios of 4:1 to 100:1 allow the power of Tritex II to be applied over a broad range of torque requirements.

Roller Screw Basics

Exlar's patented, inverted roller screw is a mechanism for converting rotary torque into linear motion, in a similar manner to acme screws or ball screws. But, unlike those devices, roller screws can carry heavy loads for thousands of hours in the most arduous conditions. This makes roller screws the ideal choice for demanding, continuous-duty linear motion applications. The difference is in the roller screw's design for transmitting forces. Multiple threaded helical rollers are assembled in a planetary arrangement around a threaded shaft as seen below, which converts a motor's rotary motion into linear movement of the shaft or nut.



Compare a similar size ball screw to Exlar's planetary roller screw design and see many more contact points on the roller screw. This results in higher load-carrying capacity and improved stiffness.

The Exlar Advantage

Exlar has delivered thousands of roller screw linear actuator solutions around the world in applications ranging from demanding automatic welding to controlling fuel or steam valves on turbine generators. Exlar's linear actuators provide trouble-free, precise linear motion control for millions of cycles of operation.

Typical Applications

- Process Control
- Test
- Simulation
- Food Processing
- Industrial Automation
- Forestry
- Semi-conductor
- Remote Vehicles
- Medical Equipment
- Automotive Assembly
- Molding
- Die Casting
- Welding

Class I Division 2 Rating

Exlar's Tritex II actuators are available for applications requiring CSA Class I Division 2 certification. Ordering a standard I/O interconnect with or without 4-20 mA Analog I/O, and the N option for the NPT port will provide you with Class I Division 2 rated product.

Tritex II 230 V AC Agency Approvals

Agency/Standard	Tritex Models/Options
CE, EMC EN61800-3, Safety EN 61800-5-1	All models
CSA 139	All models
CSA Class I, Div 2	Requires NPT Connection Option. EIP, TCP and ABZ options are not covered
UL 508 C, Type 4 Enclosure	Requires NPT Connection Option. EIP, TCP and ABZ options are not covered
IP 65	Standard on T2X, R2M, R2G models, available on T2M models with P5 option
Vibration Rating	Standard: IEC 61800-5-1 safety standard for drives. 1g peak, up to 150 Hz for <2 hrs. Optional: (HV option) IEC 60068-2-64 random vibration standard, 2.5g rms, 50 to 500 Hz.

Tritex II Models

- T2M standard mechanical capacity actuator, 90 and 115 mm
- T2X high mechanical capacity actuator, 90 and 115 mm
- R2M rotary motor, 90 and 115 mm
- R2G rotary gearmotor, 90 and 115 mm

Power Requirements

- AC Power 100V - 240V, +/- 10%, single phase
- Built-in AC line filter
- Connections for external braking resistor

Feedback Types

- Analog Hall with 1000 count resolution
- Incremental encoder with 8192 count resolution
- Absolute Feedback (analog hall with multi-turn, battery backup)

Communications & I/O

Digital I/O:

- 8 digital inputs
  - 10 to 30 VDC opto-isolated
- 4 digital outputs
  - 30 VDC maximum, 100 mA, opto-isolated

Analog I/O:

- 1 analog input
  - 0-10V or +10V/-10V, 12 bit resolution
  - Force/torque, velocity, position
- 1 analog output
  - 0-10V mode
  - Force/torque, velocity, position
- Optional isolated 4-20mA board
  - 1 4-20 mA isolated analog input, 16 bit resolution
  - 1 4-20 mA isolated analog output, 12 bit resolution

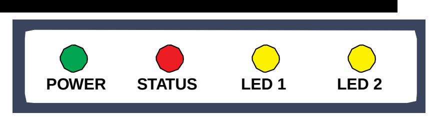
Standard Communications:

- 1 RS 485 port, Modbus RTU, opto-isolated for programming, controlling and monitoring

Tritex II rotary motor with cable glands shown left and Tritex II linear actuator with threaded ports shown below.

Class I Div 2

163694



Backpanel LED Display

Tritex II Series Operation

The Tritex II Series actuators can operate in one of five different motion-producing modes. These modes solve an endless variety of applications in industrial automation, medical equipment, fastening and joining, blow molding, injection molding, testing, food processing, and more.

Programmed functions are stored in the Tritex II non-volatile memory. A standard RS/485 serial interface allows control, programming and monitoring of all aspects of the motor or actuator as it performs your application. Optional communications protocols are available.

Operating Modes

1) Move to a position (or switch)
The Tritex II Series actuators allow you to execute up to 16 programmed positions or distances. You may also use a limit switch or other input device as the end condition of a move. This combination of index flexibility provides a simple solution for point-to-point indexing.

2) Move to a preset force or torque
The Tritex II Series allows you to terminate your move upon the achievement of a programmed torque or force. This is an ideal mode for pressing and clamping applications.

3) Position proportional to an analog signal
Ideal for process control solutions, the Tritex II Series provides the functionality to position a control valve by following an analog input signal. This allows the Tritex II Series to deliver precise valve control — control that cannot be achieved by other electric, hydraulic or pneumatic actuators.

4) Velocity proportional to an analog signal
Tritex II actuators offer you the capability to control velocity with an analog signal. This is particularly useful with Tritex II rotary motors offering precise control of the speed of any process or operation.

5) Force/torque proportional to analog signal
Perfect for pressing and torquing applications, you can control torque from an analog input while in torque mode.

Tritex Option Boards

- Option boards offer additional functionality to the base Tritex II actuators
  - Terminal board for customer I/O
  - Terminal board for customer I/O plus encoder output (requires encoder feedback (IE option))
  - Isolated 4-20mA analog input and output
  - Customer specific
- Communication buses
  - EtherNet/IP
  - Modbus TCP
  - CANopen
  - PROFINET I/O
  - HART

Connectivity

- Internal terminals accessible through removable cover
- Threaded ports for cable glands
- Optional connectors
  - M23 Power
  - M16 I/O
- M8 connector for RS485
- M12 connector for Ethernet options
- Custom connection options

Selectable Input Functions

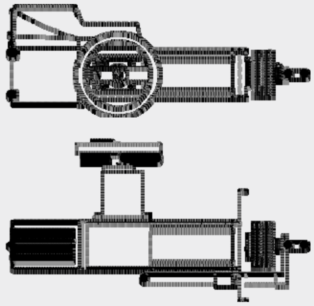
- Enable
- Move (0-15)
- Dedicated Position
- Jog+
- Jog- select move (0-15)
- Jog Fast
- Home
- Extend Switch
- Retract Switch
- Home Switch
- Teach Enable
- Teach Move (0-15)
- Stop
- Hold
- Alternate Mode; allows you to switch between 2 operating modes.

Selectable Output Functions

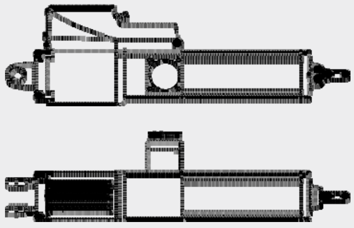
- Enabled
- Homed
- Ready (Enabled and Homed)
- Fault
- Warning
- Fault or Warning Active
- Move (0-15) in Progress
- Homing
- Jogging
- Jogging+
- Jogging-
- Motion
- In Position
- At Home Position
- At Move (0-15)
- Position
- Stopped
- Holding
- In Current Limit
- In Current Fold back
- Above Rated Current
- Home

Manual Override Options

Handwheel
This option gives you a manual engagement switch that can be used to disable the power to the actuator for manual operation without any external tools.



Side Drive
This option allows for emergency operation in a power down condition using a standard socket wrench.



Expert User Interface

Expert, the Tritex II user interface software, provides you with a simple way to select all aspects of configuration and control required to set up and operate a Tritex II actuator. Easy-to-use tabbed pages provide access to input all of the parameters necessary to successfully configure your motion application. ‘Application’ files give you a convenient way to store and redistribute configurations amongst multiple computers, and ‘Drive’ files allow the same configuration to be distributed to multiple Tritex II actuators. Motion setup, homing, teach mode, tuning parameters, jogging, I/O configuration, and local control are all accomplished with ease using Expert software.

Protocol Options

The standard communication protocol for Tritex is an RS485 connection using Modbus RTU. The Modbus protocol provides a simple and robust method to connect industrial electronic devices on the same network. The Expert software acts as a Modbus Master and the Tritex II acts as the Slave device, only responding to requests commanded from the software. The Expert software allows full access to commissioning, configuring, monitoring and controlling the Tritex II.

In addition to Modbus RTU communications, the following protocol options are available by selecting communication option boards. Exlar requires initial commissioning of a Tritex II actuator to be performed with the Modbus protocol.

Modbus TCP

Modbus TCP couples Modbus communication structure from Modbus RTU with EtherNet connectivity. The Modbus TCP option is fully supported by the Expert software and offers seamless use for commissioning, configuring, monitoring and controlling the Tritex II. A Modbus mapping table allows you to map all of the parameters you wish read and modify into a register bank of up to 100 registers. This will allow a PLC program to perform a single read operation and a single write operation to all the parameters.

To maintain standard connectivity, we offer the EtherNet connection through a sealed M12 connector.

EtherNet/IP

EtherNet/IP allows you to change, monitor and control the Tritex II through implicit or explicit messaging initiated from your Rockwell PLC. Tritex parameters are set up through the Expert software using a Tritex II parameter to EtherNet/IP parameter mapping table. Up to 100 input and 100 output 16 bit registers can be mapped to Tritex II parameters.

To maintain standard connectivity, we offer the EtherNet/IP connection through a sealed M12 connector.

CANopen

The Tritex II implementation of CANopen follows the DS402 device profile for motion control distributed through CAN in Automation (CiA). CANopen protocol specifies which identifier is used for predefined purposes.

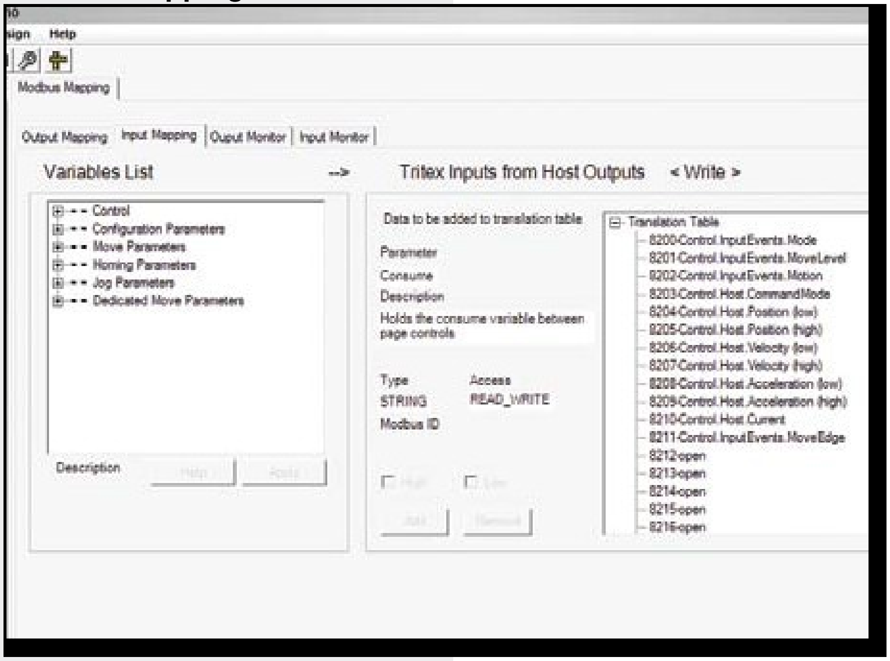
PROFINET IO

PROFINET IO allows you to change, monitor and control the Tritex II from your Siemens PLC. Tritex parameters are set up through the Expert software using a Tritex II parameter to PROFINET IO parameter mapping table. Up to 100 input and 100 output, 16 bit registers can be mapped to Tritex II parameters. Connection through sealed M12 connector.

HART

The HART Protocol is the global standard for sending and receiving digital information across analog wires between smart devices and the control or monitoring system.

Modbus Mapping Screen



Motion Setup

Exlar configuration provides several templates for various applications. These can serve as your configuration, or as a starting point for your configuration. You can also begin by selecting configuration details specific to your application. You can configure a move to position, move to switch, or move to force motion at the click of a button. The Tritex II products offer absolute and incremental motion, as well as moves ending on a condition such as a specific force or torque.

Control Page

The Expert control page gives you the ability to initiate all motion functions from one single, simple screen. This screen provides you with very easy system start-up and testing without all the inconvenience of machine wiring.

The control page offers the capability to enable and disable the drive and perform fast and slow jogs. This gives you the ability to verify motion before needing any I/O wiring.

Monitoring and Diagnostics

All input functions can be monitored and activated from the Expert monitor page, and all output functions can be monitored. Information on critical fault and status data is available as a separate page, or as a fixed window on the bottom of each page of the software.

Configuring I/O

A pull down menu allows all I/O to be set up in minutes.

Inputs can be configured to be maintained, or momentary, depending on the application requirements. Input and output logic can also be inverted with a simple click.

Homing

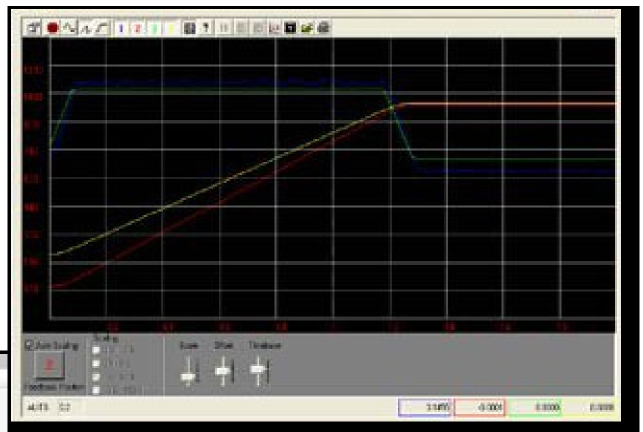
You can home to an input, by using a proximity or limit switch, or home to a specific force or torque.

Homing to a force or torque is ideal for setting up applications that require motion referenced to a hard stop, like the closed position of a valve, or the final position of a press.

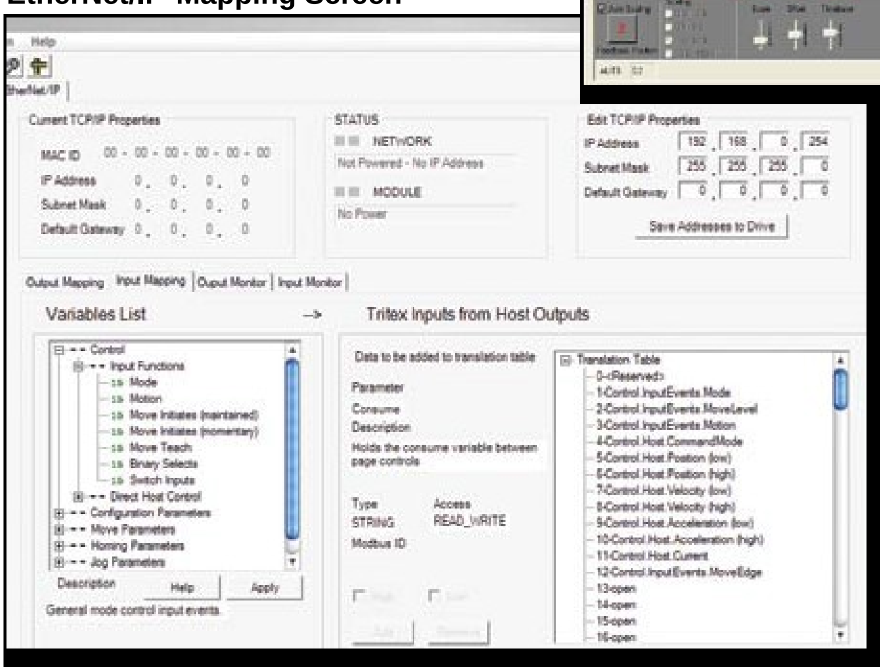
Teach Mode

In this mode, you can jog the actuator to the desired position, and activate an input, or click a button in the Expert software and the current position of the actuator becomes the defined distance or absolute position associated with a particular move command.

