California Olive Ranch Hedger

Sponsor: California Olive Ranch

Tyler Enos, Seth Abbott, & David Gamba

Tylerenos@gmail.com
Sabbott@calpoly.edu
Dgamba@calpoly.edu

Mechanical Engineering
CAL POLY

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Introduction:

The purpose of this project is to evaluate the problems of the current KCI (Kingsburg Cultivator Incorporated) olive tree hedger in use at California Olive Ranch (COR) in Artois, CA, and then correct these problems which should yield a better performing, more efficient, and reliable machine. These problems include: the hydraulic oil temperature getting too high, the saw blades not having enough horsepower, and poor cutting performance due to operator error as well as terrain variations.

The stakeholders for this project are the California Olive Ranch, the senior project team, and Cal Poly Mechanical Engineering Department. The specific timing goal of the project is to have as many of the modifications designed and implemented by the end of March, when the machine will be needed back in Artois for spring pruning.

The benefits of the improved system will increase cutting performance, cutting more branches than the previous design. These improvements will also reduce the down time of the machine due to overheating and bearing failure. The improvements will also allow the operator to control the hedger easier and more accurately.

Figure 1. Current KCI hedger used at Cal Olive Ranch. Machine is shown in the hedging position. Side panels removed due to heat buildup within the hedger from operation.

Background:

The current olive tree hedger in use at Cal Olive Ranch was developed by Kingsburg Cultivator Inc. (KCI). It employs a four head cutting system, two on each side of the machine. The cutting heads consists of a “star”, each with three eighteen inch saw blade at the end. The “stars” rotate in opposite directions by using two timing chains connected to the same hydraulic motor. Horsepower at the blades is one of the most important measurements for this project. The horsepower needed at the blades will determine the requirements for the rest of the hydraulic system.

There are other different style hedgers currently on the market. They are classified by the style in which they cut. The most common styles include sickle bar, mower type blades, and saw blades either on stars on in line. A sickle bar utilizes a stationary bar with triangular blades sitting below another bar also with triangular blades that oscillate back and forth very rapidly. After researching the other options on the market; the current rotating stars with saw blades is the best option based on the needs of the California Olive Ranch. The rotating stars style works well because as the branches are cut, the debris is thrown off the tree and lands in the middle of the row. This eliminates the problem of getting debris in the olive bin when the trees are harvested.

Figure 2. The above images are of the three most common cutting systems employed by olive farmers today. From left to right: sickle bar, mower style blades, and saw blades arranged in line.

Although the current system works, it has much room for improvement. For one, the hydraulic components are undersized for the environment the hedger operates in. The blade shaft carriers are also overly complicated and require too much time to replace the blades. Research has shown that there is many other options for all the hydraulic components on the hedger. Replacement of these hydraulic components should result in increased performance and efficiency from the hedger.

The current hydraulic system on the KCI hedger is comprised of a double PTO driven pump, four gear motors that operate the blades, and two orbit motors that turn the stars. The pump is made by Cessna

and flows 15 gallons per minute per side at 1100 psi. The motors are made by Sanders and all are gear type motors. A flow divider directs 11 gallons per minute to the blade motors while 4 gallons per minute are routed to the star motors. The blade motors are plumbed in series for both sides. We will be meeting with Wendy Soderblom, the owner of Central Coast Bearing in San Luis Obispo to help us analyze the current system and make improvements by possibly changing motor types and or changing the series plumbing to a parallel system.

There are a variety of different style hydraulic pump types on the market. The current pump styles on the KCI hedger are gear pumps. Gear pumps are relatively cheap, durable, very simple, but less efficient because they are a fixed displacement unit. They work best at pressures under 3000 psi and are suited for high speed applications. Vane pumps are also cheap, simple, and reliable, but they are designed for higher-flow, lower-pressure applications. Piston pumps are another possible pump replacement. They are more expensive than the gear or vane pumps, but they have a longer life at higher pressures. There are two basic styles of piston pumps. The axial piston pump has variable displacement therefore the output flow rate and pressure can be varied. There is also the radial piston pump which is designed for high pressure, low flow systems.

We looked up a few possible hydraulic distributors near California Olive Ranch that we can order hydraulic components from. The first is Motion Industries Incorporated (www.motionmro.com). Their phone number is (530) 662-9651, and they have offices in Ukiah, Woodland, and Sacramento. The next company is Applied Industrial Technologies (www.applied.com) in Redding (930) 224-4050 and Yuba City (530) 671-0700. The last company is Berendsen Fluid Power (www.bfpna.com) in Sacramento (916) 372-0550.

As mentioned earlier, the blade motors are plumbed in series for each side. This poses a potential problem if there is a pressure drop across the first motor. Both motors would still be seeing the same flow rate but different pressures. Because horsepower is directly related to the product of flow rate and pressure, the motors would not be making the same horsepower therefore resulting in decreased cutting performance. We will be exploring the issue of parallel versus series more in depth with Wendy as well as other hydraulic companies. From Womack Machine, "**Parallel Motors**: Two identical motors connected in parallel will develop twice the torque and half the speed as one of these motors working from the same pump. Unless the motors are mechanically tied together in some way, more oil will go to the motor with the lighter load. Sometimes flow splitting valves are used to divide the flow equally. **Series Motors**: Two identical motors in series will run approximately the same speed

regardless of the difference in their load. They will divide the pump pressure in proportion to the load on each. Make sure that motors used in series are capable of having both ports pressurized."

To cool down the hydraulic fluid to keep the motors running at optimum viscosity, the hedger uses a heat exchanger. Heat exchangers are used to transfer thermal energy from one medium to another for the purpose of cooling and heating. The heat exchanger in the Cal Olive hedger convects heat from the hydraulic fluid to its environment for the purpose of cooling that fluid. The current system utilizes a heat exchanger from the company Thermal Transfer Products. This exchanger is one of their smaller base models that have a hydraulic fan attached. This unit sits inside the hedger towards the rear.

Objectives:

The main objective is to redesign components of the hedger system to increase efficiency, resulting in improved cutting percentage of the olive branches. To accomplish this, the first component of the hedger to be redesigned is the hydraulic system. The current system has undersized components and is inefficient causing heating issues for the duty cycle required. This leads to a drop in horsepower and therefore a reduction in cutting efficiency. A sub objective is to redesign the bearing carriers that the blade shafts are held by for easier blade changes. The final objective is to implement a self-leveling and aligning controller to improve the quality of the cutting and put less strain on the operator. The leveling sensor will be placed on the cutting head to automatically adjust the angle of the stars depending on the terrain. While in the hedging position the sensors will adjust the cutting head clockwise or counter-clockwise in unison to maintain a constant cutting width for each row.

∘Specifications: (The engineering requirements are found in Table A.2 in Appendix A.)

- Redesign blade shaft and bearing housing
- Redesign heat exchanger
- Redesign the hydraulics of hedger to be implemented in existing system and future models.
- Implement self-leveling controller
- Implement aligning system

The results of the Quality Function Deployment (QFD) spreadsheet are presented under Table A.1 in Appendix A. This QFD is a method to correlate customer requirements with engineering specifications in which each customer requirement is ranked by correlation strength to the engineering specifications. The customer requirements are also compared to the current model specifications. The engineering requirements are found in Table A.2 in Appendix A.

Design Development:

Hydraulic Oil:
Currently the hedger is being used in the middle of summer and can thus see ambient temperatures in the 100+F range with the hedger running 10 hours a day in the pure sunlight. This means that the hydraulic fluid can run extra hot. During a typical day, the hydraulic fluid can get up to or above 200 degrees F. After passing through a heat exchanger the temperature goes down to about 180 degrees F. This is a problem because as the temperature goes up, the viscosity of the fluid goes down. When the viscosity goes down the losses in the pump and motors increase. When the pump pressure goes down the horsepower the blades see is diminished. This in turn means that the hedger's cutting performance will decrease.

Currently, the fluid being used is the Statoil Hydraulic Lift Oil 46. In the morning when temperatures are lower, there is satisfactory performance from the cutting blades, but once the temperatures start to rise, the cutting performance also starts to diminish. At this operating point the temperature is about 180 degrees F and a Viscosity of about 11 centistokes. Ideally the hedger should not run lower than 15 centistokes to maintain pump performance.

Our first approach was to simply exchange the hydraulic fluid with one that runs at the desired viscosity. We went through many fluids and made a note of 15 fluids and out of those 15, the top 5 were chosen for comparison.

Fluid	Viscosity (cSt)		Cost ($)	Amount (gal)
	40	*100*		
Mobil SHC 526	68	11.5	$1,893.54	55
Conoco FR Fluid/Glycol 32/46	39.3	8.5	$1,309.07	55
Conoco Quintolubric 822-450	100	14.8	$1,986.81	55
Conoco Syndustrial FR Hydra Fluid 68	68	14	$1,909.58	55
Statoil Hydraulic Lift Oil 46	45.3	8.1	$800	55

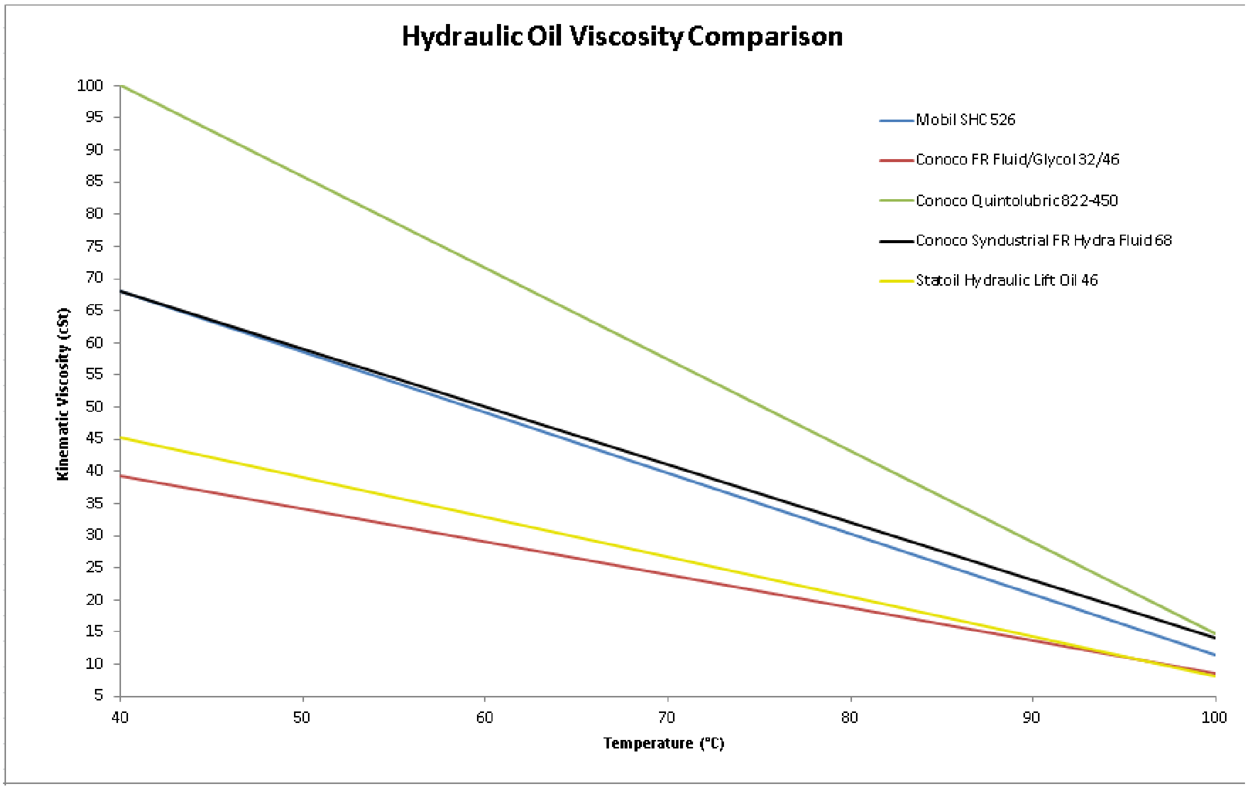


Figure 3. Comparison of Viscosity for top 5 hydraulic fluids chosen.