Scope



EtherNet/IP Mapping Screen



Scope

The Expert Software includes a 4 channel digital oscilloscope feature.

The user can select up to 4 Tritex drive parameters to be monitored simultaneously.

For high speed requirements the data can be captured in the drive's memory at an adjustable rate down to 100 micro sec, then uploaded for plotting. The plots can be saved or printed and the captured data can be saved as a comma separated file for further analysis with Excel.

Process Control Functionality

Tritex II actuators, available in both rotary and linear versions, provide a perfect solution for your valve actuation needs. Small hysteresis and dead band, quick response to small signal changes and stable dynamic responses delivered by Tritex II actuators are all key parameters for process control.

Fully programmable to follow an analog signal representing either position or force, the Tritex II linear actuator is perfectly designed for sliding stem valve applications with thrust requirements up to 3685 lbs. Highly accurate position feedback allows the Tritex II to achieve combined repeatability and hysteresis as low as 0.25%.

The Tritex II Rotary actuators are ideal for operating quarter-turn, full-turn, or multi-turn valves or shaft driven dampers. In shaft driven applications, the rotary Tritex II actuators are directly coupled shaft-to-shaft. This eliminates the ungainly mechanisms usually necessary to convert the linear motion of pneumatic and hydraulic cylinders to rotational motion. Gear ratios of 4:1 to 100:1 allow the power of Tritex II to be applied to a broad range of applications.

Tritex II actuators can be mounted on any valve from any manufacturer.

Valve Software

Our valve software is simple to use, featuring a teach mode for foolproof configuration. Included is a programmable valve cut off position feature that enables a firm valve seat on both new valves, or retrofitted valves.

Class I Division 2 Rating

Exlar's Tritex II actuators are available for applications requiring CSA Class I Division 2 certification. Ordering a standard I/O interconnect with or without 4-20 mA Analog I/O, and the N option for the NPT port will provide you with Class I Division 2 rated product.

Class I, Div 2
163694 8

Benefits for Process Control Applications

100% Torque Availability

Full Torque means almost zero deadband, and stiction in the valve stem is no problem. Current is always available so it will hold its position. This provides excellent process loop control.

Speed of response

Tritex II response rate is measured in milliseconds. This provides excellent modulating control of both ball valves and butterfly valves.

High Accuracy

Tritex II actuators have a built-in position feedback sensor, providing much higher accuracy over potentiometer-based actuators.

Custom Valve Seat

Exlar linear actuators stroke the valve based on position, but can switch to torque mode when seating the valve. This allows a tight cut-off. It also helps with retrofitting valves that may have some wear. For new valves, it makes sure damage isn't done due to over-forcing the stroke.

High Stiffness

Similar to hydraulic actuators, but without the cost or maintenance issues, Tritex II actuators are extremely stiff. This allows control down to the smallest operating range (<1%) and also eliminates dynamic flow problems such as negative gradients.

Fast Stroke Speeds

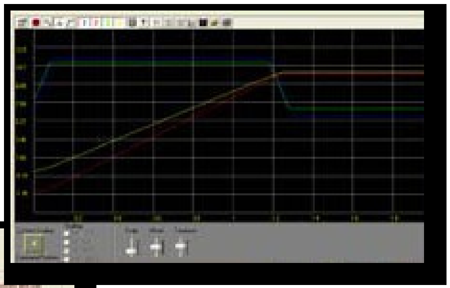
Most other electric actuators are known for being slow - a major disadvantage. Tritex actuators can close a valve in milliseconds if needed.

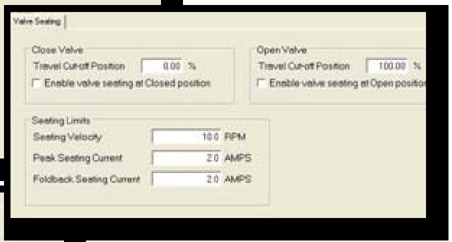
Improved Control

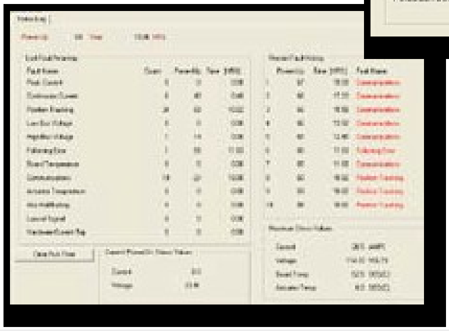
Under modulating conditions, Tritex II actuators provide precise closed loop tracking by effectively eliminating non-linearities and deadtime.

Absolute Feedback

The absolute feedback option gives the actuator memory after teaching the valve limits. Upon power loss, the battery backup will maintain the valve limits.







Travel Life

T2M/T2X Lifetime Curves

The L^{10} expected life of a roller screw linear actuator is expressed as the linear travel distance that 90% of properly maintained roller screws manufactured are expected to meet or exceed. For higher than 90% reliability, the result should be multiplied by the following factors: 95% x 0.62; 96% x 0.53; 97% x 0.44; 98% x 0.33; 99% x 0.21. This is not a guarantee and these charts should be used for estimation purposes only.

The underlying formula that defines this value is:

Travel life in millions of inches, where: $L_{10} = \left(\frac{C}{F}\right)^3 \times S =$

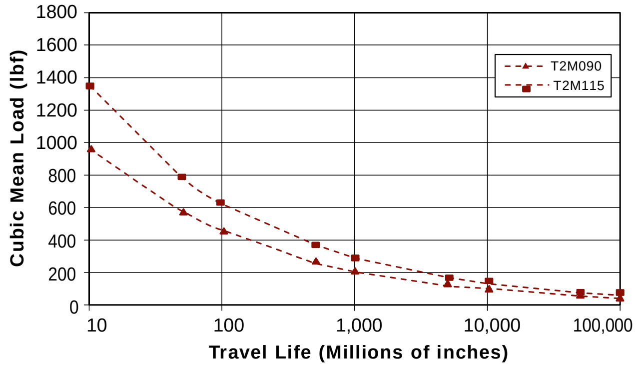
C = Dynamic load rating (lbf)

F = Cubic mean applied load (lbf)

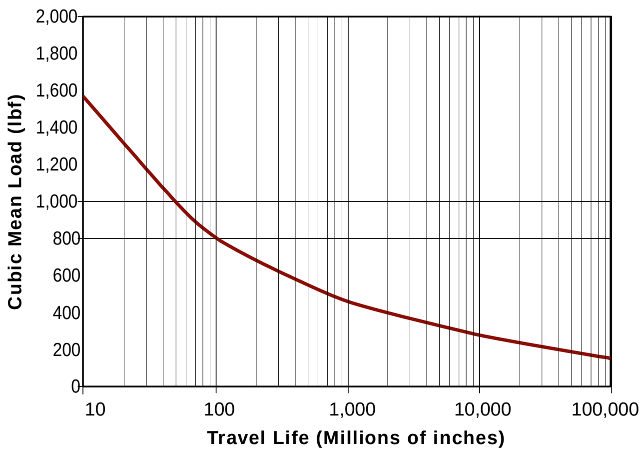
S = Roller screws lead (inches)

All curves represent properly lubricated and maintained actuators.

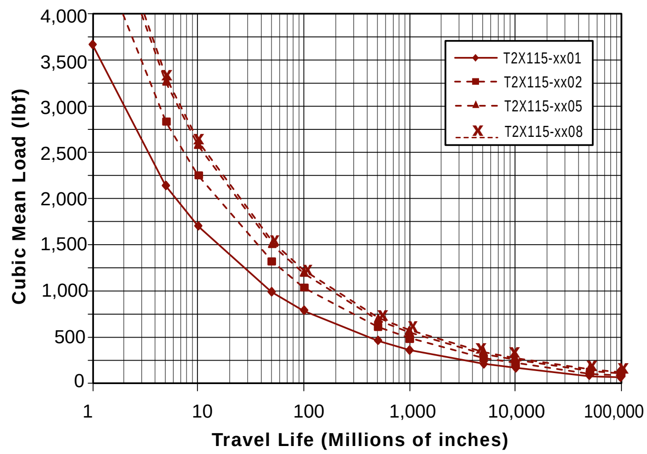
T2M090 and T2M115
L_{10} Travel Life



T2X090
L_{10} Travel Life

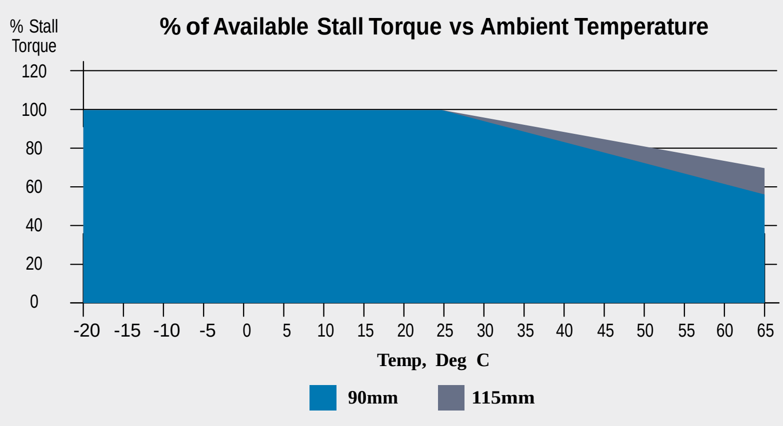


T2X115
L_{10} Travel Life

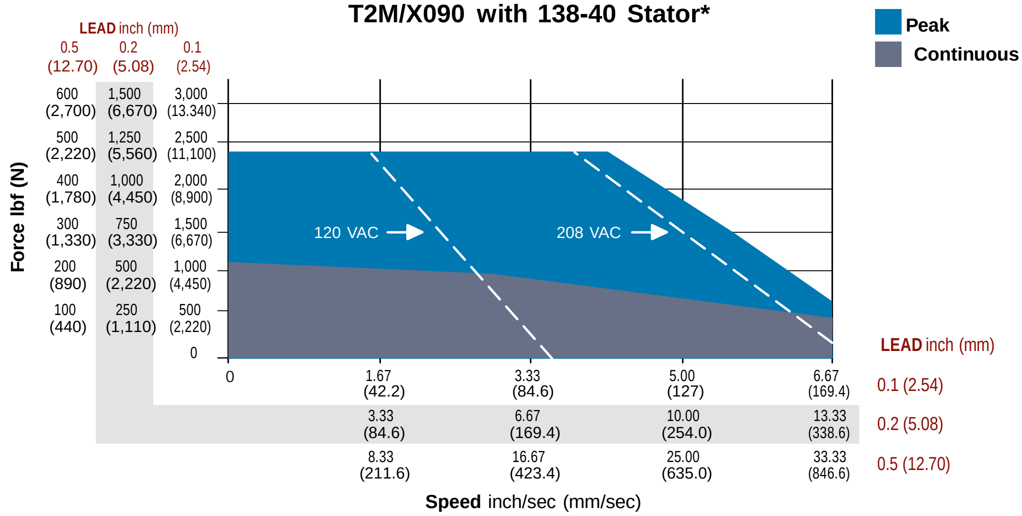


Extended Temperature De-Rating Curve

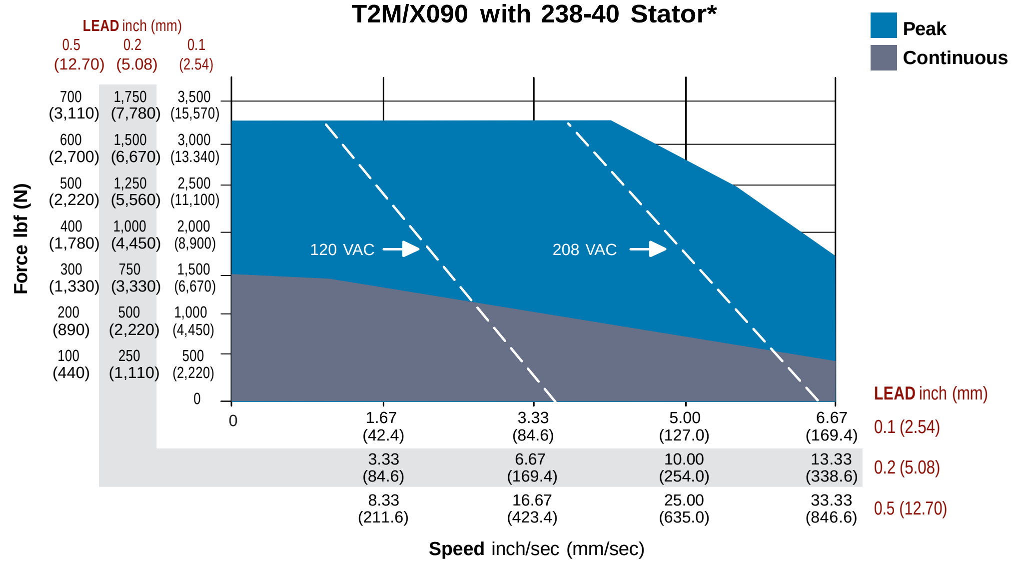
The speed/torque curves are based on 25˚ C ambient conditions. The actuators may be operated at ambient temperatures up to 65˚ C. Use the curve shown right for continuous torque/force deratings above 25˚ C.