For our system, the Mobil SHC 526, Conoco Quintolubric 822-450, and the Conoco Syndustrial FR Hydra Fluid 68 were all possible replacements to the Statoil Hydraulic Lift Oil 46. The problem we now faced was that all of these replacement oils were more than twice the price for a 55 gallon price when compared to the current oil. This may not seem that much of a difference but changing hydraulic fluid is a regularly occurring maintenance item that will add to cost greatly in the long run. Cal Olive also uses the Statoil Fluid for all their other hydraulic machinery, adding an extra item to inventory and keep track of. Therefore upgrading to a better hydraulic fluid has a higher long term cost to benefit ratio and we will need a different way to solve the issue about viscosity somehow else. That is why we decided that the best route to pursue would be to keep the current hydraulic fluid and to upgrade the heat exchanger.

Heat Exchanger:

As stated earlier, during peak temperatures, the temperature of the hydraulic fluid can get up to 200+ degrees F and the current heat exchanger will cool it down to 180 degrees F. At this temperature the viscosity is about 11 centistokes. But we would like to be above 15 centistokes. So eventually our goal will be to bring the temperature of the oil down to less than 160 degrees F.

Figure 4. Original Oil-to-Air Heat Exchanger in the Cal Olive hedger.

The current system is a forced convection oil-to-air heat exchanger that uses the surrounding air to receive excess heat. The fins are designed to promote turbulent air flow to improve heat transfer capability. The goal with the new heat exchanger will be to get the hydraulic fluid down to less than 160 degrees F on the hottest days in the summer.

The heat exchanger company Hydac has a unique way to compute the heat dissipated based on the hydraulic fluid tank volume, fluid temperature difference at the beginning of operation then at steady state, and the time it takes to get to steady state.

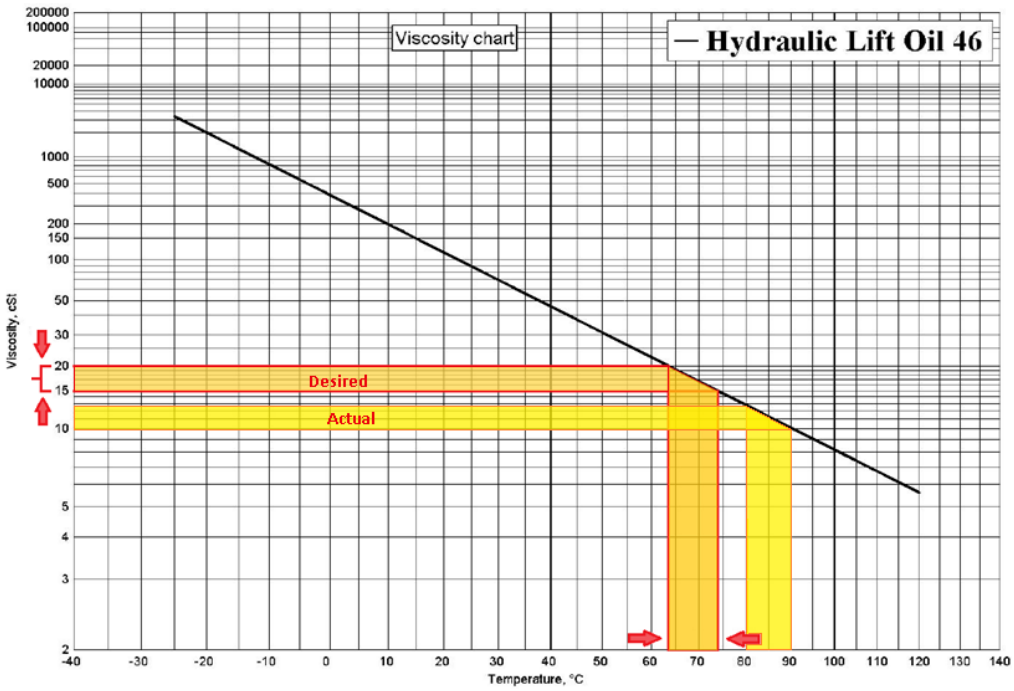


Figure 5. Viscosity chart of actual versus desired range of viscosity.

The variables necessary to compute the calculation are the volume of the tank, the density of the oil, the specific heat capacity, the desired oil temperature, the ambient air temperature, the system temperature increase from start to steady state and the time it takes to reach steady state.

Having the hedger start operation in the morning, the initial starting temperature is around 70°F and it takes approximately 4 hours to reach the steady state hot side hydraulic fluid temperature of 200°F. The tank volume is 75 gallons, or 284 liters. The density is 0.874 kg/L. The specific heat capacity is approximately 2.161 kJ/kg K.

$$V = 75 \text{ gallons} \rightarrow 284 \text{ Liters}$$

$$t = 4 \text{ hours} \rightarrow 240 \text{ minutes}$$

$$\Delta T = 200°F - 70°F \rightarrow 72.2°C$$

$$\rho_{oil} = 0.874 \frac{kg}{L}$$

$$c_{oil} = 2.161 \frac{kJ}{kg\, K}$$

$$P_v = \frac{(\Delta T)(c_{oil})(\rho_{oil})(V)}{(t)(60)} = \frac{(72.2°C)\left(2.161 \frac{kJ}{kg\, K}\right)\left(0.874 \frac{kg}{L}\right)(284\ L)}{(240\ min)(60)}$$

$$\boxed{P_v = 2.7kW}$$

T_1 is the desired oil temperature, and T_3 is the ambient air temperature. T_3 is assumed to be 120°F to relate to the hottest possible temperatures during the summer. The desired temperature for the old system is the actual 180°F. The desired temperature for the new temperature is 160°F.

OLD System	NEW System
$$P_{01} = \frac{P_v}{T_1 - T_3}$$ $$P_{01} = \frac{2.7\text{kW}}{82.2℃ - 48.8℃}$$ $$\boxed{P_{01} = 0.0808\ \text{kW}/℃}$$	$$P_{01} = \frac{P_v}{T_1 - T_3}$$ $$P_{01} = \frac{2.7\text{kW}}{60℃ - 48.8℃}$$ $$\boxed{P_{01} = 0.241\ \text{kW}/℃}$$

P_{01} represents the heat dissipation per degree Celsius required to reduce the system steady state temperature of 200°F to the desired oil temperature. Many heat exchangers are categorized by this value.

Alignment System:

Currently there is no way for the hedger operator to know exactly where he is side-to-side in the olive row while hedging. There is a product on the market currently that is designed for an application such as this that utilizes a special camera and a computer to let the operator know his location. The only problem with this system is that it is extremely expensive (approximately $10,000), and is not a very cost effective method for the California Olive Ranch.

The head mechanic at the California Olive Ranch, Steve Howe, has been prototyping an alignment system on another piece of machinery and wants us to see if we can improve on his design to make it more robust and hopefully more accurate. The alignment system will incorporate arms that protrude from both sides of the hedger. Attached to these arms will be spring loaded "feeler arms" that will be made out of nylon and be the part of the system that will make contact with the trunk of the olive tree. When the "feeler arm" makes contact with the tree trunk, a micro-switch will be activated causing a light in the operator's cabin to become illuminated signaling that the operator is too far to the right or left. The feeler arms will be adjustable in multiple directions to accommodate variations in row width and trunk height.

Figure 6. Prototype alignment system on another piece of equipment at Cal Olive.

<u>Bearing Carrier:</u>
The development of the new bearing carrier begins with a study of the forces the component will see during operation. The main focus of this analysis is to determine the reaction forces on the bearings and housing. This will yield the primary problem areas and how to correct them for a more efficient component. A free body diagram (FBD) of these forces applied to the blade shaft is depicted in figure B.1 of Appendix B. The forces shown in the FBD are calculated assumptions based on suggestions from the blade manufacturer, Cal Olive Ranch, and personal experience. After the analysis was completed the primary concern is the axial load produced by the torque applied to king nut when tightening the blade down. All the other forces included cause normal wear to the bearings; making improvement in these areas would not be cost effective.

Figure 7. Shown above is the current bearing carrier and blade shaft used in the KCI hedger.

Upon further inspection and analysis the axial load produced by the common style of tightening the king nut produces a force of approximately 4300 pounds (lbs.). This value was confirmed by solving for the preload based off of the friction keeping the blade from spinning. This calculation resulted in a value of approximately 4500 lbs., confirming the results of the initial calculation.

Equations and values used to determining the axial load “P”,

$$P = \frac{T}{kd}$$

$$P = \frac{960\ [in * lbs]}{(.22)(1\ [in.])}$$

$$P \approx 4300[lbs]$$

$$P = \frac{T[3(D^2 - d^2)]}{f(D^3 - d^3)}$$

$$P = \frac{80\{ft * lbs\}[3(.1242^2 - .1025^2)]}{.15(.1242^3 - .1025^3)}$$

$$P \approx 4500[lbs]$$

Some key assumptions needed to be made to arrive at these values. The primary assumption is the torque applied to the king nut by the impact gun used to tighten it. To be conservative, an estimate of 80 ft*lbs of torque is used to secure the king nut and allow placement of the cotter pin.

After coming to the solution for the axial load and inspecting the bearing carrier design further a question began to trouble the group. “If such a high axial load was applied to the ball bearing, how did they last as long as they typically did without burning up?” The solution came in the subtle addition of a steel collar between the bearings. The axial force is never meant to be applied directly to the bearings but is to be transmitted through the inner ring of the bearings along this collar. In an ideal case the bearing never sees this axial load due to the design of the drive shaft which should support the entire force. On occasion however the bearings do see this force resulting in bearing failure.

Based on this problem a new bearing carrier design has been generated to eliminate the possibility of bearing failure due to the possible axial load. The solution includes two improvements to the current design. The first is an extension of the drive shaft which will stop any contact between the bearings and blade clamps. This will transfer the load through the bearing more efficiently than the original system. A simple collar will be welded to the top blade clamp and rest on the inner bearing ring. The second improvement will be to install single row tapered roller bearings to replace the existing ball bearings. The purpose of the tapered rollers is to be a secondary fail safe if the axial load should be applied to the bearings. The tapered rollers will be installed in opposite directions therefore sharing any thrust loading between them equally. A Solidworks model of the new system is shown below in figure 9.

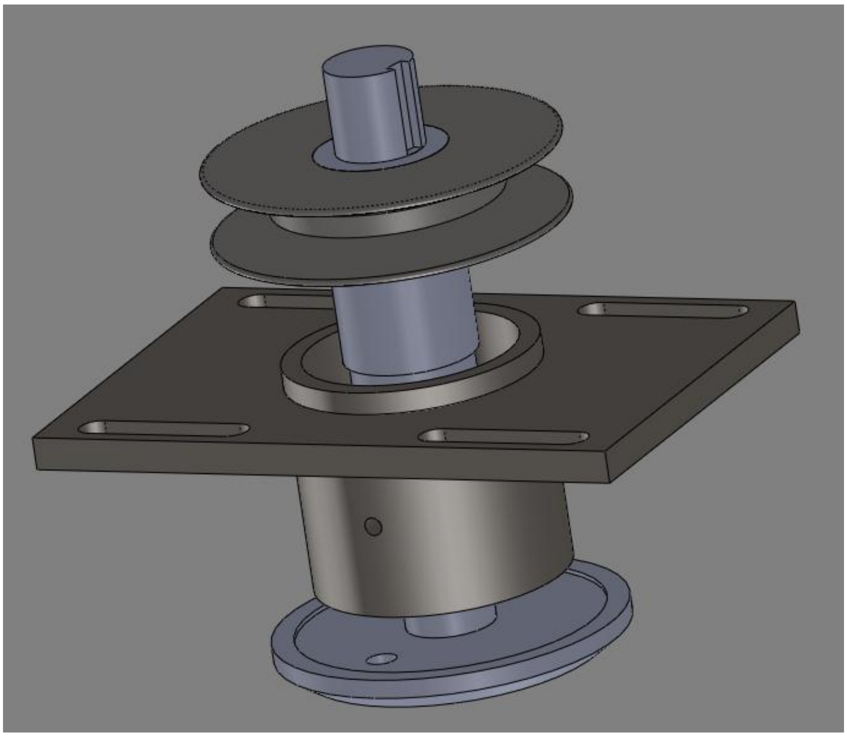


Figure 8. The rendering of the completed bearing carrier includes both the extended drive shaft and tapered roller bearings as mentioned in the above paragraph. This rendering does not include the new Blade shafts. Mechanical drawings of the assembly and components can be found in figures B.2 –B.8 of Appendix B.

The current ball bearings in the bearing carrier are produced by ZKL bearings. The new tapered roller bearings are produced by Timken (See Table D.1 for bearing specifications) with common dimensions which allow minimal machining to adjust the current carriers to accept the new bearings. This machining will not weaken the carrier, so continued quality of operation remains the same. The redesigned bearing carrier will reduce unscheduled maintenance and precious downtime of the hedger increasing productivity and profits.

Figure 9. Image of tapered roller bearing similar to the Timken bearing mentioned above.

Final Design:

Alignment System:

The alignment system for the hedger will be a rather simple mechanism that will be robust enough to handle the abuse that it will see from daily use in the field. One four foot section of 2.5" square tubing will be welded onto the hedger frame at the bottom front of the hydraulic tank. It will have two 5/8" set screws to hold the feeler arm tubes in place.

The feeler arm tubes will be constructed of 2" square tubing approximately three feet in length. At the outer end of the tubes, a small length of 1.25" square tubing will be welded in vertical for adjusting the pivot arms up and down. These will also have set screws, but of a 3/8" diameter.

Inside the 1.25" square tubing, a 1" diameter round tube will placed. This 1" diameter tube is what the feeler arm will pivot in. A piece of .75" solid round stock will be the shaft that is rotating. Washers will be welded on both ends of the solid stock to prevent it from moving axially in the housing. At the very bottom of the solid stock, another short piece of tubing will be welded perpendicularly to the shaft. This short piece of tubing will have one 3/8" diameter set screw that will hold the nylon rod which is going to be contacting the olive tree trunk.

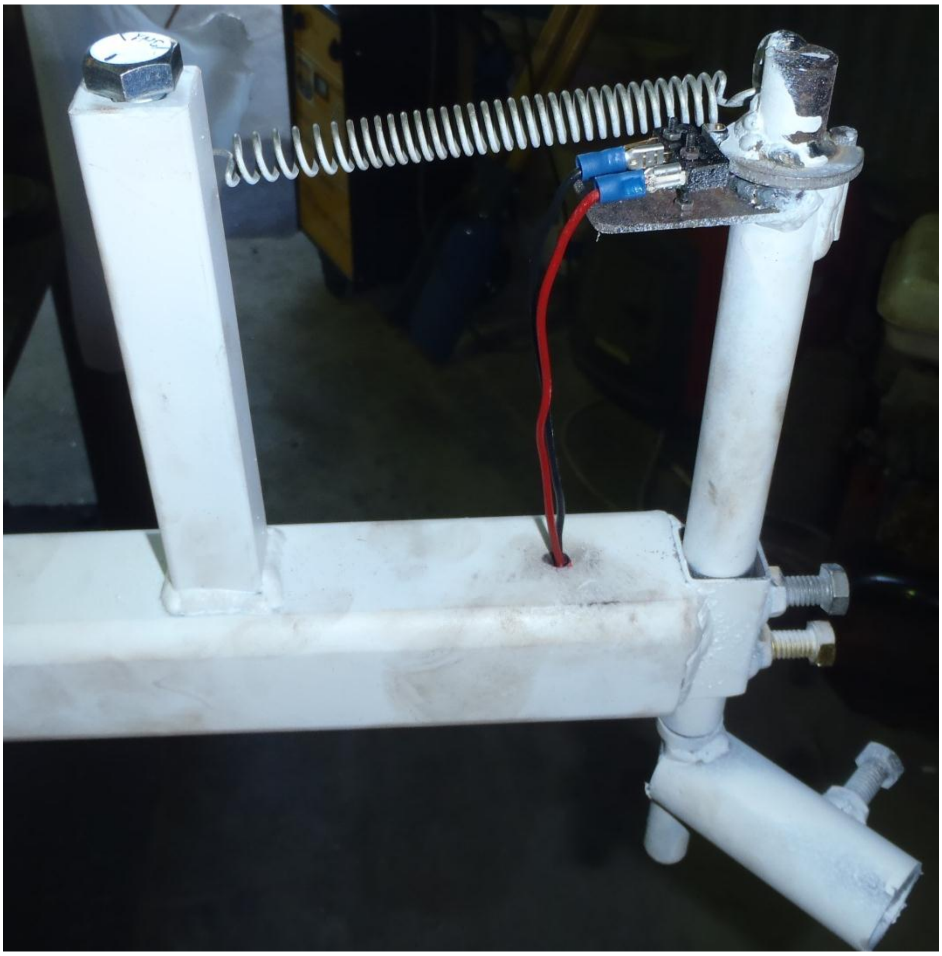


Figure 10. The image shown is the completed feeler arm. The bow rod is not attached and the shielding plate is removed to show components.

The washer on the top of the shaft will have a cam profile ground into it so that when the nylon rod comes into contact with the tree trunk, the shaft will pivot and the micro-switch that will be mounted next to the washer, will be activated. The activation of this micro-switch will complete the circuit of the light bar that will be mounted in front of the operator. This light bar will be nothing more than an electrical box with two lights on it, one for the left side, and one for the right side. When one of the lights flashes, it's telling the operator that he or she is too far to that side, and they can adjust accordingly. The washer will also have a section of its body removed, so a pin welded to the housing will prevent the shaft from over rotating, and locate its equilibrium position.

The feeler arm will return to its equilibrium position from the moment caused by a tension spring that will be mounted between the front top of the rotating shaft and another post located approximately six inches away on the long tube. This spring will not be permanent; therefore making spring changes based on field conditions will not be an issue. Solidworks drawings of the feeler arm components are shown in Appendix B figure B.10 – B.14.

Bearing Carriers and Blade shafts:

A major part of the KCI hedger redesign is the implementation of tapered roller bearing and new blade shafts. The Idea behind the new blade shafts came as an added requirement to the project. The design of these shafts was already completed by COR but manufacturing was placed on our senior project group to ensure the new blade shafts mated with the existing bearing carriers. A Solidworks drawing of the new blade shaft is found in Appendix B figures B.9. To allow the new bearings and shafts to fit the existing bearing carriers, machining was required. The bearing carrier housings needed to be machined down to allow for the thicker but same diameter tapered roller bearings. The Solidworks drawing for the new bearing carrier housings is found in Appendix B figures B.5. The New blade shafts needed to be built from stock materials. The last components which needed to be made were spacers to correctly preload the new bearings and allow for the bearings to seal containing the lubricating grease.

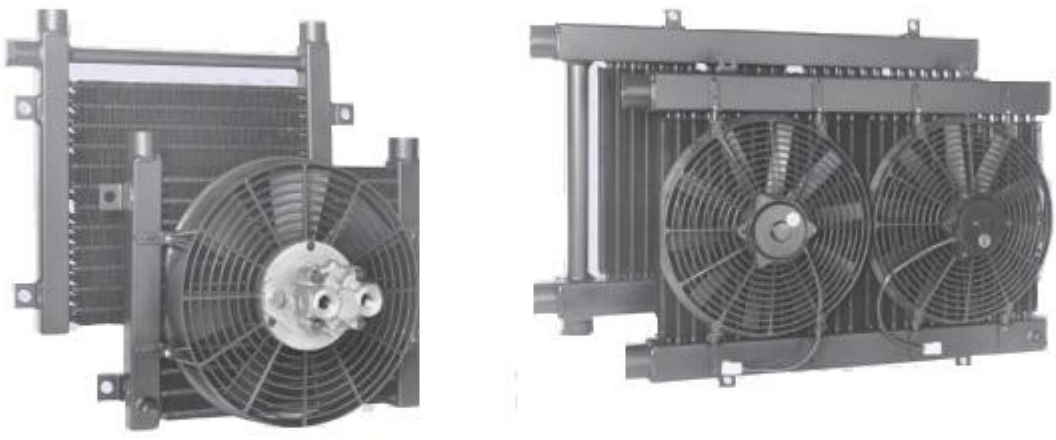
Figure 11. Shown above are the new blade shafts and spacers awaiting installation into the modified bearing carriers.

There is twelve of each of the components and due to the limited amount of time before the hedger had to be returned to COR and the limited access to the machine shop during winter quarter, the only option for manufacturing the components was to get outside help. Pablo Aguirre at Precision Machine Co. in San Luis Obispo, CA was able to meet the required deadline and was able to manufacture all the parts needed. A complete order form with approximate pricing is shown in appendix C, table C.4. The process of payment for goods and services was handled through Steve Howe at COR who directly contacted Precision Machine when the order had been completed.

Figure 12. Business card for Pablo at Precision Machine

<u>Heat Exchanger:</u>

Cal Olive wanted to replace the heat exchanger with one from the same company as the old one, Thermal Transfer Products. Based on their catalog we decided to go with the MF-60 model. The current heat exchanger is the MF-15. The new MF-60 heat exchanger will be approximately double the size and use dual electric fans instead of a hydraulic fan. This is to reduce any more loads on the hydraulic system and ensure that the fluid does not overheat.



Old System **New System**

Figure 13. Old and new heat exchangers

Based on the calculations earlier, we can now see how much heat dissipation is needed. The performance curve below plots the heat dissipation against the oil flow. The heat dissipation is based on a temperature difference of 50°F. A temperature change of 50°F translates to a temperature change of 27.8°C.

OLD System	NEW System
$P_{01} = 0.0808\ \text{kW/°C}$ $q = (P_{01})(\Delta T[27.8°\text{C}])$ $q = 2.24\ \text{kW}$ $\boxed{q = 7{,}600\ \text{BTU/hr}}$	$P_{01} = 0.241\ \text{kW/°C}$ $q = (P_{01})(\Delta T[27.8°\text{C}])$ $q = 6.7\ \text{kW}$ $\boxed{q = 23{,}000\ \text{BTU/hr}}$

The old heat exchanger has approximately 12 gallons per minute of flow because the hedger was only plumbed for one side of the system. The new heat exchanger will incorporate both sides of the hedger and will thus have an approximate oil flow of 25 gallons per minute.