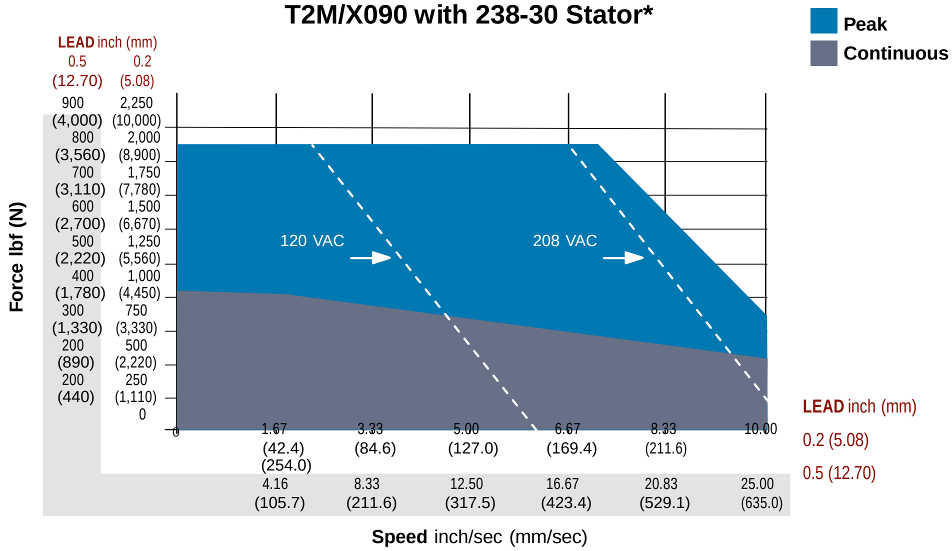
T2M/X090 with 138-40 Stator*



T2M/X090 with 238-40 Stator*

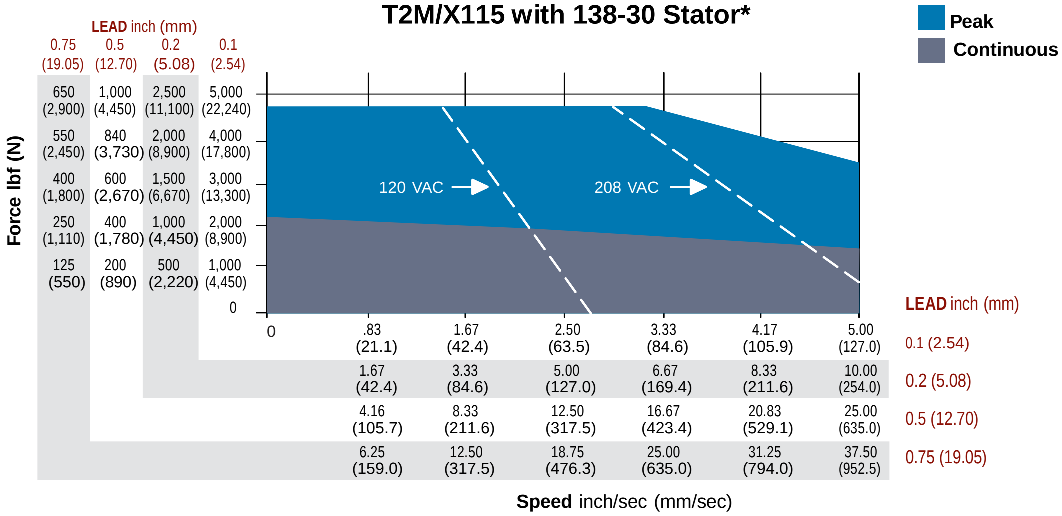


T2M/X090 with 238-30 Stator*

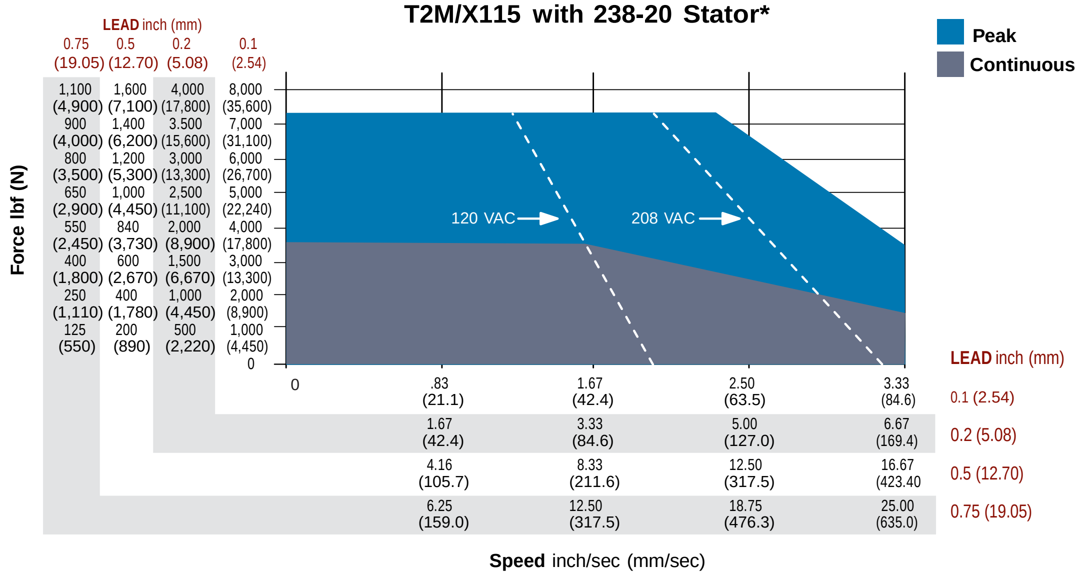


*Test data derived using NEMA recommended aluminum heatsink 10" x 10" x 3/8".

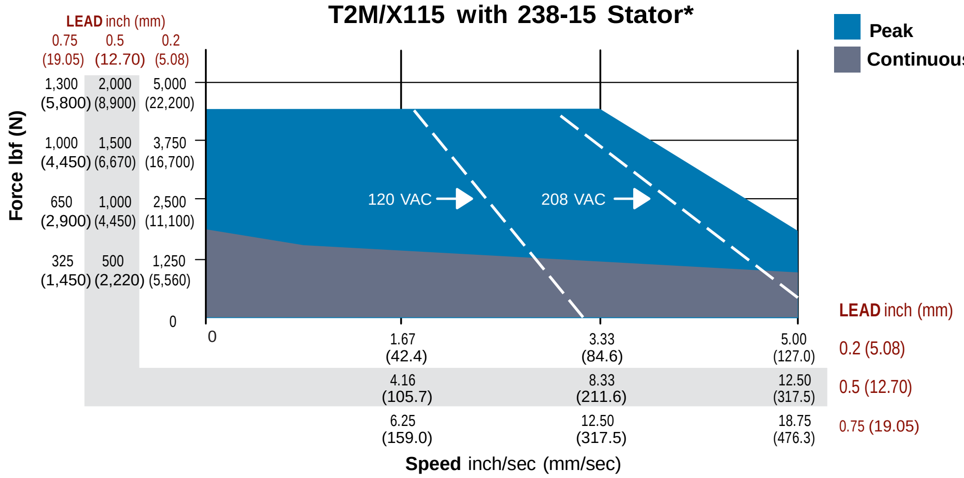
T2M/X115 with 138-30 Stator*



T2M/X115 with 238-20 Stator*



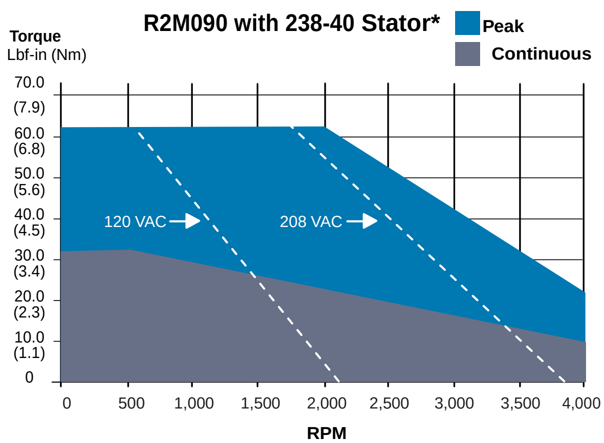
T2M/X115 with 238-15 Stator*

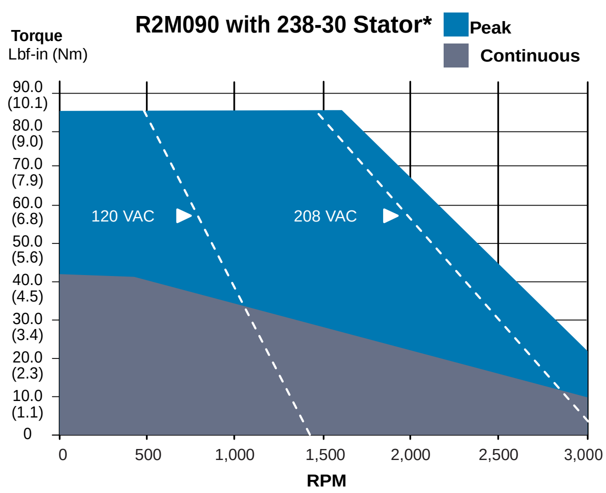


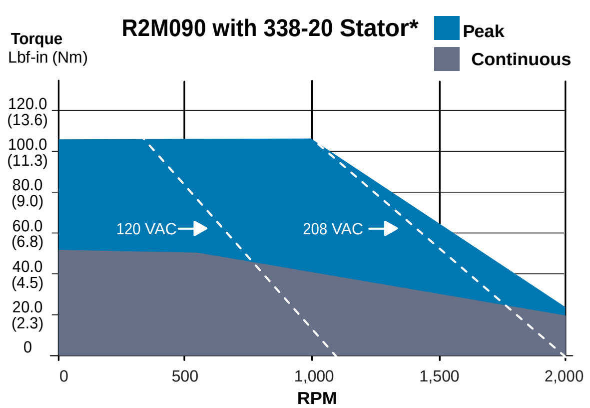
*Test data derived using NEMA recommended aluminum heatsink 12" x 12" x 1/2".

R2M Rotary Motor Speed vs. Torque Curves

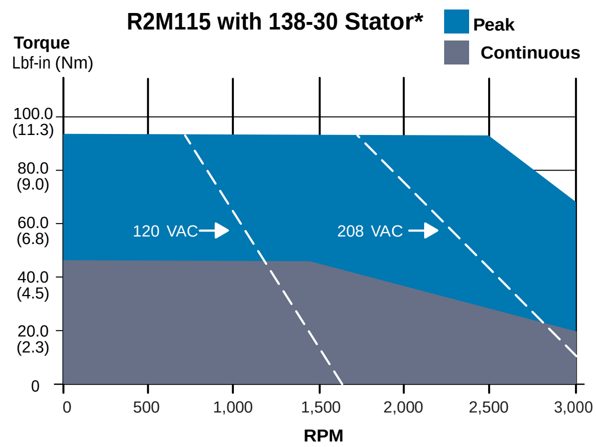
R2M090

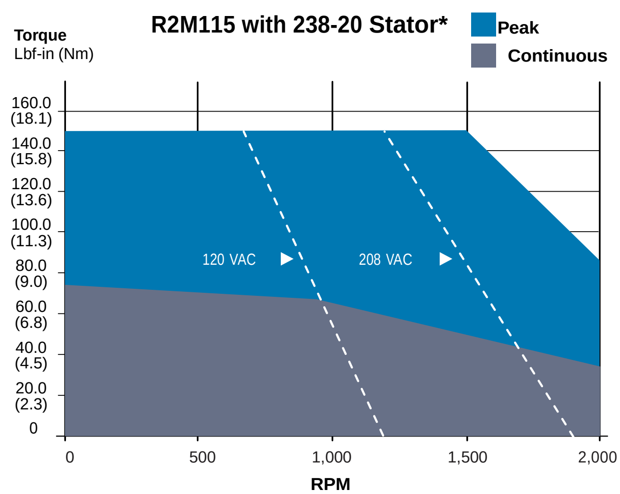


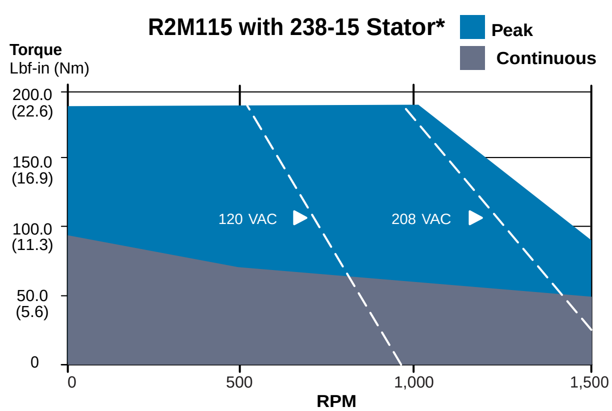




R2M115







For R2G gearmotors, multiply torque by gear ratio and efficiency. Divide speed by gear ratio.

*R2M090 test data derived using NEMA recommended aluminum heatsink 10" x 10" x 3/8".

*R2M115 test data derived using NEMA recommended aluminum heatsink 12" x 12" x 1/2".

T2M/X Linear Actuator Performance Specifications

Lead Accuracy in/ft (mm/300 mm)			.001 (.025)		
Maximum Radial Load lb (N)			15 (67)		
Environmental Rating: Std			IP54 / IP65		
Lead		**Stator** **RPM @ 240 VAC**	**1 Stack 138-40** **4000**	**2 Stack 238-40** **4000**	**2 Stack 238-30** **3000**
0.1	**Continuous Stall Force**	lbf (N)	1205 (5360)	1587 (7059)	NA
	Peak Stall Force	lbf (N)	2411 (10725)	3175 (14123)	NA
	Max Speed	in/sec (mm/sec)	6.67 (169)	6.67 (169)	NA
0.2	**Continuous Stall Force**	lbf (N)	603 (2682)	794 (3532)	1047 (4657)
	Peak Stall Force	lbf (N)	1205 (5360)	1587 (7059)	2094 (9315)
	Max Speed	in/sec (mm/sec)	13.33 (338)	13.33 (338)	10.00 (254)
0.5	**Continuous Stall Force**	lbf (N)	241 (1072)	317 (1410)	419 (1864)
	Peak Stall Force	lbf (N)	482 (2144)	635 (2825)	838 (3728)
	Max Speed	in/sec (mm/sec)	33.33 (846)	33.33 (846)	25.00 (635)
Drive Current @ Continuous Stall Force		Amps	5.7	7.5	7.5
Available Stroke Lengths in (mm)			3 (75), 6 (150), 10 (254), 12 (300), 18 (450)		
Approximate Weight lb (kg)		14 (6.35) 3 stack inch stroke, 1	1 (0.5) Added weight per in of stroke	3 (1.4) Added weight per motor stack	3 (1.4) Added weight for brake

Continuous AC Input Current*	Amps	6.3	6.3	6.3

Continuous input current rating is defined by UL and CSA.
Ratings based on 25˚C conditions.

T2M/X115 Linear Actuator Performance Specifications

Backlash in (mm)			.008 (.20)		
Lead Accuracy in/ft (mm/300 mm)			.001 (.025)		
Maximum Radial Load lb (N)			15 (67)		
Environmental Rating: Std			IP54 / IP65		
		Stator	**1 Stack 138-30**	**2 Stack 238-20**	**2 Stack 238-15**
Lead		**RPM @ 240 VAC**	**3000**	**2000**	**1500**
0.1	**Continuous Stall Force**	lbf (N)	2354 (10470)	3685 (16391)	NA
	Peak Stall Force	lbf (N)	4709 (20947)	7370 (32783)	NA
	Max Speed	in/sec (mm/sec)	5.00 (127)	3.33 (84)	NA
0.2	**Continuous Stall Force**	lbf (N)	1177 (5235)	1843 (8198)	2380 (10586)
	Peak Stall Force	lbf (N)	2354 (10471)	3685 (16392)	4760 (21174)
	Max Speed	in/sec (mm/sec)	10.00 (254)	6.67 (169)	5.00 (127)
0.5	**Continuous Stall Force**	lbf (N)	471 (2095)	737 (3278)	952 (4234)
	Peak Stall Force	lbf (N)	942 (4190)	1474 (6557)	1904 (8469)
	Max Speed	in/sec (mm/sec)	25.00 (635)	16.67 (423)	12.50 (317)
0.75	**Continuous Stall Force**	lbf (N)	314 (1397)	491 (2184)	635 (2825)
	Peak Stall Force	lbf (N)	628 (2793)	982 (4368)	1370 (6094)
	Max Speed	in/sec (mm/sec)	37.5 (953)	25 (635)	18.75 (476)
Drive Current @ Continuous Stall Force		Amps	8.5	8.5	8.5
Available Stroke Lengths in (mm)			6 (150), 10 (254), 12 (300), 18 (450)		
Approximate Weight lb (kg)		34 (15.5) 6 stack inch stroke, 1	2 (1) Added weight per in of stroke	8 (4) Added weight per motor stack	4 (2) Added weight for brake

Continuous AC Input Current*	Amps	8.3	8.3	8.3

Continuous input current rating is defined by UL and CSA.
Ratings based on 25˚C conditions.

R2M090 Rotary Motor Torque and Speed Ratings

	Stator	2 Stack 238-40	2 Stack 238-30	3 Stack 338-20
	RPM at 240 VAC	4000	3000	2000
Continuous Stall Torque	lbf-in (Nm)	30 (3.4)	40 (4.5)	52 (5.9)
Peak Torque	lbf-in (Nm)	60 (6.8)	80 (9.0)	105 (11.9)
Drive Current @ Continuous Stall Torque	Amps	7.5	7.5	6.6
Continuous AC Input Current*	Amps	6.3	6.3	6.3

*Continuous input current rating is defined by UL and CSA. Ratings based on 25˚C ambient conditions.
For output torque of R2G gearmotors, multiply by ratio and efficiency. Please note maximum allowable output torques found at bottom of page.

R2M/R2G090 Inertia

	Stator	2 Stack	3 Stack
R2M Motor Armature Inertia (+/-5%)	lb-in-sec² (kg-cm²)	0.00097 (1.09)	0.00140 (1.58)
R2G Gearmotor Armature Inertia*	lbf-in-sec² (kg-cm²)	0.00157 (1.77)	0.00200 (2.26)

*Add armature inertia to gearing inertia for total inertia.

Radial Load and Bearing Life

RPM	50	100	250	500	1000
lbf (N)	389 (1730)	309 (1375)	227 (1010)	180 (801)	143 (636)

Side load ratings shown above are for 10,000 hour bearing life at 25mm from motor face at given rpm.