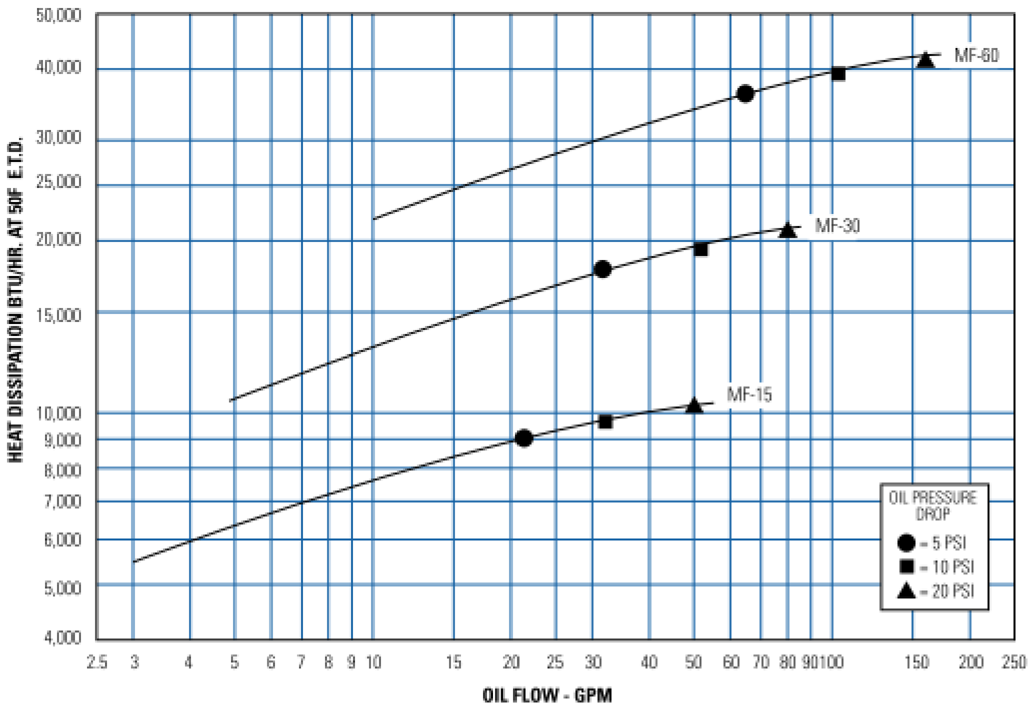


Figure 14. Performance curves of heat exchangers from Thermal Transfer Products.

Based on these flow values, we can correlate the actual performance numbers to the calculated. For the old system, the calculated heat dissipation is about 7600 BTU/hr and the graphical heat dissipation is 8000 BTU/hr based on the oil flow. The calculated and graphical value is 5% off thus verifying that the calculations to achieve the numbers are reliable.

For the new system at 25 gallons per minute, the graphical heat dissipation will be about 28,000 BTU/hr. The calculated minimum heat dissipation rate is 23,000 BTU/hr. There is an 18% discrepancy, but this value can be considered as a factor of safety since the heat exchanger will build up a thermal resistance due to fouling. Working in an agricultural field will slowly clog the fins of the heat exchanger and using a heat exchanger with a higher heat dissipation rate than required will ensure that fouling resistances will not cause overheating.

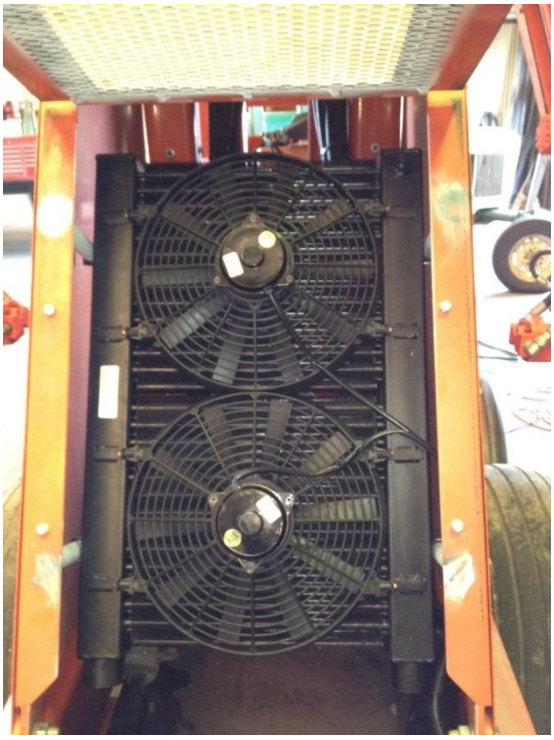


Figure 15. New heat exchanger mounted on the Cal Olive hedger.

Fan Reversing:

A reversing sub-system will be added to the electric fans of the heat exchanger. This system will stop the fans after a certain amount of time, and reverse the directions of the fans for a short time. Then the system will return back to normal. This reversing cycle is to help remove or reduce the amount of fouling between the fins of the heat exchanger. This is very important because it is guaranteed that debris will enter the fins of the exchanger and reduce the heat transfer effectiveness.

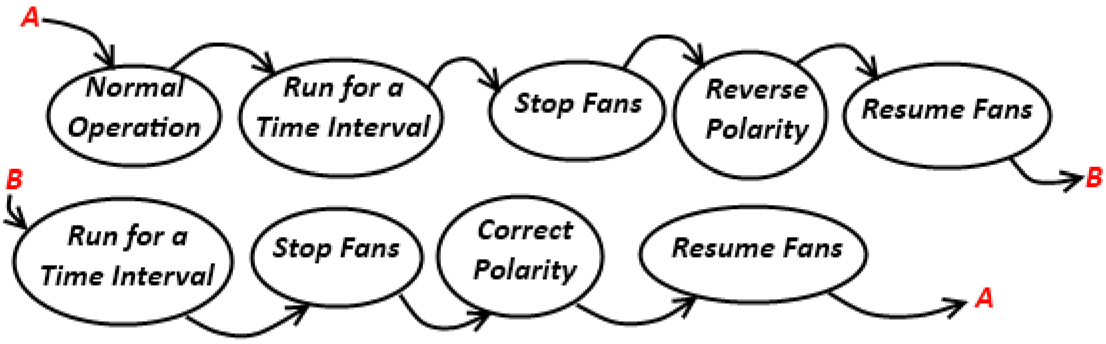


Figure 16. Transition Diagram for Fan Reversal Program

The fan reversing system will consist of 2 relays: a simple Single Pole Double Throw (SPDT) relay and a Double Pole Double Throw (DPDT). The SPDT relay will be the relay that enables or disables the power going to the fans while the DPDT relay reverses the polarity. Firstly, the SPDT relay will be wired as normally open so that relay allows power to the fan motors when it is off and cuts the power

to them when the relay activates. This is to ensure that if the relay were to fail, the electric fans would still be able to operate. Cutting power to the fans before switching polarity makes sure that the fans do not get damaged with an instantaneous switch. Such a switch would create a very large voltage spike and possible blow the relays.

Controller Board:

There are sections of the Cal Olive ranch which are on a hill and it is important that the hedger, while hedging, to stay vertically. Therefore there is a need for a device to auto level the hedging arms to maintain the blades at a vertical angle.

Figure 17. Cal Olive hedger in hedging position.

A controller board will be in charge of determining the angle of the blades and send a duty cycle, or pulse width modulation to the solenoid valves controlling the hydraulic arms. Since the device controlling the arms is a solenoid, the arms cannot be adjusted by a variable voltage. The valve is either fully open or fully closed. A servo valve would be required to have a variable voltage input, and it would be too expensive and complicated to implement. Therefore a pulse width modulation can obtain similar results to a variable voltage by sending 12V pulses at certain duty cycles.

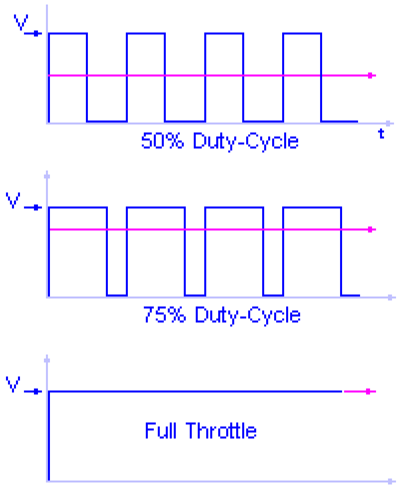


Figure 18. Pulse width modulation with differing duty cycles.

The controller board is in charge of many different things, it is in charge of creating and sending a duty cycle to the solenoids, receiving and converting the signal from the angle sensors, control the fan reversal system, give power to the sensors, and interface with a laptop.

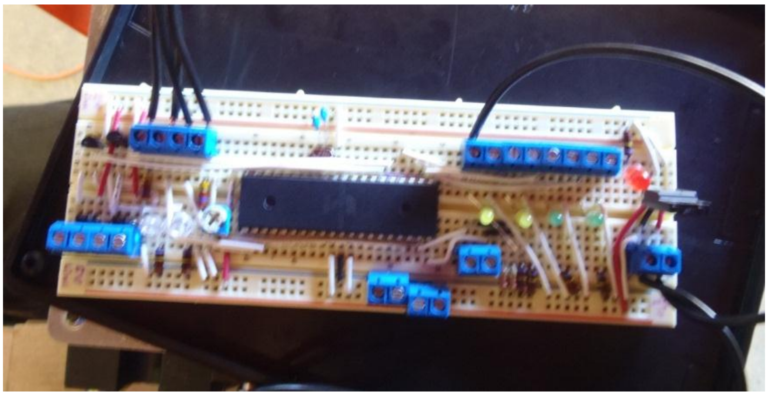


Figure 19. Prototype controller board for testing.

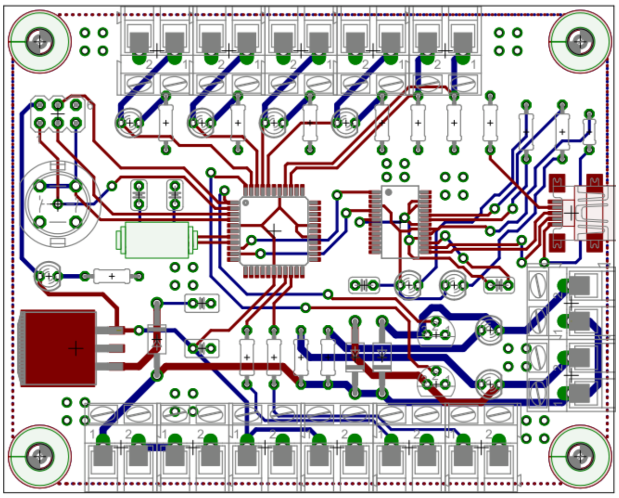


Figure 20. PCB board for controller.

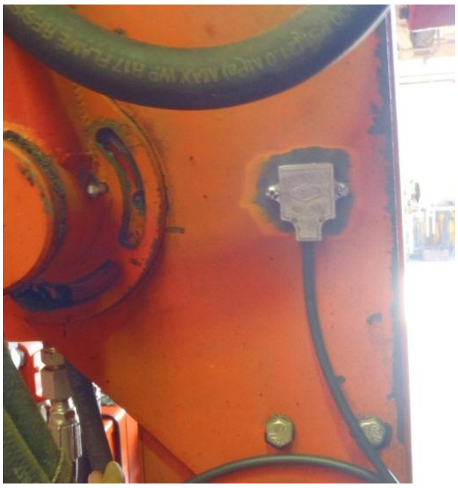


Figure 21. Inclinometer sensors that detect angles of blades.