R2G090 Gearmotor Mechanical Ratings

Model	Ratio	Maximum Allowable Output Torque-Set by User lbf-in (Nm)	Output Torque at Motor Speed for 10,000 Hour Life		
			1000 RPM lbf-in (Nm)	1500 RPM lbf-in (Nm)	2000 RPM lbf-in (Nm)
R2G090-004	4:1	2078 (234.8)	600 (67.8)	552 (62.4)	504 (56.9)
R2G090-005	5:1	1798 (203.1)	775 (87.6)	714 (80.7)	652 (73.7)
R2G090-010	10:1	1126 (127.2)	890 (100.6)	820 (92.7)	750 (84.7)
R2G090-016	16:1	2078 (234.8)	912 (103.4)	830 (94.7)	763 (86.2)
R2G090-020	20:1	2078 (234.8)	980 (110.7)	900 (101.7)	820 (92.6)
R2G090-025	25:1	1798 (203.1)	1250 (141.2)	1150 (130)	1050 (118.6)
R2G090-040	40:1	2078 (234.8)	1200 (135.6)	1107 (125)	1013 (114.4)
R2G090-050	50:1	1798 (203.1)	1550 (169.4)	1434 (162)	1317 (148.8)
R2G090-100	100:1	1126 (127.2)	1100 (124.3)	1100 (124.3)	1100 (124.3)

Two torque ratings for the R2G gearmotors are given in the table above. The left hand columns give the maximum (peak) allowable output torque for the indicated ratios of each size R2G gearmotor. This is not the rated output torque of the motor multiplied by the ratio of the reducer.

It is possible to select a configuration of the motor selection and gear ratio such that the rated motor torque, multiplied by the gear ratio exceeds these ratings. It is the responsibility of the user to ensure that the settings of the system do not allow these values to be exceeded.

The right hand columns give the output torque at the indicated speed which will result in 10,000 hour life (L10). The setup of the system will determine the actual output torque and speed.

R2G090 Gearing Reflected Inertia

Single Reduction			Double Reduction		
Gear Stages	lbf-in-sec²	(kg-cm²)	Gear Stages	lbf-in-sec²	(kg-cm²)
4:1	0.000154	(0.174)	16:1	0.000115	(0.130)
5:1	0.000100	(0.113)	20:1, 25:1	0.0000756	(0.0854)
10:1	0.0000265	(0.0300)	40:1, 50:1, 100:1	0.0000203	(0.0230)

Backlash and Efficiency

	Single Reduction	Double Reduction
Backlash at 1% Rated Torque	10 Arc min	13 Arc min
Efficiency	91%	86%

R2M090 Motor and RTG090 Gearmotor Weights

		R2M090 without Gears	R2G090 with 1 Stage Gearing	R2G090 with 2 Stage Gearing	Added Weight for Brake
1 Stack Stator	lb (kg)	11 (4.9)	19 (8.6)	22 (10)	3 (1.4)
2 Stack Stator	lb (kg)	14 (6.4)	22 (10)	25 (11.3)	
3 Stack Stator	lb (kg)	17 (7.7)	25 (11.3)	28 (12.7)	

R2M/R2G115 Rotary Motor/Gearmotor Performance Specifications

R2M115 Rotary Motor Torque and Speed Ratings

	Stator	1 Stack 138-30	2 Stack 238-20	2 Stack 238-15
	RPM at 240 VAC	3000	2000	1500
Continuous Stall Torque	lbf-in (Nm)	47 (5.3)	73 (8.3)	95 (10.7)
Peak Torque	lbf-in (Nm)	94 (10.6)	146 (16.5)	190 (21.5)
Drive Current @ Continuous Stall Torque	Amps	8.5	8.5	8.5
Continuous AC Input Current*	Amps	8.3	8.3	8.3

*Continuous input current rating is defined by UL and CSA. Ratings based on 25˚C ambient conditions.
For output torque of R2G gearmotors, multiply by ratio and efficiency. Please note maximum allowable output torques found at bottom of page.

R2M/R2G115 Inertia

	Stator	1 Stack	2 Stack
R2M Motor Armature Inertia (+/-5%)	lb-in-sec² (kg-cm²)	0.00344 (3.89)	0.00623 (7.036)
R2G Gearmotor Armature Inertia*	lbf-in-sec² (kg-cm²)	0.00538 (6.08)	0.00816 (9.22)

*Add armature inertia to gearing inertia for total R2M system inertia.

Radial Load and Bearing Life

RPM	50	100	250	500	1000
lbf (N)	939 (4177)	745 (3314)	549 (2442)	435 (1935)	346 (1539)

Side load ratings shown above are for 10,000 hour bearing life at 25mm from motor face at given rpm.

R2G115 Gearmotor Mechanical Ratings

Model	Ratio	Maximum Allowable Output Torque-Set by User lbf-in (Nm)	Output Torque at Motor Speed for 10,000 Hour Life: 1000 RPM lbf-in (Nm)	2000 RPM lbf-in (Nm)	3000 RPM lbf-in (Nm)
R2G115-004	4:1	4696 (530.4)	1392 (157.3)	1132 (127.9)	1000 (112.9)
R2G115-005	5:1	4066 (459.4)	1455 (163.3)	1175 (132.8)	1040 (117.5)
R2G115-010	10:1	2545 (287.5)	1660 (187.6)	1350 (152.6)	1200 (135.6)
R2G115-016	16:1	4696 (530.4)	2112 (238.6)	1714 (193.0)	1518 (171.0)
R2G115-020	20:1	4696 (530.4)	2240 (253.1)	1840 (207.9)	1620 (183.0)
R2G115-025	25:1	4066 (459.4)	2350 (265.5)	1900 (214.7)	1675 (189.2)
R2G115-040	40:1	4696 (530.4)	2800 (316.4)	2240 (253.1)	2000 (225.9)
R2G115-050	50:1	4066 (459.4)	2900 (327.7)	2350 (265.5)	2100 (237.3)
R2G115-100	100:1	2545 (287.5)	2500 (282.5)	2500 (282.5)	2400 (271.2)

Two torque ratings for the R2G gearmotors are given in the table above. The left hand columns give the maximum (peak) allowable output torque for the indicated ratios of each size R2G gearmotor. This is not the rated output torque of the motor multiplied by the ratio of the reducer.

It is possible to select a configuration of the motor selection and gear ratio such that the rated motor torque, multiplied by the gear ratio exceeds these ratings. It is the responsibility of the user to ensure that the settings of the system do not allow these values to be exceeded.

The right hand columns give the output torque at the indicated speed which will result in 10,000 hour life (L10). The setup of the system will determine the actual output torque and speed.

R2G115 Gearing Reflected Inertia

Single Reduction			Double Reduction		
Gear Stages	lbf-in-sec²	(kg-cm²)	Gear Stages	lbf-in-sec²	(kg-cm²)
4:1	0.000635	(0.717)	16:1	0.000513	(0.580)
5:1	0.000428	(0.484)	20:1, 25:1	0.000350	(0.396)
10:1	0.000111	(0.125)	40:1, 50:1, 100:1	0.0000911	(0.103)

Backlash and Efficiency

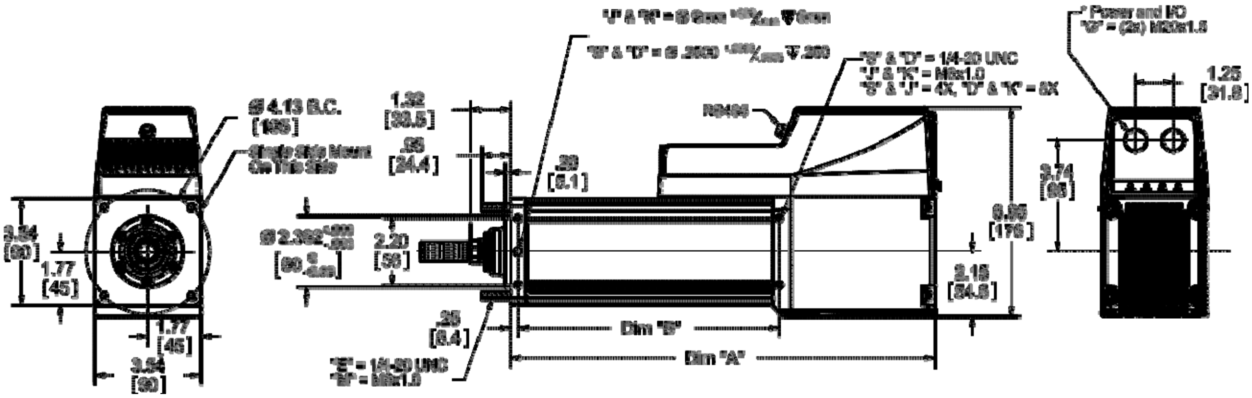
	Single Reduction	Double Reduction
Backlash at 1% Rated Torque	10 Arc min	13 Arc min
Efficiency	91%	86%

R2M115 Motor and RTG115 Gearmotor Weights

		R2M115 without Gears	R2G115 with 1 Stage Gearing	R2G115 with 2 Stage Gearing	Added Weight for Brake
1 Stack Stator	lb (kg)	19 (8.6)	34 (15.4)	40 (18.1)	4 (2)
2 Stack Stator	lb (kg)	27 (12.2)	42 (19.1)	48 (21.8)	
3 Stack Stator	lb (kg)	35 (15.9)	50 (22.7)	56 (25.4)	

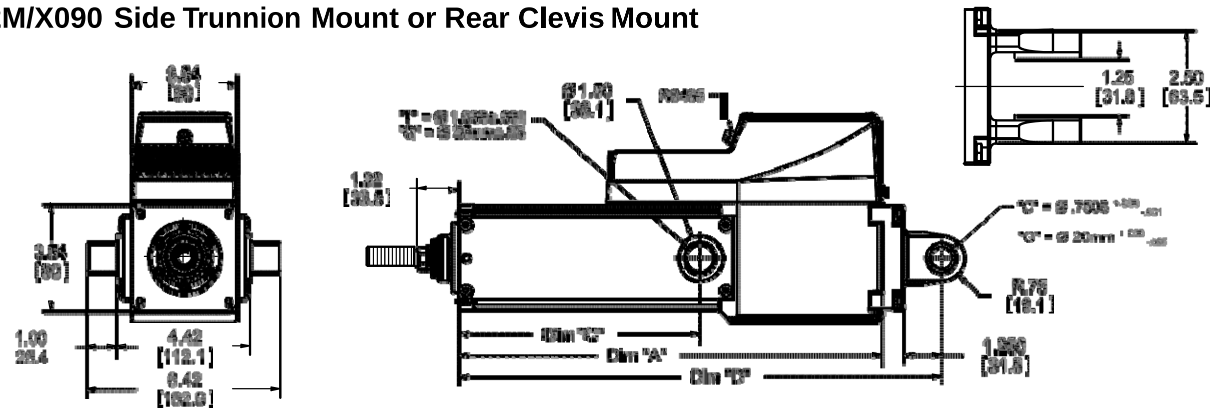
T2M/X090 Linear Actuator Dimensions

T2M/X090 Double Side Mount or Extended Tie Rod Mount



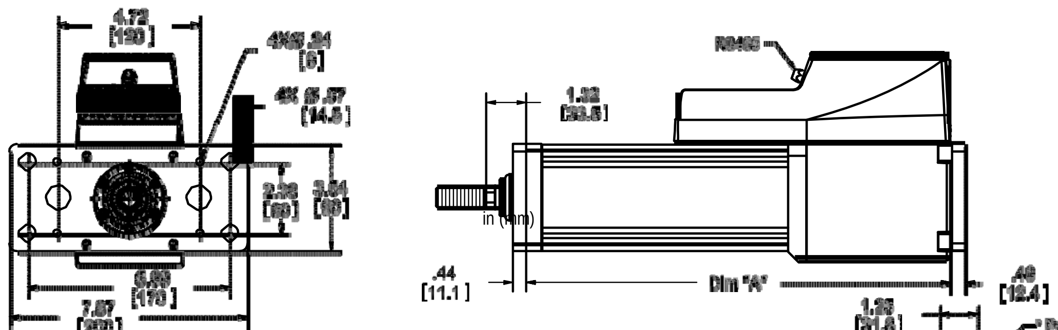
* “N” option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

T2M/X090 Side Trunnion Mount or Rear Clevis Mount



* “N” option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

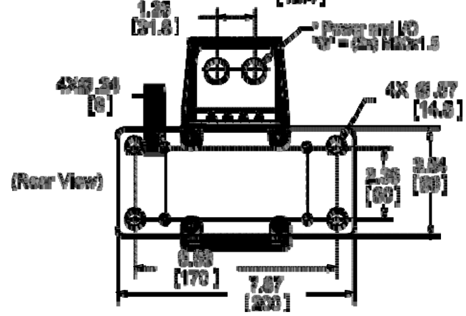
T2M/X090 Front, Rear, or Front and Rear Flange Mount



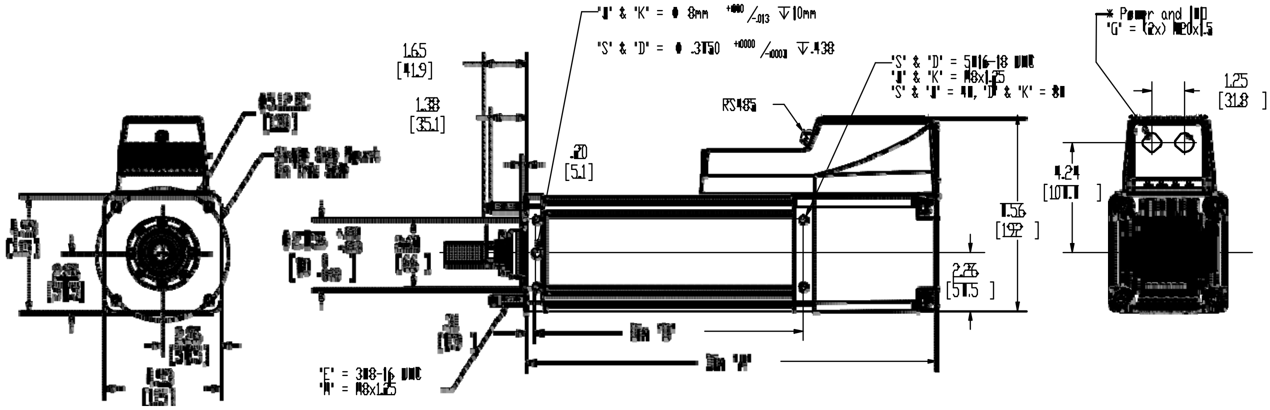
* “N” option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24 mm), length 3/4" (19 mm).

DIM	3 inch (75 mm) stroke in (mm)	6 inch (150 mm) stroke in (mm)	10 inch (250 mm) stroke in (mm)	12 inch (300 mm) stroke in (mm)	18 inch (450 mm) stroke in (mm)
A	11.54 (293.1)	14.01 (355.9)	18.53 (470.7)	20.53 (521.5)	26.53 (673.9)
B	6.15 (156.1)	8.62 (218.9)	13.12 (333.3)	15.12 (434.8)	21.12 (536.4)
C	5.38 (136.7)	8.01 (203.4)	10.00 (254.0)	12.00 (304.8)	18.00 (457.2)
D	13.52 (343.3)	15.99 (406.1)	20.49 (520.4)	22.49 (571.2)	28.49 (723.6)

Note: Add 1.61 inches to dimensions “A” and “D” if ordering a brake.