The sensors that will be detecting the angle of the blades are inclinometers. These inclinometers are analog devices that output a voltage from 0-5 Volts. The controller picks up this signal, converts it to a digital number (8 bits) and creates a duty cycle for the solenoids. The sensors chosen are very robust and highly over damped to filter out any vibrations. The sensors can also handle up to 20,000g mechanical shocks.

Figure 22. Solid State relays that actuate hydraulic pistons.

In order to get the hydraulic arms to move, the microcontroller creates a duty cycle, but the problem is, is that the controller cannot allow enough current to flow to get the actuators to move. The solenoids typically activate at 3 Amps, and the max the microcontroller can safely output is 20mA. Therefore there is a problem that needs to be overcome. To solve this, solid state relays are utilized. A solid state relay allows a small amount of voltage or current to activate the relay and permits large amounts of current to flow on the other side. Most importantly, the solid state relay can turn on and off in milliseconds. This is important because the duty cycle created by the microcontroller pulses very rapidly, also in the milliseconds.

Test Plan:

The test for our project will be completed the last weekend of April (4/28/12 - 4/29/12). Upon arriving in Artois, CA we will install the new more robust printed microcontroller circuit board. The next test will be to check circuit board performance by testing the auto-leveling system and the fan reverser. Once these systems check out and meet our and COR's standards in a controlled shop environment. The system will be field tested on actual olive trees. During this phase of the testing, all systems will be monitored so conclusions and recommendations can be made. Closer to the travel date an itinerary of when each of these tests will be formed to ensure nothing is left out.

Results:

Based on the testing done while the hedger was on campus and from the feedback given by California Olive Ranch head mechanic Steve Howe, the modifications made to the hedger have resulted in both positive and negative results. Each of the components were tested in a controlled shop setting and then in the field. All field testing was completed by COR employees.

<u>Alignment System:</u>
This component of the project met all the requirements when tested in the shop. The system responded as designed with the appropriate light illuminating when either senor was activated. When tested in the field the system was too sensitive to be beneficial to the operator. The springs were not stiff enough to push through the lower brush on the olive trees. This resulted in the operator adjusting course when it was not necessary. The robust design, the adjustability and the detachment of the arms met the requirements of COR.

<u>Bearing Carriers and Blade shafts:</u>
Many issues were met in the manufacture and installation of these components. The bearings carriers had to be machined down to meet the new bearing thickness. This made the distance between the two bearings less than an inch. Though this has not yielded any apparent problems a larger gap is desired. The blade shafts, though tough to build, worked perfectly. The new blades easily attached using the new interface, resulting in much less down time when the blades need replacing. One area of concern is the pre loading of the bearings. Spacers were made to slide over the blade shaft to apply a preload on the bearings. If the bearings don't receive the minimum amount of preload to compress the rollers into the cup, the bearings do not adequately support the blade shaft. If too much preload is applied, the amount of torque to spin the shaft becomes too high. COR did report that when this

preload is correctly applied the system worked perfectly. To our knowledge no bearings have had to be replaced due to premature wear.

Heat Exchanger:

The new heat exchanger that was installed has had no issues. According to COR, neither the hedger nor the tractor hydraulic oil has over heated. The machine has been put through 10-12 hour work days when the ambient temperature was around 70-80 degrees Fahrenheit, but has not yet operated in the height of summer when temperatures can reach as high as 110 degrees Fahrenheit. This will be the true test to see how well the new heat exchanger is performing.

Fan Reverser:

The fan reversing system works perfectly when simulated in the shop environment. The fan starts, spinning in the normal direction, then the controller board takes over. First it will cut the power to let the fans coast to a stop to avoid overloading the motors. Next, it switches polarity and starts the fans back up spinning in the opposite direction. Once this occurs the fan runs for the allotted time and repeats the process. COR has yet to use the system because of the low dust and particulates in the air after the spring rains. As summer gets underway the system will be tested in the field because there will be sufficient airborne particulates.

Controller Board:

The prototype board had issues of wires detaching and faulty components. Even with these short comings the board has allowed us to test the various components controlled by the board with great success. A better system is needed, which is more robust and permanent.

Conclusions and next steps:

Alignment System:

Stronger springs are needed to reduce the amount of “noise” in the signal to the tractor operator. Due to the fact that each tree is different, some thicker and thinner, a trial and error approach would be most efficient in choosing a new spring. We recommend running the system through the older trees as their growth with provides the highest resistance to the feeler arms. Steve Howe said that he would install stiffer springs and possibly increase the lever arm on the pivot shaft to acquire the needed resistance on the feeler arms.

Bearing Carriers and Blade shafts:

Though the system currently works, we believe a better approach to implementing the tapered roller bearings would be to redesign the bearing carriers and blade shaft housing from the ground up. This would allow proper preload each time and reduce the number of components and associated costs. The blade shafts for the current system have had no bad reviews from COR and to our knowledge are working properly.

Heat Exchanger:

As mentioned in the results section, the heat exchanger seems to be functioning up to the design specifications. The system has not been tested in the height of summer but we are confident that the cooling the electric fans and larger area provide will be more than adequate.

Fan Reversing:

This system works properly but also has yet to be used in the field because fouling of the heat exchanger has been kept to a minimum due to the low amount of dust, pollen, and other particulates during the spring. When summer arrives, and the amount of particles in the air increases, the reversing system will able to be utilized. However, the increase of particulates should have no effect on the electronic controller system.

Controller Board:

The controller board has been simplified from the prototype and has been printed on a pcb board versus the bread board that it was on originally. The board was designed to minimize the size but also keep it large enough to be able to solder components easily. A USB interface has been added to see information about the controller on the terminal screen of a laptop, and allow COR to change the parameters of the controller.

Appendix A:

Table A.1 QFD for Cal Olive Ranch Hedger

California Olive Ranch Hedger

Customers:
Adam Englehardt
Steve Howe

Engineering Requirements (HOWS)

Customer Requirements	Weighting (Total 100)	Blade horsepower	Forces on blade shaft	Cutting arm controller	Oil temp vs. viscosity	Pump & motor efficiencies	Plumbing efficiencies	Reduce oil temperature	Cutting swath width		KCI Hedger
design bigger star	15		○						●		3
new bearing carrier	20	○	●			Δ			Δ		2
hydraulics heat	20	Δ			●	●	○	●			2
different hydraulic oil?	5	Δ			●			○			3
different pumps & motors?	10	●			●	●		○	Δ		3
self-leveling arms	10			●							1
self-aligning in the row	15			●							1
parallel vs. series for motors	5	●			Δ	○	●				3
Units		hp	lbs	n/a	cst	%	%	deg	in.		
Targets		6	4500	n/a	30	80	80	150	108		
Benchmark #1		2	4500	n/a	11	?	?	180	90		
Benchmark #2											

● = 9
Srong Correlation

○ = 3
Medium Correlation

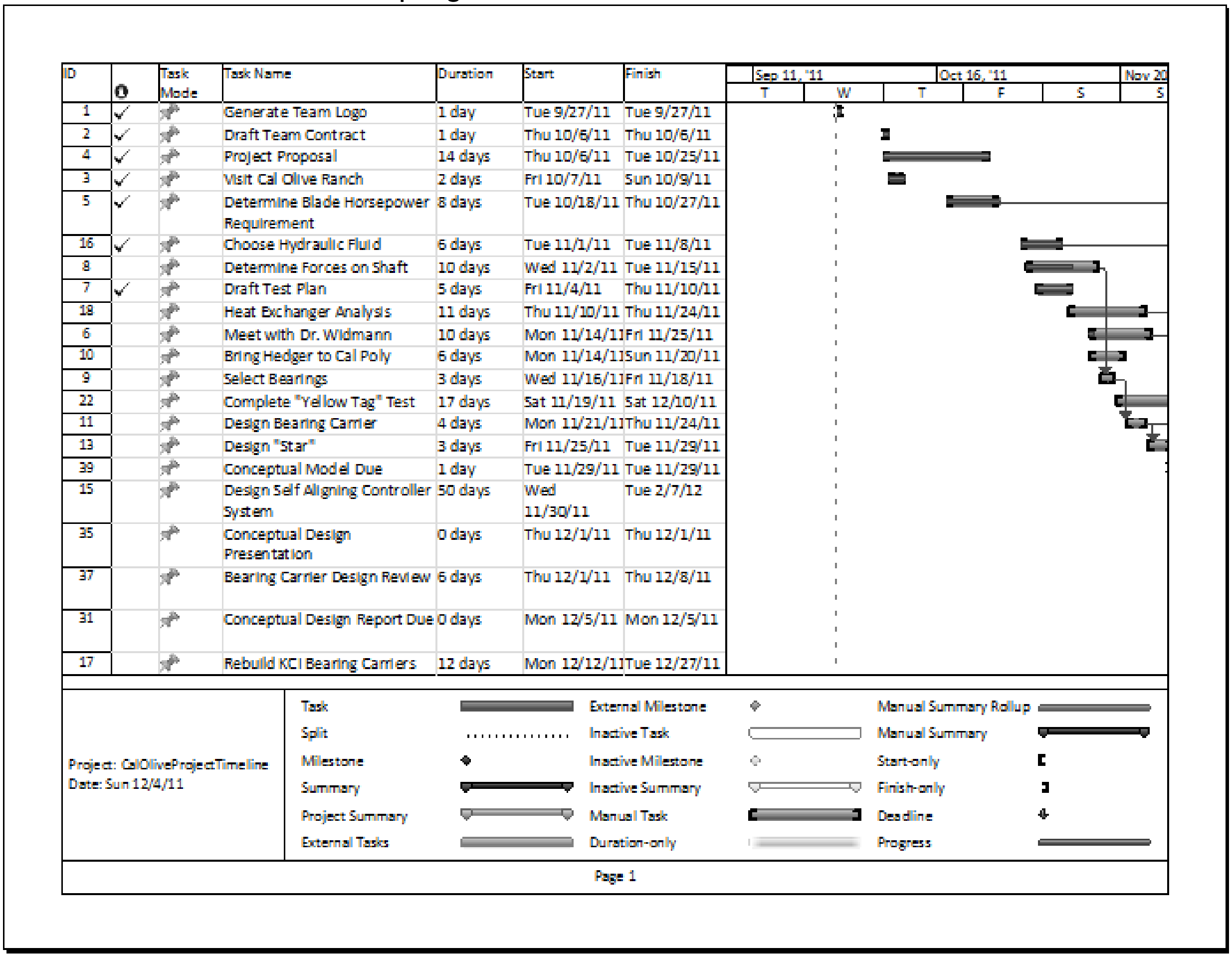
Δ = 1
Small Correlation

Table A.2. Cal Olive Ranch hedger formal engineering requirements. Shown in the table are the design parameters, then the required measurement followed by the tolerance of the parameter. In the Risk column the