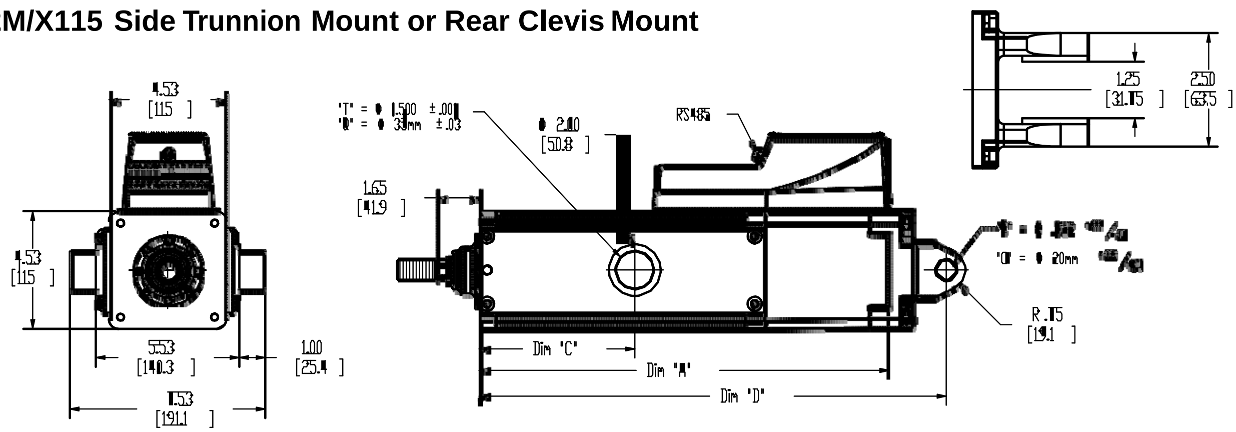


T2M/X115 Double Side Mount or Extended Tie Rod Mount



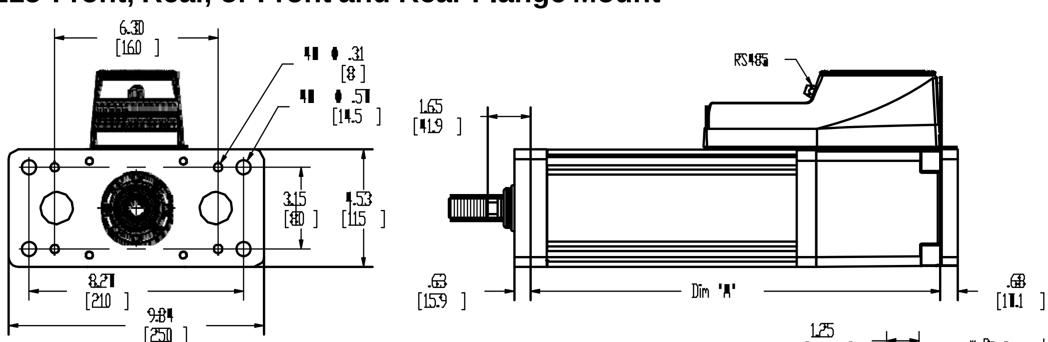
* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

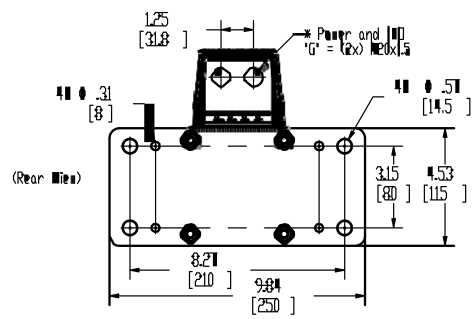
T2M/X115 Side Trunnion Mount or Rear Clevis Mount



* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

T2M/X115 Front, Rear, or Front and Rear Flange Mount





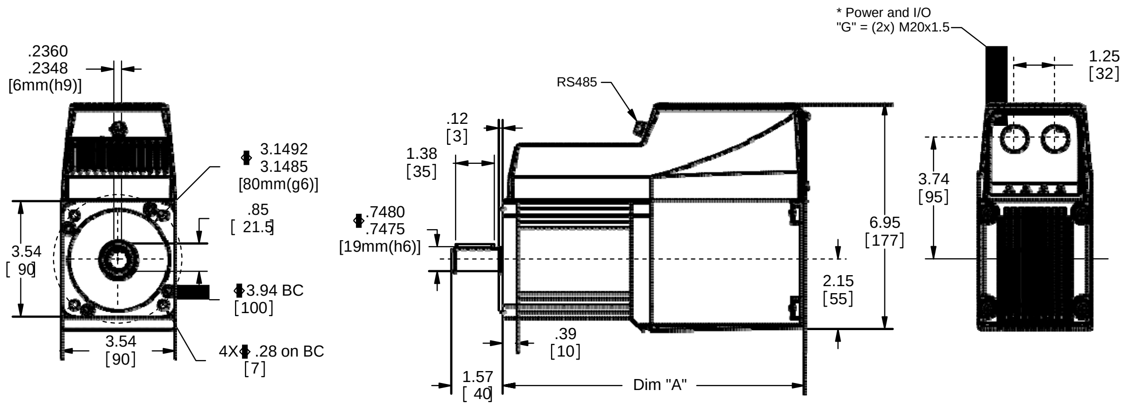
* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24 mm), length 3/4" (19 mm).

DIM	6 inch (150 mm) **stroke** in (mm)	10 inch (250 mm) **stroke** in (mm)	12 inch (300 mm) **stroke** in (mm)	18 inch (450 mm) **stroke** in (mm)
A	15.79 (401.1)	19.79 (502.7)	21.79 (553.5)	27.79 (705.9)
B	10.31 (261.8)	14.31 (363.5)	16.31 (414.3)	22.31 (566.7)
C	6.00 (152.4)	10.00 (254.0)	12.00 (304.8)	18.00 (457.2)
D	17.99 (456.9)	21.99 (558.5)	23.99 (609.3)	29.99 (761.7)

Note: Add 2.33 inches to dimensions "A" and "D" if ordering a brake.

R2M/R2G090 Rotary Motor/Gearmotor Dimensions

R2M090 Dimensions

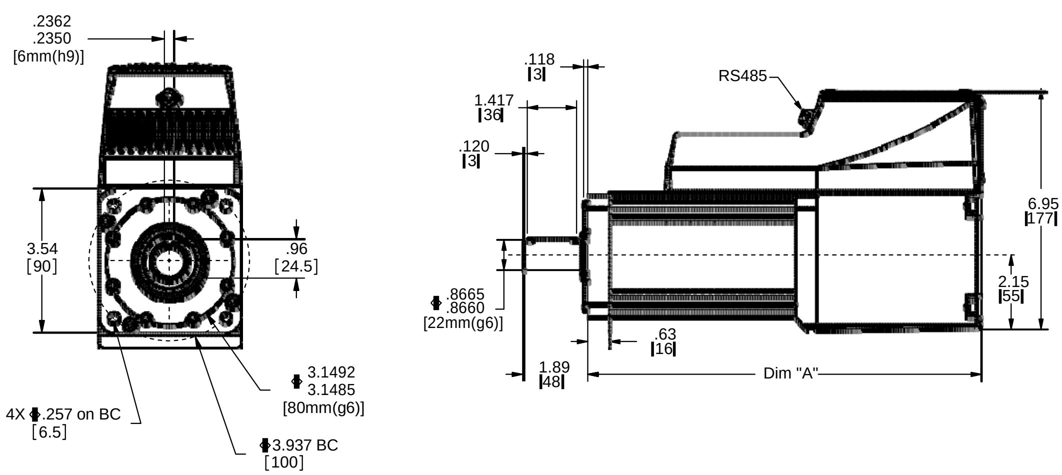


* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

Without Brake Option		
DIM	2 Stack Stator	3 Stack Stator
A	9.25 (235.0)	10.25 (260.4)

With Brake Option		
DIM	2 Stack Stator	3 Stack Stator
A	10.6 (269.2)	11.6 (294.6)

R2G090 Dimensions

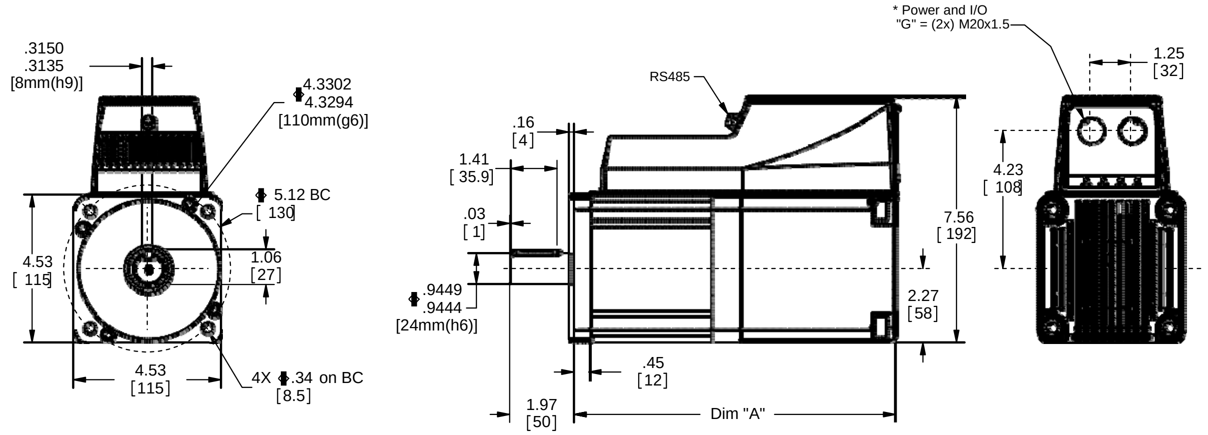


* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

Without Brake Option		
DIM	2 Stack Stator 1 Stage Gearhead	3 Stack Stator 1 Stage Gearhead
A	12.36 (313.9)	13.36 (339.3)
DIM	2 Stack Stator 2 Stage Gearhead	3 Stack Stator 2 Stage Gearhead
A	13.63 (346.2)	14.63 (371.6)

With Brake Option		
DIM	2 Stack Stator 1 Stage Gearhead	3 Stack Stator 1 Stage Gearhead
A	13.67 (347.2)	14.67 (372.6)
DIM	2 Stack Stator 2 Stage Gearhead	3 Stack Stator 2 Stage Gearhead
A	14.94 (379.5)	15.94 (404.9)

R2M115 Dimensions

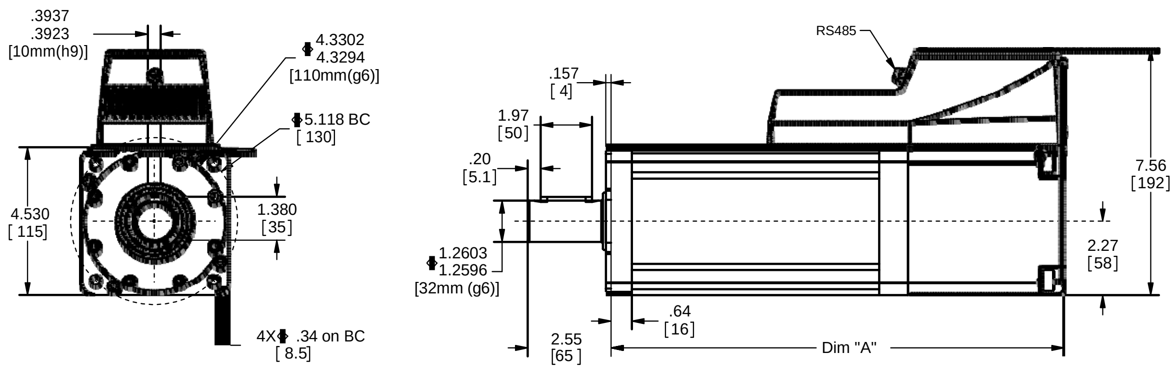


* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

Without Brake Option		
DIM	1 Stack Stator	2 Stack Stator
A	9.87 (250.7)	11.87 (301.5)

With Brake Option		
DIM	1 Stack Stator	2 Stack Stator
A	11.60 (294.6)	13.60 (345.4)

R2G115 Dimensions

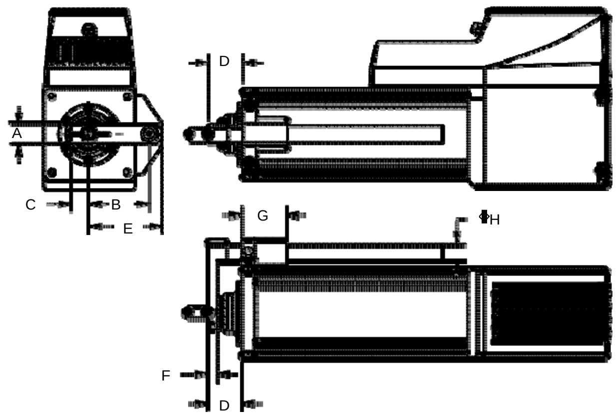


* "N" option utilizes adapter from M20 x 1.5 to 1/2" NPT thread. Dia. 1-5/16 (24mm), length 3/4" (19mm).

Without Brake Option		
DIM	1 Stack Stator 1 Stage Gearhead	2 Stack Stator 1 Stage Gearhead
A	13.88 (352.6)	15.88 (403.4)
DIM	1 Stack Stator 2 Stage Gearhead	2 Stack Stator 2 Stage Gearhead
A	15.49 (393.4)	17.49 (444.2)

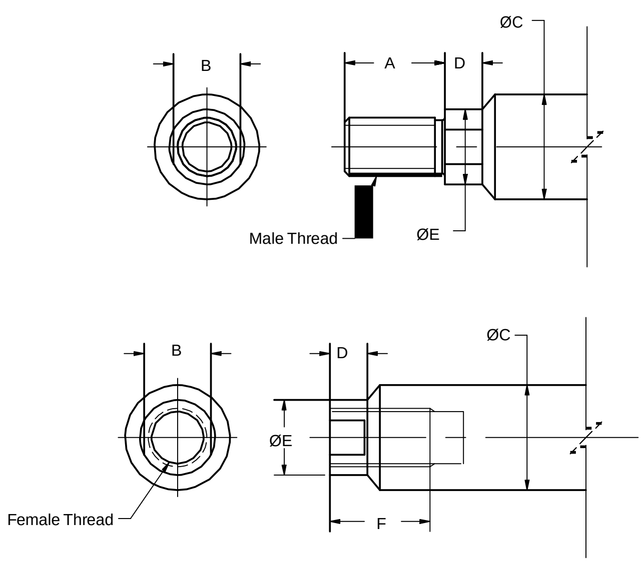
With Brake Option		
DIM	1 Stack Stator 1 Stage Gearhead	2 Stack Stator 1 Stage Gearhead
A	15.43 (391.9)	17.43 (442.7)
DIM	1 Stack Stator 2 Stage Gearhead	2 Stack Stator 2 Stage Gearhead
A	17.04 (432.8)	19.04 (483.6)

Anti-Rotate Option



DIM inch (mm)	T2M/X090	T2M/X115
A	0.75 (19.1)	1.13 (28.7)
B	2.32 (58.9)	3.06 (77.7)
C	0.70 (17.8)	1.00 (25.4)
D	1.32 (33.5)	1.65 (41.9)
E	2.82 (71.6)	3.63 (92.2)
F	0.38 (9.7)	0.50 (12.7)
G	1.70 (43.2)	1.97 (50.0)
ØH	0.63 (16.0)	0.75 (19.1)

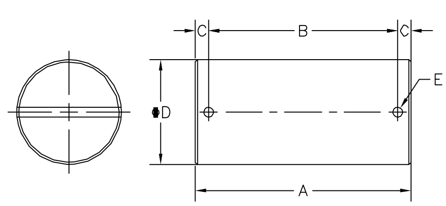
Actuator Rod End Option



Fem

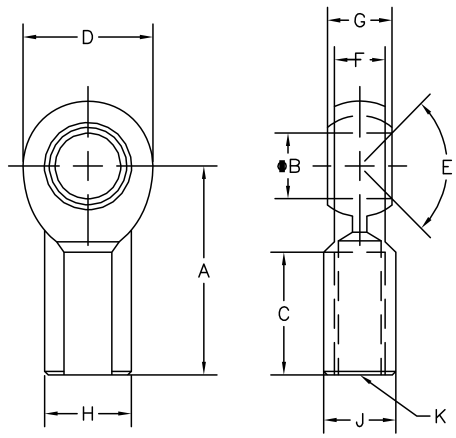
DIM inch (mm)	T2M/X090	T2M/X115
A	1.250 (31.8)	1.500 (38.1)
B	0.625 (17.0)	0.750 (19.1)
ØC	0.787 (20.0)	1,000 (25.4)
D	0.281 (7.1)	0.381 (9.7)
ØE	0.725 (18.4)	0.875 (22.2)
F	1,000 (25.4)	1,000 (25.4)
Male–Inch "M", "W"	1/2-20 UNF-2A	3/4-16 UNF-2A
Male–Metric "A", "R"	M16 x 1.5 6g	M16 x 1.5 6g
Female–Inch "F", "V"	1/2-20 UNF-2B	5/8-18 UNF-2B
Female–Metric "B", "L"	M16 x 1.5 6h	M16 x 1.5 6h