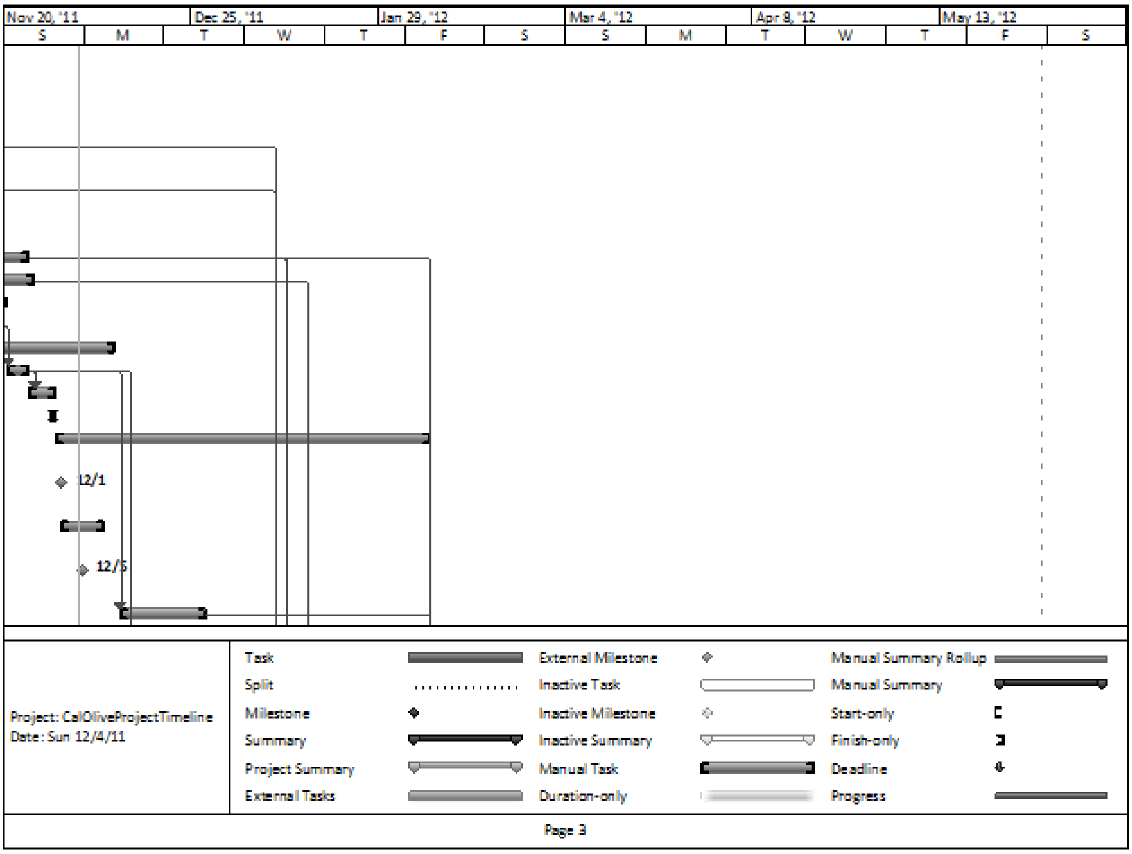
likely hood of meeting the requirement is ranked from low to high. The compliance column assesses the method of solving the design requirement. The symbols mean the following: Analysis (A), Test (T), Similarity to Existing Designs (S), and Inspection (I).

Cal Olive Ranch Hedger Formal Engineering Requirements					
Spec. #	**Parameter Description**	**Requirement or Target (units)**	**Tolerance**	**Risk**	**Compliance**
1	Hydraulic viscosity	25 to 36 (centistokes)*	± 5	M	A, T, S, I
2	Oil Temperature	150 F	± 30	M	A,T, I
3	Cutting Width	108 (in) = 9(ft)	±0.25	L	I, A
4	Production Cost	$?	Max	M	A
5	Blade Power	6 (hp)	Min	L	A
6	Blade Rotation Speed	5000-6000 (rpm)	± 500	M	A, T, I
7	Star Rotation Speed	60 (rpm)	± 2	M	A, T, I
8	Tractor Speed	3 (mph)	± 3	M	A, T, S, I

Table A.3 Gantt chart of planned senior project schedule. The following four images are the progression of the Gantt chart.



ID		Task Mode	Task Name	Duration	Start	Finish
1	✓		Generate Team Logo	1 day	Tue 9/27/11	Tue 9/27/11
2	✓		Draft Team Contract	1 day	Thu 10/6/11	Thu 10/6/11
4	✓		Project Proposal	14 days	Thu 10/6/11	Tue 10/25/11
3	✓		Visit Cal Olive Ranch	2 days	Fri 10/7/11	Sun 10/9/11
5	✓		Determine Blade Horsepower Requirement	8 days	Tue 10/18/11	Thu 10/27/11
16	✓		Choose Hydraulic Fluid	6 days	Tue 11/1/11	Tue 11/8/11
8			Determine Forces on Shaft	10 days	Wed 11/2/11	Tue 11/15/11
7	✓		Draft Test Plan	5 days	Fri 11/4/11	Thu 11/10/11
18			Heat Exchanger Analysis	11 days	Thu 11/10/11	Thu 11/24/11
6			Meet with Dr. Widmann	10 days	Mon 11/14/11	Fri 11/25/11
10			Bring Hedger to Cal Poly	6 days	Mon 11/14/11	Sun 11/20/11
9			Select Bearings	3 days	Wed 11/16/11	Fri 11/18/11
22			Complete "Yellow Tag" Test	17 days	Sat 11/19/11	Sat 12/10/11
11			Design Bearing Carrier	4 days	Mon 11/21/11	Thu 11/24/11
13			Design "Star"	3 days	Fri 11/25/11	Tue 11/29/11
39			Conceptual Model Due	1 day	Tue 11/29/11	Tue 11/29/11
15			Design Self Aligning Controller System	50 days	Wed 11/30/11	Tue 2/7/12
35			Conceptual Design Presentation	0 days	Thu 12/1/11	Thu 12/1/11
37			Bearing Carrier Design Review	6 days	Thu 12/1/11	Thu 12/8/11
31			Conceptual Design Report Due	0 days	Mon 12/5/11	Mon 12/5/11
17			Rebuild KCI Bearing Carriers	12 days	Mon 12/12/11	Tue 12/27/11

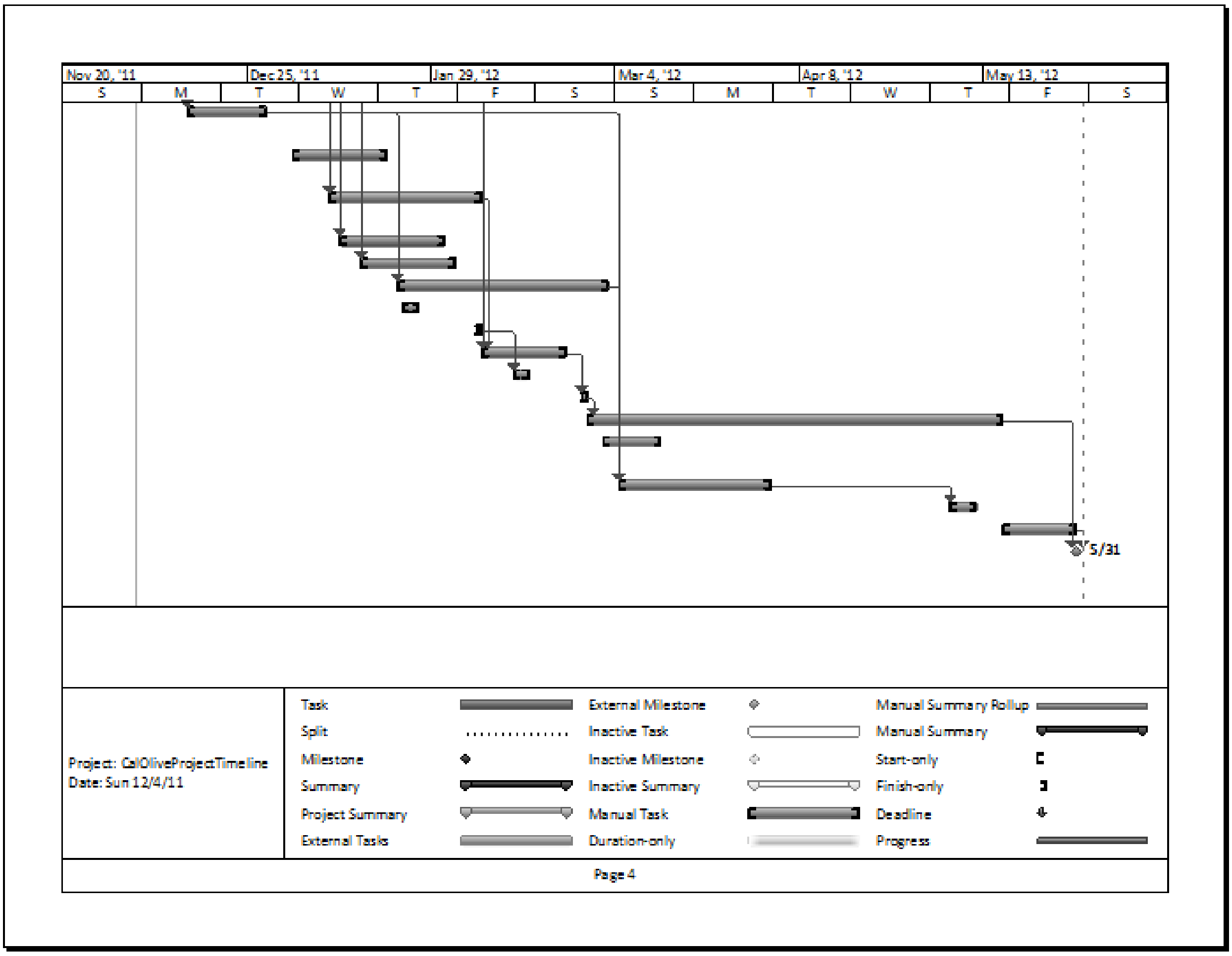

Nov 20, '11
Dec 25, '11
Jan 29, '12
Mar 4, '12
Apr 8, '12
May 13, '12
S
M
T
W
T
F
S
S
M
T
W
T
F
S
12/1
12/5
Project: CalOliveProjectTimeline
Date: Sun 12/4/11
Task
Split
Milestone
Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
Deadline
Progress
Page 3

ID		Task Mode	Task Name	Duration	Start	Finish
24			Fabricate New Bearing Carriers	11 days	Wed 12/14/11	Wed 12/28/11
14			Design Self Leveling Controller	14 days	Tue 1/3/12	Fri 1/20/12
20			Hydraulic Component Selection	21 days	Tue 1/10/12	Tue 2/7/12
19			Install Heat Exchanger on KCI	14 days	Thu 1/12/12	Tue 1/31/12
12			Hydraulic System Schematic	14 days	Mon 1/16/12	Thu 2/2/12
25			Build New Stars	30 days	Mon 1/23/12	Fri 3/2/12
34			Practice CDR Presentation	3 days	Tue 1/24/12	Thu 1/26/12
32			Ind. Ethics Memo Due	1 day	Tue 2/7/12	Tue 2/7/12
23			Test Updated KCI Hedger	12 days	Wed 2/8/12	Thu 2/23/12
28			Ethics Presentation	3 days	Tue 2/14/12	Thu 2/16/12
21			Return Hedger to Cal Olive	1 day	Mon 2/27/12	Mon 2/27/12
27			Finalize Report	57 days	Tue 2/28/12	Wed 5/16/12
38			Hydraulics/Alignment System Design Review	7 days	Fri 3/2/12	Mon 3/12/12
26			Assemble New Stars	21 days	Mon 3/5/12	Mon 4/2/12
29			Hardware Demo	5 days	Mon 5/7/12	Fri 5/11/12
33			Build Project Poster	10 days	Thu 5/17/12	Wed 5/30/12
30			Project Expo	0 days	Thu 5/31/12	Thu 5/31/12
36						