Clevis Pin



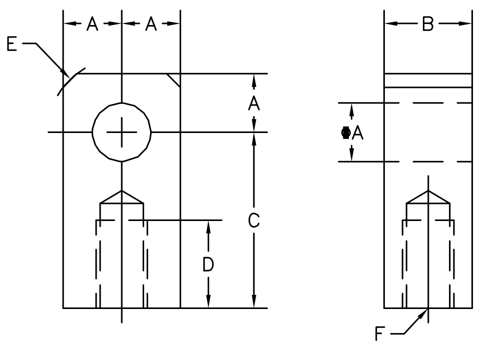
DIM	T2M/X090	T2M/X090	T2M/X115
inch (mm)	CP050 Rod Eye, Rod Clevis	CP075 Rear Clevis	CP075 Rod Eye, Rod Clevis, Spherical Eye, Rear Clevis
A	2.28 (57.9)	3.09 (78.5)	3.09 (78.5)
B	1.94 (49.28)	2.72 (69.1)	2.72 (69.1)
C	0.17 (4.32)	0.19 (4.82)	1.19 (4.82)
ØD	0.50 +0.000/-0.002 (112.7 mm +0.00/-0.05)	0.75 +0.000/-0.002 (19.1 mm +0.00/-0.05)	0.75 +0.000/-0.002 (19.1 mm +0.00/-0.05)
ØE	0.106 (2.69)	0.14 (3.56)	0.14 (3.56)

Spherical Rod Eye



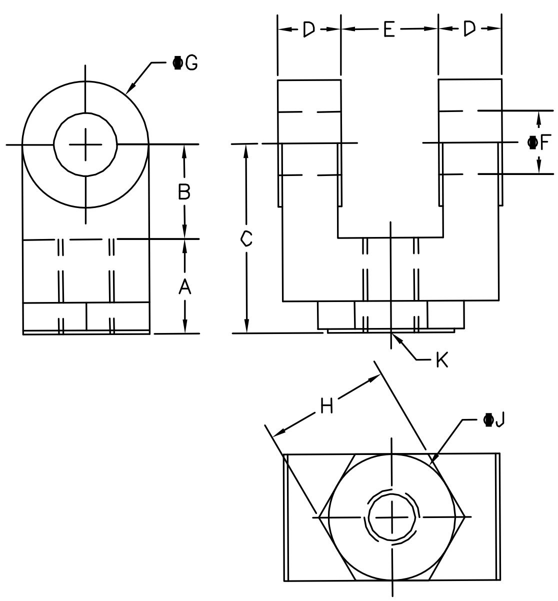
DIM inch (mm)	T2M/X090	T2M/X115
	SRM050	SRM075
A	2.125 (54.0)	2.88 (73.2)
ØB	0.500 (12.7)	0.75 (19.1)
C	1.156 (29.4)	1.72 (43.7)
D	1.312 (33.3)	1.75 (44.5)
E	6 Deg	14 Deg
F	0.500 (12.7)	0.69 (17.5)
G	0.625 (15.9)	0.88 (22.3)
H	0.875 (22.2)	1.13 (28.7)
J	0.750 (19.1)	1.00 (25.4)
K	1/2-20	3/4-16

Rod Eye



DIM inch (mm)	T2M/X090	T2M/X115
	REI050	RE075
ØA	0.50 (12.7)	0.75 (19.05)
B	0.75 (19.05)	1.25 (31.8)
C	1.50 (38.1)	2.06 (52.3)
D	0.75 (19.05)	1.13 (28.7)
E	0.375 (9.53)	0.88 (22.2)
F	1/2-20	3/4-16

Rod Clevis



DIM inch (mm)	T2M/X090	T2M/X115
	RCI050	RC075
A	0.750 (19.05)	1.125 (28.58)
B	0.750 (19.05)	1.25 (31.75)
C	1.500 (38.1)	2.375 (60.3)
D	0.500 (12.7)	0.625 (15.88)
E	0.765 (19.43)	1.265 (32.12)
ØF	0.500 (12.7)	0.75 (19.1)
ØG	1.000 (25.4)	1.50 (38.1)
H	1.000 (25.4)	1.25 (31.75)
ØJ	N/A	1.25 (31.75)
K	1/2-20	3/4-16

Tritex II AC T2M/X Linear Actuator Ordering Information

T2M/XBBB-CCDD-EFG-HH-III-II-JJJ-KKK- (XX..XX - #####)

T2M/X = Actuator Type
T2M = Tritex II Linear Actuator, standard mechanical capacity
T2X = Tritex II Linear Actuator, high mechanical capacity

BBB = Actuator Frame Size
090 = 90 mm
115 = 115 mm

CC = Stroke Length
03 = 3 inch (75 mm) (T2M/X090 only)
06 = 6 inch (150 mm)
10 = 10 inch (250 mm)
12 = 12 inch (305 mm)
18 = 18 inch (455 mm)

DD = Lead (linear travel per screw revolution)
01 = 0.1 inch (2.54 mm)
02 = 0.2 inch (5.08 mm)
05 = 0.5 inch (12.7 mm)
08 = 0.75 inch (19.05 mm) (T2M/X115 only) (5)

E = Connections
G = Standard Straight Threaded Port with Internal terminals, M20 x 1.5
N = NPT Threaded Port via Adapter with Internal Terminals, 1/2" NPT
I = Intercontec Style - Exlar std, M16/M23 Style Connector
X = Custom Connectivity

F = Mounting
B = Front & Rear Flange
C = Rear Clevis
D = Double Side Mount
E = Extended Tie Rod
F = Front Flange
G = Metric Rear Clevis
J = Metric Side Mount
K = Metric Double Side Mount
M = Metric Extended Tie Rod
Q = Metric Side Trunnion
R = Rear Flange
S = Side Mount
T = Side Trunnion
X = Special

G = Rod End
A = Male Metric Thread (1)
B = Female Metric Thread (1)
F = Female US Standard Thread (1)
L = Female Metric Thread 17-4 SS
M = Male US Standard Thread (1)
R = Male Metric Thread 17-4 SS
V = Female US Standard Thread 17-4 SS
W = Male, US Standard Thread 17-4 SS
X = Special (please specify)

HH = Feedback Type
HD = Analog Hall Device
IE = Incremental Encoder, 8192 count resolution
AF = Absolute Feedback

III-II = Motor Stator, All 8 Pole

T2M/X090 Stator Specifications
138-40 = 1 Stack, 230 VAC, 4000 rpm
238-40 = 2 Stack, 230 VAC, 4000 rpm
238-30 = 2 Stack, 230 VAC. 3000 rpm (10)

T2M/X115 Stator Specifications
138-30 = 1 Stack, 230 VAC, 3000 rpm
238-20 = 2 Stack, 230 VAC, 2000 rpm
238-15 = 2 Stack, 230 VAC, 1500 rpm (N/A with 0.1" lead)

JJJ = Voltage
230 = 115-230 VAC, single phase

KKK = Option Board (only 1 selection allowed)
SIO = Standard I/O Interconnect
IA4 = SIO plus Isolated 4 - 20 mA Analog I/O
EIP = SIO plus Ethernet IP
ABZ = SIO plus encoder output signal, requires IE Feedback option. Includes M12 connector for encoder output signals. (2)
TCP = Modbus TCP

X..XX = Travel and Housing Options (Multiples Possible)

Travel Options
AR = External Anti-rotate
PF = Preloaded Follower (3)
L1/2/3 = External Limit Switches (7)
RB = Rear Brake
XT = Special Travel Options

Housing Options
P5 = IP65 Sealed Housing (T2M only)
HC = Type III Hard Coat Anodized (4)
FG = White Epoxy Coating (4)

Special Motor Options
HW = Manual Drive Hand Wheel (T2X only)
SD = Side Manual Drive
HV = High Vibration Option-EIC (9)
ET = External Linear Transducer
XL = Special Lubrication (6)
XM = Special Motor Option
XH = Special Housing Option
XT = Protective Bellows (N/A with extended tie rod mounting option)
XT = Splined Main Rod (8)

= Part Number Designator for Specials
Optional 5 digit assigned PN to designate unique model numbers

NOTES:
1. Chrome-plated carbon steel. Threads not chrome-plated.
2. Will require external cable for encoder output signals.
3. The dynamic load rating of zero backlash, preloaded screws is 63% of the dynamic load rating of the std non-preloaded screws. The calculated travel life of a preloaded screw will be 25% of the calculated travel life of the same size and lead of a non-preloaded screw.
4. This housing option may indidate the need for special material main rods or mounting.
5. 0.75 lead not available above 12" stroke.
6. To achieve -40 operating temperature, specify -XL in the actuator model mask and define Mobilgrease 28 in order notes. Other special lubricants are also available.
7. Limit switch option requires AR option.
8. This option is not sealed and is not suitable for any environment in which contaminants come in contact with actuator and may enter the actuator.
9. EIC 60068-2-64 2.5g, 50-500 Hz. See page 4 for details.
10. N/A with 0.1" lead

Rotary Motor and Gearmotor Ordering Guide

Tritex II AC R2M Motor or R2G Gearmotor Ordering Information

R2M/GAAA-BBB-CDEF-GG-HHH-HH-III-JJJ (XX...XX) - #####)

R2M/G = Motor Type
R2M = Tritex II AC Rotary Motor
R2G = Tritex II AC Rotary Gearmotor

AAA = Frame Size
090 = 90 mm
115 = 115 mm

BBB = Gear Ratio
Blank = R2M

Single Reduction Ratios
004 = 4:1
005 = 5:1
010 = 10:1

Double Reduction Ratios
016 = 16:1 020 = 20:1
025 = 25:1 040 = 40:1
050 = 50:1 100 = 100:1

C = Shaft Type
K = Keyed
R = Smooth/Round
X = Special Shaft

D = Connections
G = Standard Straight Threaded Port with Internal Terminals, M20 x 1.5
N = NPT Threaded Port via Adapter with Internal Terminals, 1/2" NPT
I = Intercontec style - Exlar Standard, M16/M23 Style Connector
X = Custom Connectivity

E = Housing Options
G = Exlar Standard
H = Type III Hard Coat Anodized
F = Smooth White Epoxy Coating
E = Electroless Nickel Plating
X = Special or Custom

F = Brake Option
S = No Brake, Standard
B = Electric Brake, 24 VDC

GG = Feedback Type
HD = Analog Hall Device
IE = Incremental Encoder, 8192 Count Resolution
AF = Absolute Feedback

HHH-HH = Motor Stators

R2M/G090 Stator Specifications
238-40 = 2 Stack, 230 VAC, 4000 rpm
238-30 = 2 Stack, 230 VAC, 3000 rpm
338-20 = 3 Stack, 230 VAC, 2000 rpm

R2M/G115 Stator Specifications
138-30 = 1 Stack, 230 VAC, 3000 rpm
238-20 = 2 Stack, 230 VAC, 2000 rpm
238-15 = 2 Stack, 230 VAC, 1500 rpm

III = Voltage
230 = 115-230 VAC, Single Phase

JJJ = Option Board
SIO = Standard I/O Interconnect
IA4 = SIO plus Isolated 4-20 mA Analog I/O
EIP = SIO plus Ethernet IP
ABZ = SIO plus encoder output signal, requires IE Feedback option. Includes M12 connector for encoder output signals (2)
TCP = SIO plus Modbus TCP

XX = Special Options (multiples possible)
HW = Manual Drive Handwheel with Limit Switch
SD = Side Manual Drive
HV = High Vibration Option-IEC (1)
XH = Special Housing Options
XM = Special Motor Options
XL = Special Lubrication (3)

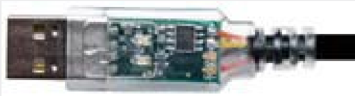
= Part Number Designator for Specials
Optional 5 digit assigned PN to designate unique model no.

NOTES:
1. EIC 60068-2-64 2.5g, 50-500 Hz. See page 4 for details.
2. Will require external cable for encoder output signals.
3. To achieve -40 operating temperature, specify -XL in the actuator model mask and define Mobilgrease 28 in order notes. Other special lubricants are also available.

Tritex II AC Series Cable & Accessories	Part No.
“G” Connection Accessories	
Nickel plated cable gland- M20 x 1.5 - CE shielding- 2 required	GLD-T2M20 x 1.5
Power cable prepared on one end for use with GLD-T2M20 x 1.5 xxx = Length in ft, Standard lengths 015, 025, 050, 075, 100	CBL-T2IPC-RAW-xxx
I/O cable prepared on one end for use with GLD-T2M20 x 1.5 xxx = Length in ft, Standard lengths 015, 025, 050, 075, 100	CBL-T2IOC-RAW-xxx
“N” Connection Accessories	
M20 x 1.5 to 1/2" NPT threaded hole adapter for use with conduit	ADAPT-M20-NPT1/2
“I” Connection	
Power cable with M23 6 pin xxx = Length in feet, std lengths 015, 025, 050, 075, 100	CBL-T2IPC-SMI-xxx
I/O cable with M16 19 pin xxx = Length in feet, std lengths 015, 025, 050, 075, 100	CBL-T2IOC-SMI-xxx
Communications Accessories - Tritex uses a 4 pin M8 RS485 communications connector	
Recommended PC to Tritex communications cable-USB/RS485 to M8 connector - xxx = Length in feet, 006 or 015 only	CBL-T2USB485-M8-xxx
Multi-Drop RS485 Accessories	
RS485 splitter - M8 Pin plug to double M8 Socket receptacle	TT485SP
Multidrop Communications Cable M8 to M8 for use with TT485SP/RS485 splitter - xxx = Length in feet, 006 or 015 only	CBL-TTDAS-xxx
Multi-Purpose Communications Accessories for long runs, requires terminal block interconnections	
USB to RS485 convertor/cable - USB to RS485 flying leads - xxx = Length in feet, 006 or 015 only	CBL-T2USB485-xxx
Communications cable M8 to flying leads cable xxx = Length in feet, Standard lengths 015, 025, 050, 075, 100	CBL-TTCOM-xxx
Option Board Cables	
EIP and TCP option Ethernet cable - M12 to RJ45 cable xxx = Length in feet, standard lengths 015, 025, 050, 075, 100	CBL-T2ETH-R45-xxx
ABZ option cable - M12 to flying leads 8 wire encoder output cable xxx = Length in feet, standard lengths 015, 025, 050, 075, 100	CBL-T2ENC-xxx
Electrical Accessories	
Dynamic Braking Resistor - 100W47Ohm	T2BR1
Replacement -AF Battery - used for absolute feedback option	T2BAT1
Replacement Normally Closed External Limit Switch (Turck Part number BIM-UNT-RP6X)	43404
Replacement Normally Open External Limit Switch (Turck Part number BIM-UNT-AP6X)	43403
Mechanical Accessories	
Clevis Pin for T2M/X090 male “M” rod end 1/2-20 thread	CP050
Clevis Pin for T2M/115 male “M” rod end 3/4-16 thread	CP075
Spherical Rod Eye for T2M/X090 male “M” rod end 1/2-20 thread	SRM050
Spherical Rod Eye for T2M/X115 male “M” rod end 3/4-16 thread	SRM075
Rod Eye for T2M/X090 male “M” rod end 1/2-20 thread	REI050
Rod Eye for T2M/X115 male “M” rod end 3/4-16 thread	RE075
Rod Clevis for T2M/X090 male “M” rod end 1/2-20 thread	RCI050
Rod Clevis for T2M/X115 male “M” rod end 3/4-16 thread	RC075
Jam Nut for T2M/X090 male rod end, 1/2 - 20	JAM1/2-20-SS
Jam Nut for T2M/X115 male rod end, 3/4-16	JAM3/4-16-SS

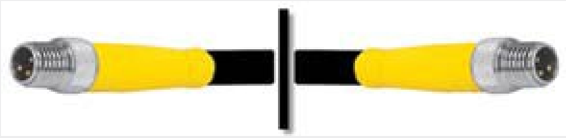
Options/Accessories

CBL-T2USB485-M8-xxx
Our recommended communications cable. No special drivers or setup required for use with MS Windows™.