Timescale: Sep 11, '11 — Oct 16, '11 — Nov 20 (T, W, T, F, S, S)

Project: CalOliveProjectTimeline
Date: Sun 12/4/11

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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Dec 25, '11
Jan 29, '12
Mar 4, '12
Apr 8, '12
May 13, '12
S
M
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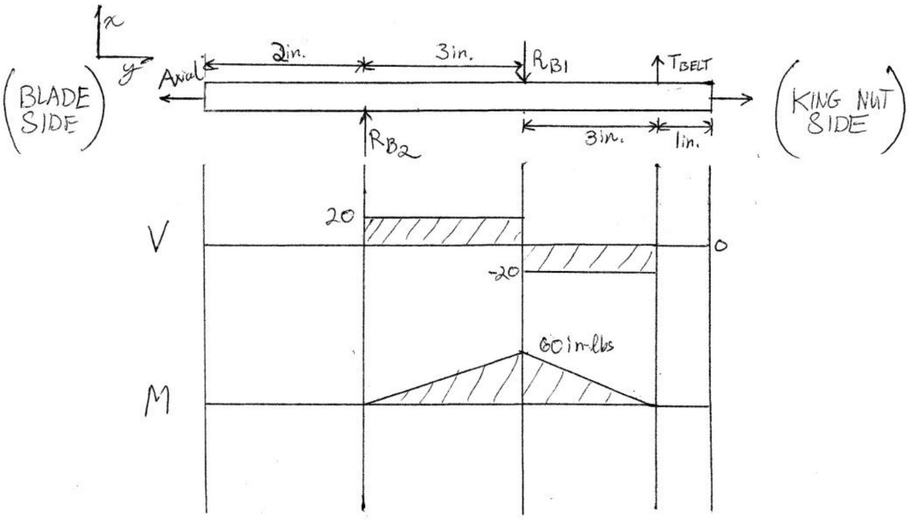
F
S
5/31
Project: CalOliveProjectTimeline
Date: Sun 12/4/11
Task
Split
Milestone
Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
Deadline
Progress
Page 4

Appendix B:
Sample Calculations and Drawings



ASSUME: $T_{BELT} = 20\,lbs$

$\Sigma F_x = 0$:

$$T_{BELT} + R_{B2} - R_{B1} = 0$$

$$R_{B1} = T_{BELT} + R_{B2}$$

$$R_{B1} = 20 + R_{B2} \qquad (1)$$

$\Sigma M_{KN} = 0$: (SUM OF THE MOMENTS ABOUT KING NUT END)

$$-R_{B2}(7in) + R_{B1}(4in.) - T_{BELT}(1in.) = 0$$

$$-R_{B2}(7in) + R_{B1}(4in.) = 20\ in\text{-}lbs \qquad (2)$$

SUBSTITUTE EQN (1) INTO (2)

$$-R_{B2}(7) + 4(20 + R_{B2}) = 20$$

$$-R_{B2}(7) + (4)R_{B2} = -60$$

$$-3R_{B2} = -60$$

$$R_{B2} = 20\,lbs$$

$$R_{B1} = 40\,lbs$$

Figure B.1 FBD and shear moment diagram of the blade shaft. Primary analysis on the reaction forces due to the tension in the belt.

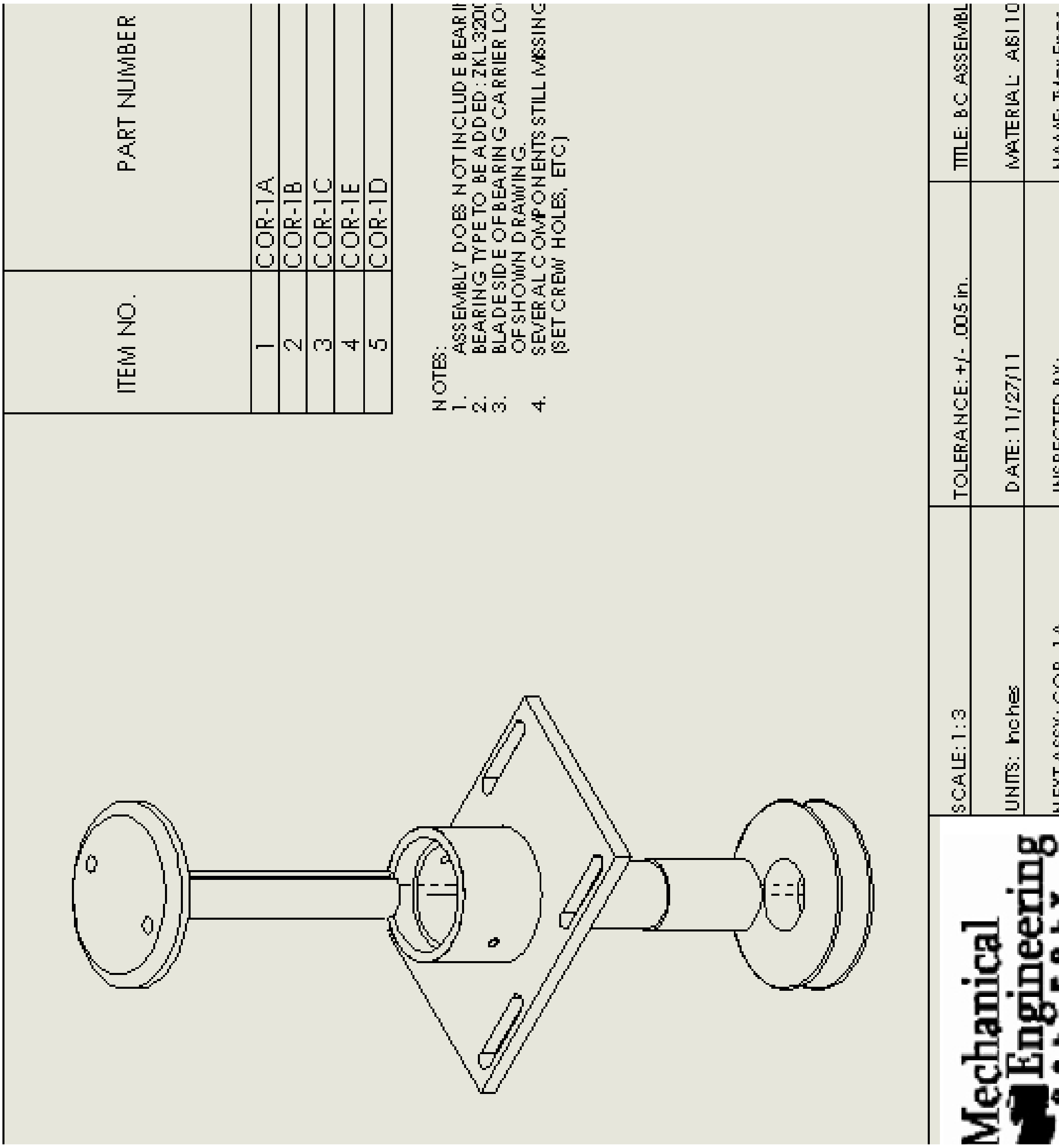


Figure B.2 Assembly drawing of redesigned bearing carrier.

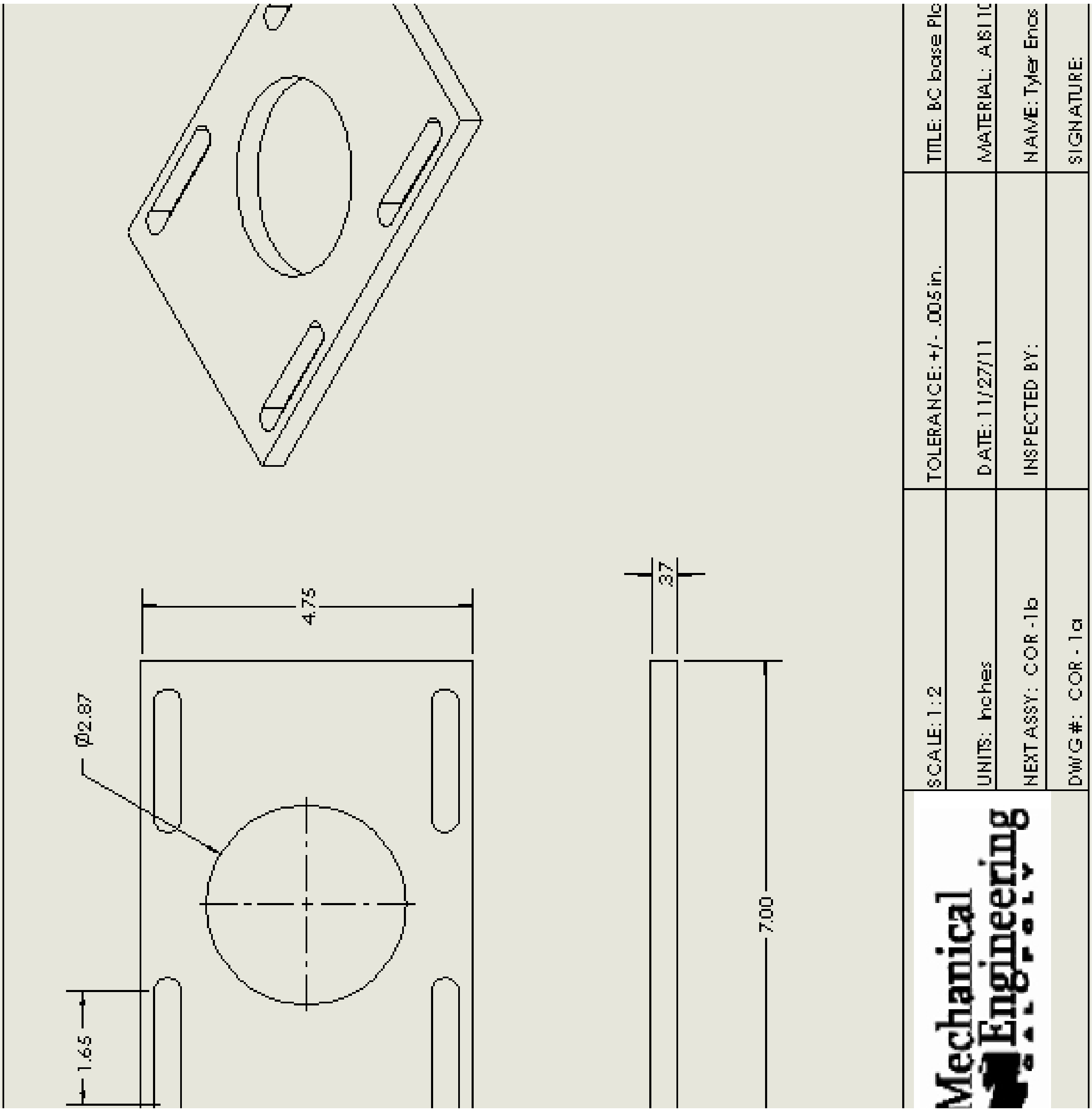


Figure B.3 Base plate for bearing shaft housing for the redesigned bearing carrier.