CBL-T2USB485-xxx
Use for terminal connections with CBL-TTCOM for long cable runs. No special drivers or setup required for use with MS Windows™.

CBL-TTCOM-xxx
Use with CBL-T2USB485-xxx for long cable runs.



For use with TT485SP for multi-drop applications.

TT485SP
RS485 communications splitter. Use to daisy-chain multiple Tritex actuators.

Visit tritex2.com
For more information

Headquartered at our manufacturing and motion control research center in suburban Minneapolis, MN, Exlar serves a global customer base with an extensive standard product line and complete engineering support for custom applications.

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EXLAR

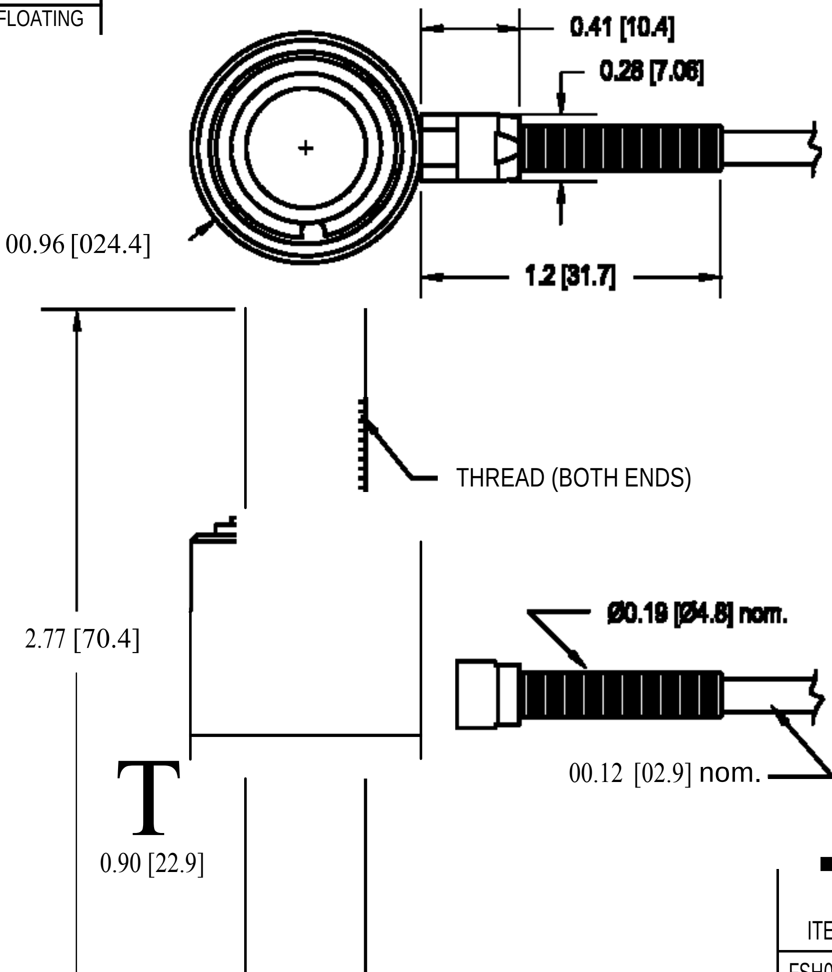
10/11-10,000 PN 50111

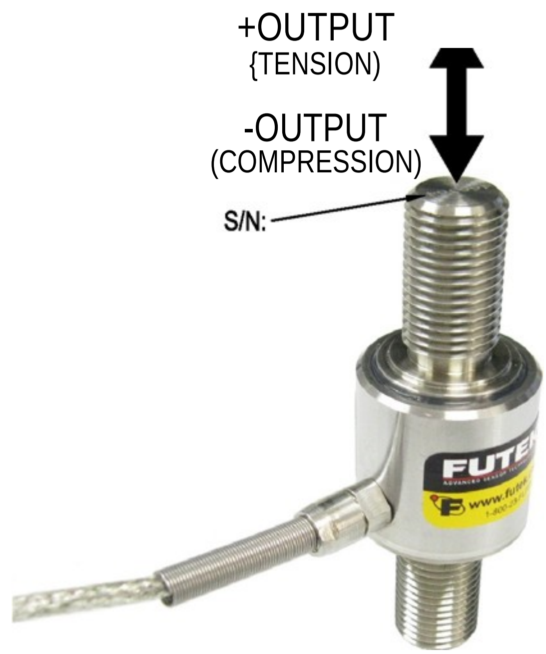
FUTEK MODEL LCM350 L1650) *MINIATUREINLINETHREADEDTENSIONANDCOMPRESSIONLOADCELL*

Drawin Number: FI1061-B

INCH [mm] | R.O.= Rated Output

WIRING CODE (WC1)			
+Excitation	-Excitation	**+Signal**	**-Signal**
RED	BLACK	**GREEN**	**WHITE**
Shield			
FLOATING			





ITEM#	CAPACITIES lb	N	THREAD	OUTPUT	SHUNTVALUE
FSH00673	4K	17792	1/2-20-2A	1.6 mVNnom.	100 Kn
FSH03671	4K	17792	M12x 1.75-6g	1.6 mVNnom.	100Kn
FSH00674	SK	22240	1/2-20-2A	2 mVNnom.	60.4 Kn
FSH03672	SK	22240	M12x 1.75-6g	2mVNnom.	60.4 Kn

SPEC/FICAT/ONS:

RATED OUTPUT	*SEE CHART*
SAFE OVERLOAD	*150% ofR.O.*
ZERO BALANCE	*±3% of R.O.*
EXCITATION (VDC OR VAG)	*18 MAX*
BRIDGE RESISTANCE	*350 n. nom.*
NONLINEARITY	*±0.5% of R.O.* } IMPROVED ACCURACY
HYSTERESIS	*±0.5% of R.O.* AVAILABLE CONTACT
NONREPEATABILITY	*±0.1% ofR.O.* FACTORY
TEMP. SHIFT ZERO	*±0.005% of R.O./"F [0.01% of R.O.fOC]*
TEMP. SHIFT SPAN	*±0.02% of LOADfOF [0.036% of LOADfOC]*
COMPENSATED TEMP.	*60 to 160°F [15 to 72°C]*
OPERATING TEMP.	*-45 to 200°F [-42 to 93°C]*
WEIGHT	*5.5oz. [156g]*
MATERIAL (FLEXURE)	*17-4PH S.S.*
DEFLECTION	*0.001 to 0.002 [0.03 to 0.05] nom.*

CABLE: #28 AWG, 4 Conductor, Spiral Shielded PVC Cable 10ft [3m] Long

ACCESSORIES AND RELATED INSTRUMENTS AVAILABLE

GAL/BRATION (STD)	*5 pt TENSION; SEE CHART FOR SHUNT CAL. VALUE*
GAL/BRATION (AVAILABLE)	*COMPRESSION*
GAL/BRATION TEST EXCITATION	*10 VDC*

10 THOMAS IRVINE, CA 92618 USA
1-800-23-FUTEK (38835)

INTERNET:
http://www.futek.com

PROTEX®
BS EN ISO 9001

TLH-UBAB-041-080

Toggle Clamp Hook Action

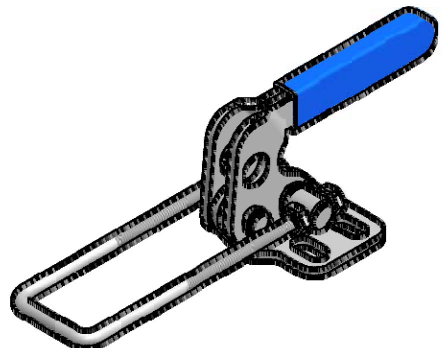
Double Hook Horizontal

TLH-UBAB-041-080-MS

Material:	Mild steel
Finish:	Zinc plated (3 microns)
Weight:	0.10 Kgs
Ultimate force:	210 Kgf
Clamping force:	See image

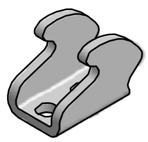
TLH-UBAB-041-080-SS

Material:	Stainless steel (304)
Finish:	Self finish
Weight:	0.10 Kgs
Ultimate force:	210 Kgf
Clamping force:	See image



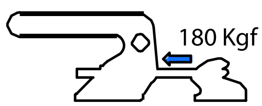
Accessories

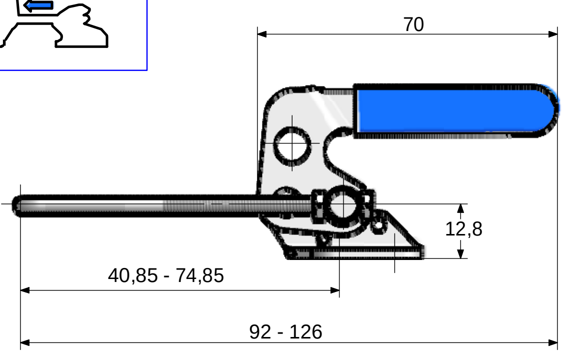
Catchplate

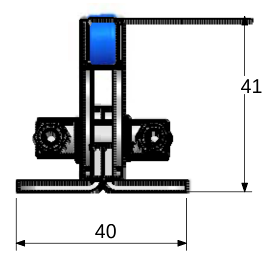


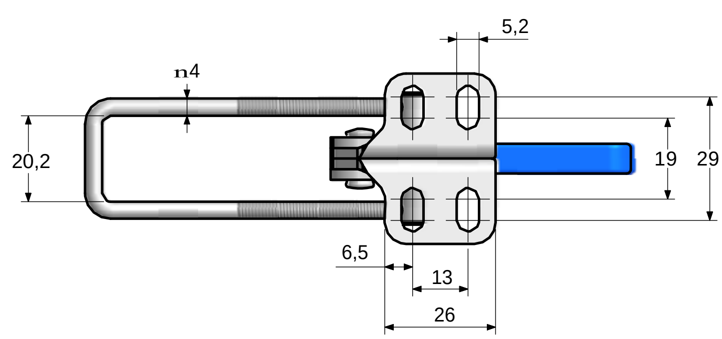
TLC-UBCP-020-024

Clamping Force









Protex Fasteners Ltd. Arrow Road, Redditch, Worcestershire. B98 8PA. United Kingdom
Tel: +44 (0) 1527 63231 Fax: +44 (0) 1527 66770 Email: sales@protex.com

PROTEX
BS EN ISO 9001

TLC-UBCP-020-024

Toggle Clamp Hook Action

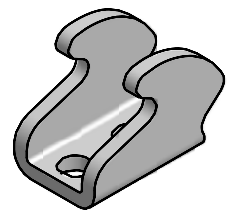
Catchplate

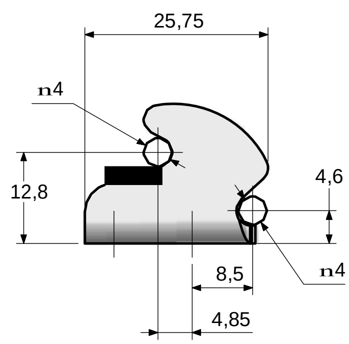
TLC-UBCP-020-024-MS

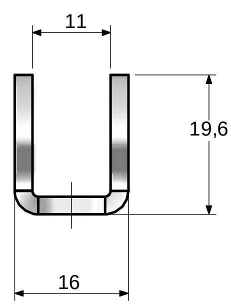
Material:	Mild steel
Finish:	Zinc plated (3 microns)
Weight:	0.02 Kgs

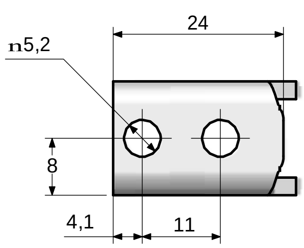
TLC-UBCP-020-024-SS

Material:	Stainless steel (304)
Finish:	Self finish
Weight:	0.02 Kgs









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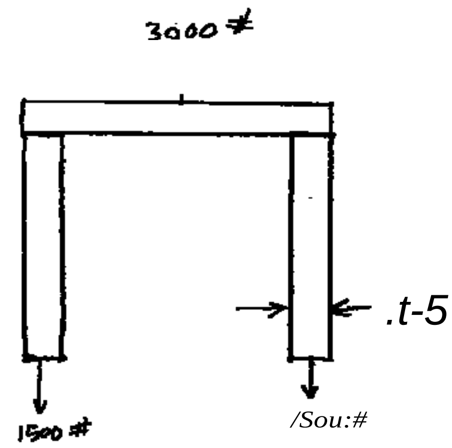
Bound Verticle Post



5fro..;f\ (,'" /t-.

£,;; A

$$= \frac{1500(13)}{0.4418(29\times10^{6})}$$

$$\varepsilon = .0015''$$

!.!i!:_ s \.._.;CA..'(_

a-:::: P/A

cs-::. ISO 0 / 1r-r'"2

(7'::::- JS'oo / o.36:21

— 4;4?-.5 pJ

Square Verticle Post

Strain Calc

&::. Pt...

A£

$$\varepsilon = \frac{1500\,(13'')}{3.0625\,in^2\,(29\times10^6)}$$

@ = ,::1, ooo ;/'l

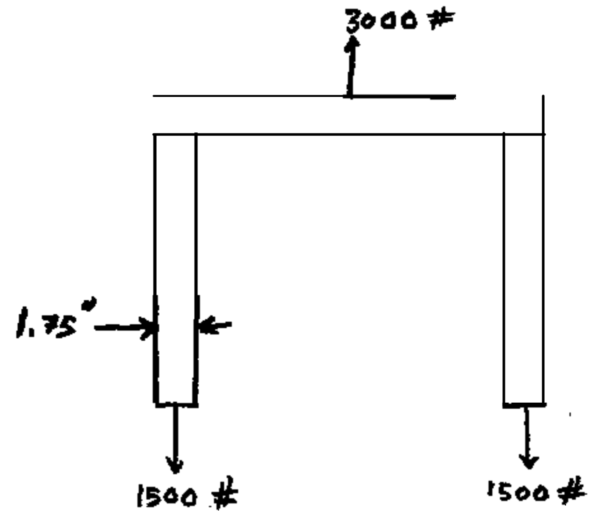
fre,ss ct:1..1c.

cr= A

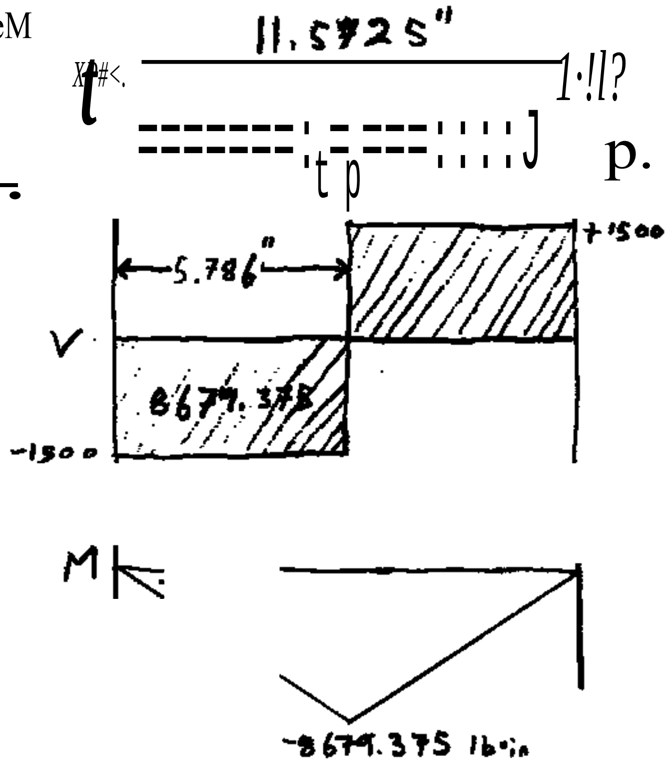
p

$$\sigma = \frac{1500}{3.0625\,in^2}$$

$$\boxed{\sigma = 489.796\ psi}$$



Horizontal Case



Bending w/ 3000 lb load

$$y_{max} = \frac{PL^3}{48EI}$$

$$I = \frac{1}{12} b h^3$$

$$I = \frac{1}{12}(3.54)(0.75)^3$$

$$I = 0.1245 \text{ in}^4$$

$$y_{max} = \frac{3000(11.5725)^3}{48(29 \times 10^6)(0.1245)}$$

$$y_{max} = [illegible]$$

Bending w/ 1000 lb load

$$y_{max} = \frac{1000(11.5725)^3}{48(29 \times 10^6)(0.1245)}$$

$$y_{max} = 0.0089''$$

Stress

$$\sigma = \frac{My}{I}$$

$$\sigma_{max} = [illegible]$$

$$\boxed{\sigma_{max} = 26142.696 \text{ psi}}$$

Percent Frame Deflection @ 3000

Assume 0.-, " clutch travel

Round verticle post

$$\% \text{ deflection} = \frac{\varepsilon}{0.4} \times 100\%$$

– O,oo1'5 / a, '{ X tao

% deflection = 0.375 %

';.v r-e.- v r+:t./?= fosf

% 4-+ +; c:Jf\ :: 0... DOO / o."f X' oo%

cl.e-+I C- .t;Of\ ";; Ol o s /;

Horizontal Cross Beam

% /_t,J;I€-G.+;or..:: _c;.o;:;.6B / o."/ x1o /c,

i! £rl c..+:0'{) =- 6,11o

lo+ f c/.M'/e--c,+l'"()

______%

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+ ! % = >·6157c; o.P c/vtc To. /

C'.

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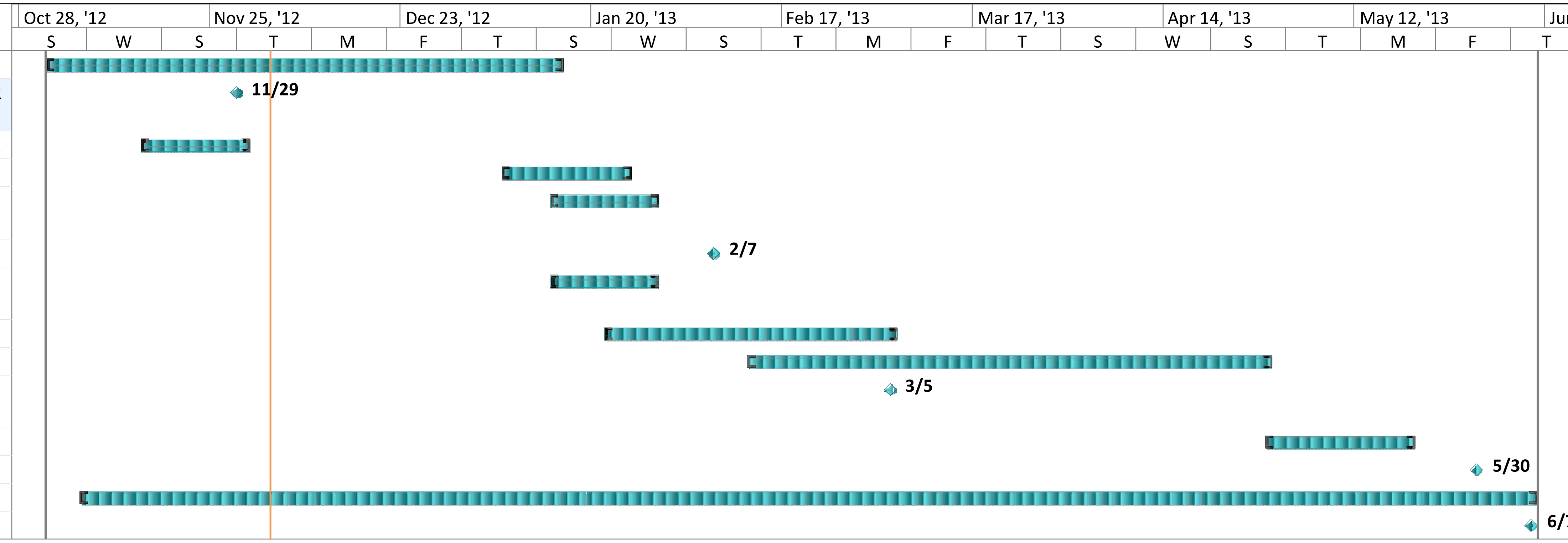
QFD

ID	Task Mode	Task Name	Duration	Start
1		Research	54 days	Thu 11/1/12
2		<Conceptual Design Review>	0 days	Thu 11/29/12
3		CAD modeling	12 days	Thu 11/15/12
4		Prototyping	15 days	Mon 1/7/13
5		Experimental Testing/Redesign	12 days	Mon 1/14/13
6		<Critical Design Review>	0 days	Thu 2/7/13
7		Component Specification	12 days	Mon 1/14/13
8		Part ordering	31 days	Tue 1/22/13
9		Manufacturing	55 days	Tue 2/12/13
10		<Manufacturing and Test Review>	0 days	Tue 3/5/13
11		Testing/Redesign	16 days	Mon 4/29/13
12		<Senior Project Expo>	0 days	Thu 5/30/13
13		Report writing	154 days	Tue 11/6/12
14		<Final Report Due>	0 days	Fri 6/7/13

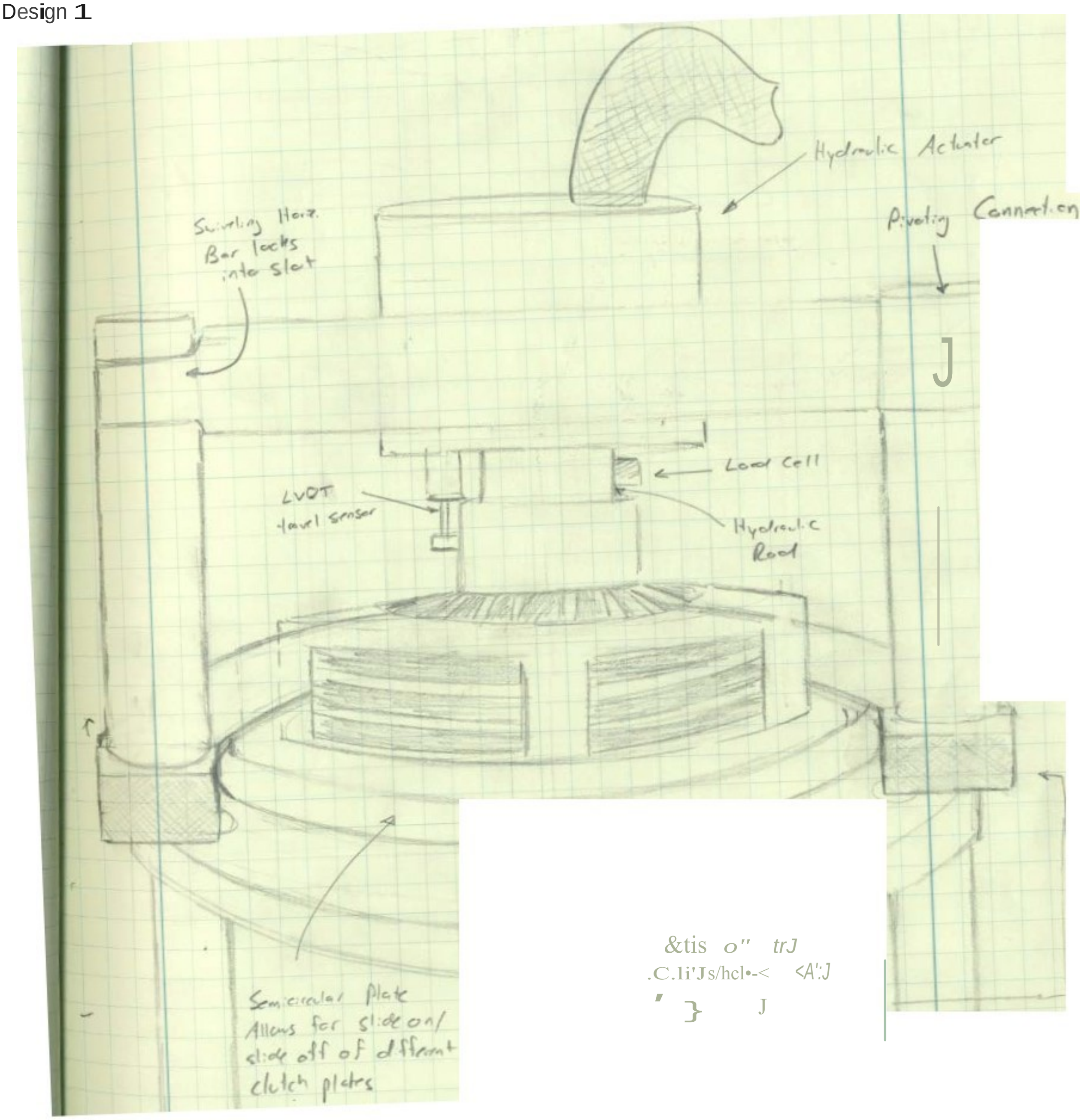


Project: Gantt_Chart.mpp
Date: Tue 12/4/12

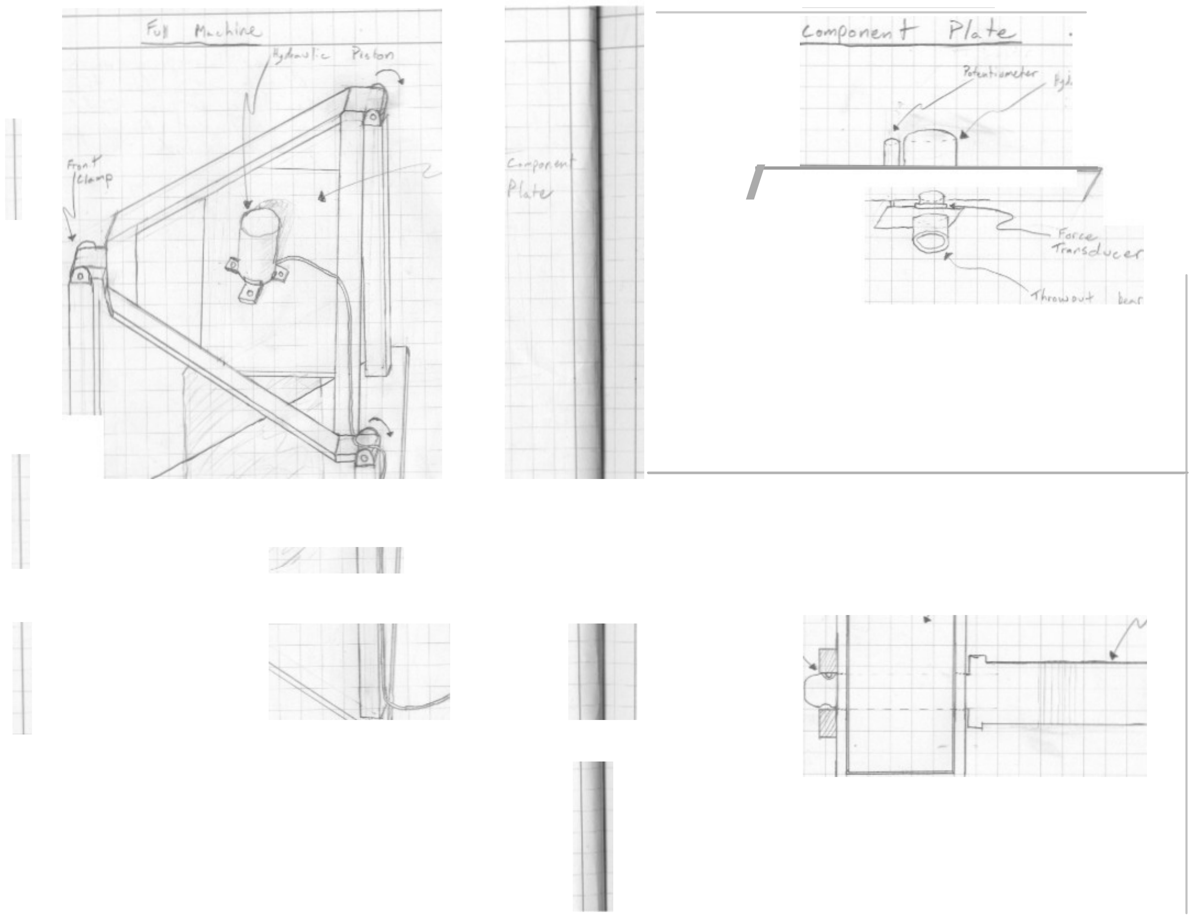
Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

Appendix G:

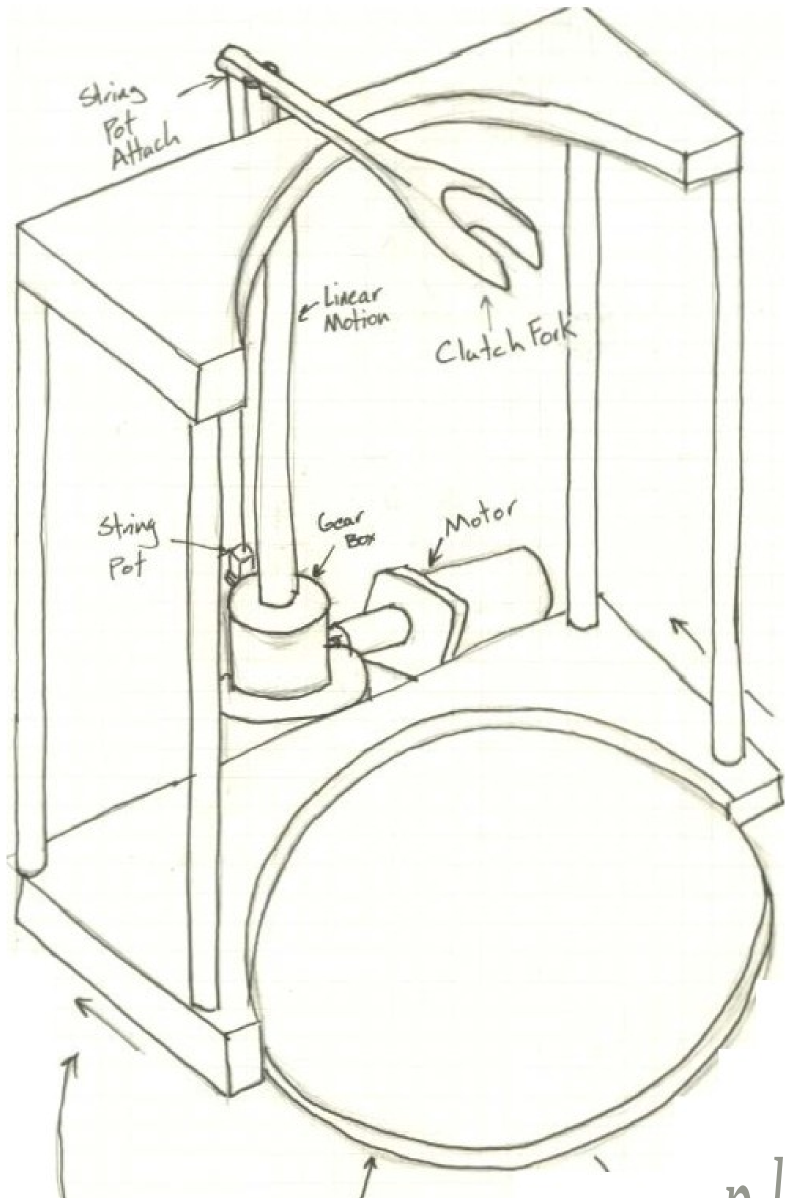
Design 1



Design 2


Full Machine
Hydraulic Piston
Front Clamp
Component Plate
Component Plate
Potentiometer
Force Transducer

Design 3



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C.T 2000