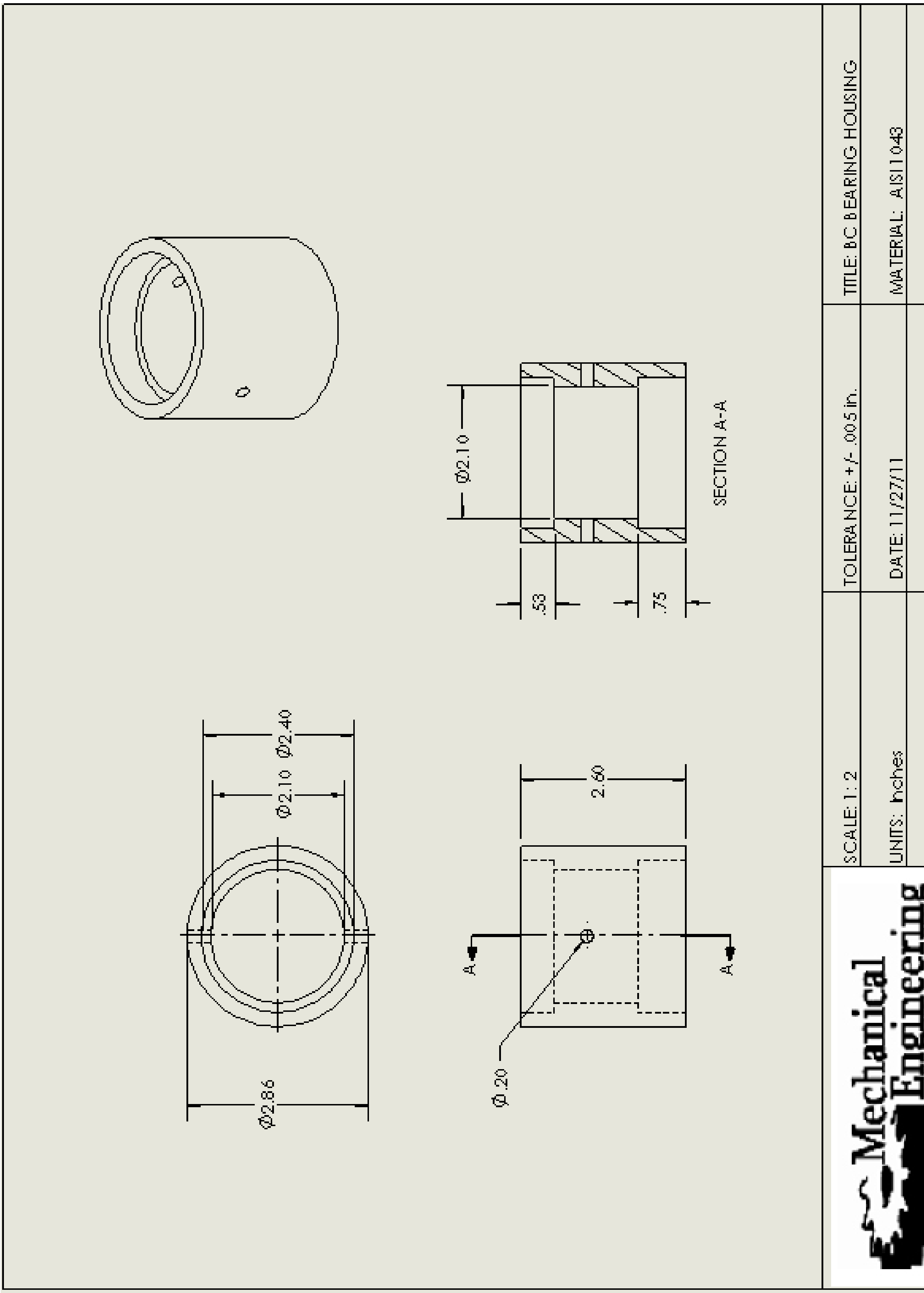


Figure B.4 Original bearing shaft housing for the COR hedger.

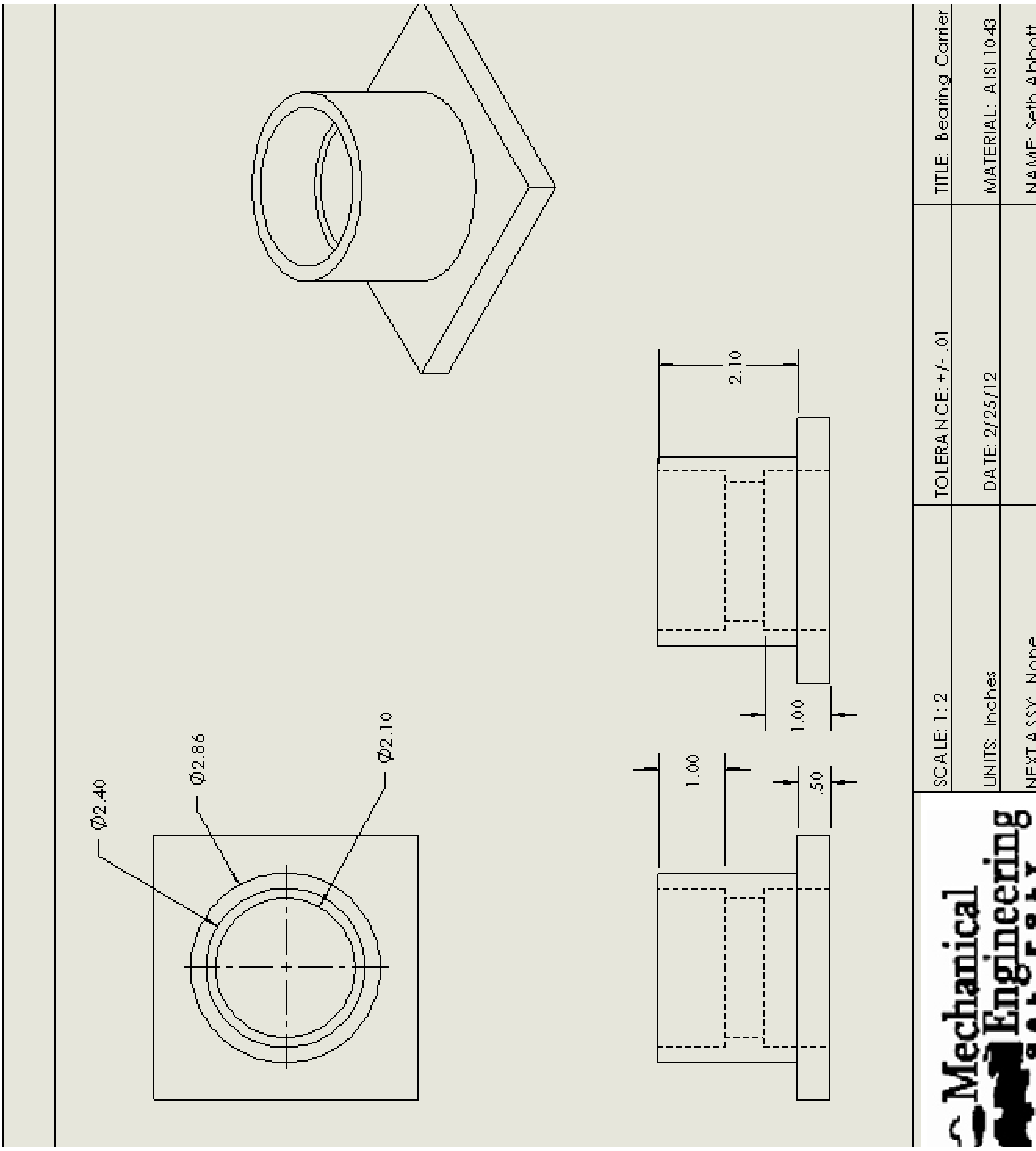


Figure B.5 New bearing shaft housing for the redesigned bearing carrier.

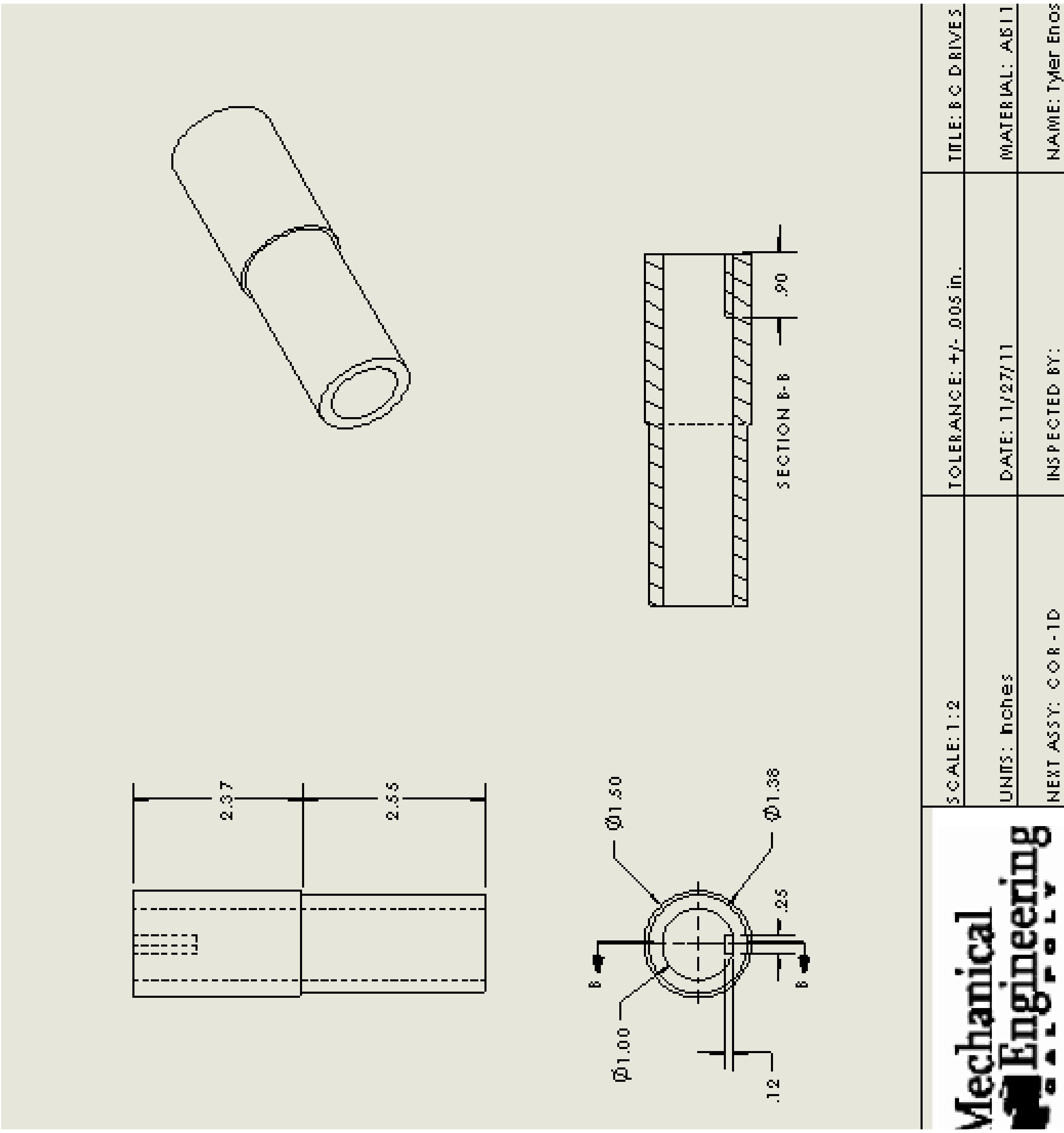


Figure B.6 Drive shaft with key for turning blade shaft for the redesigned bearing carrier.

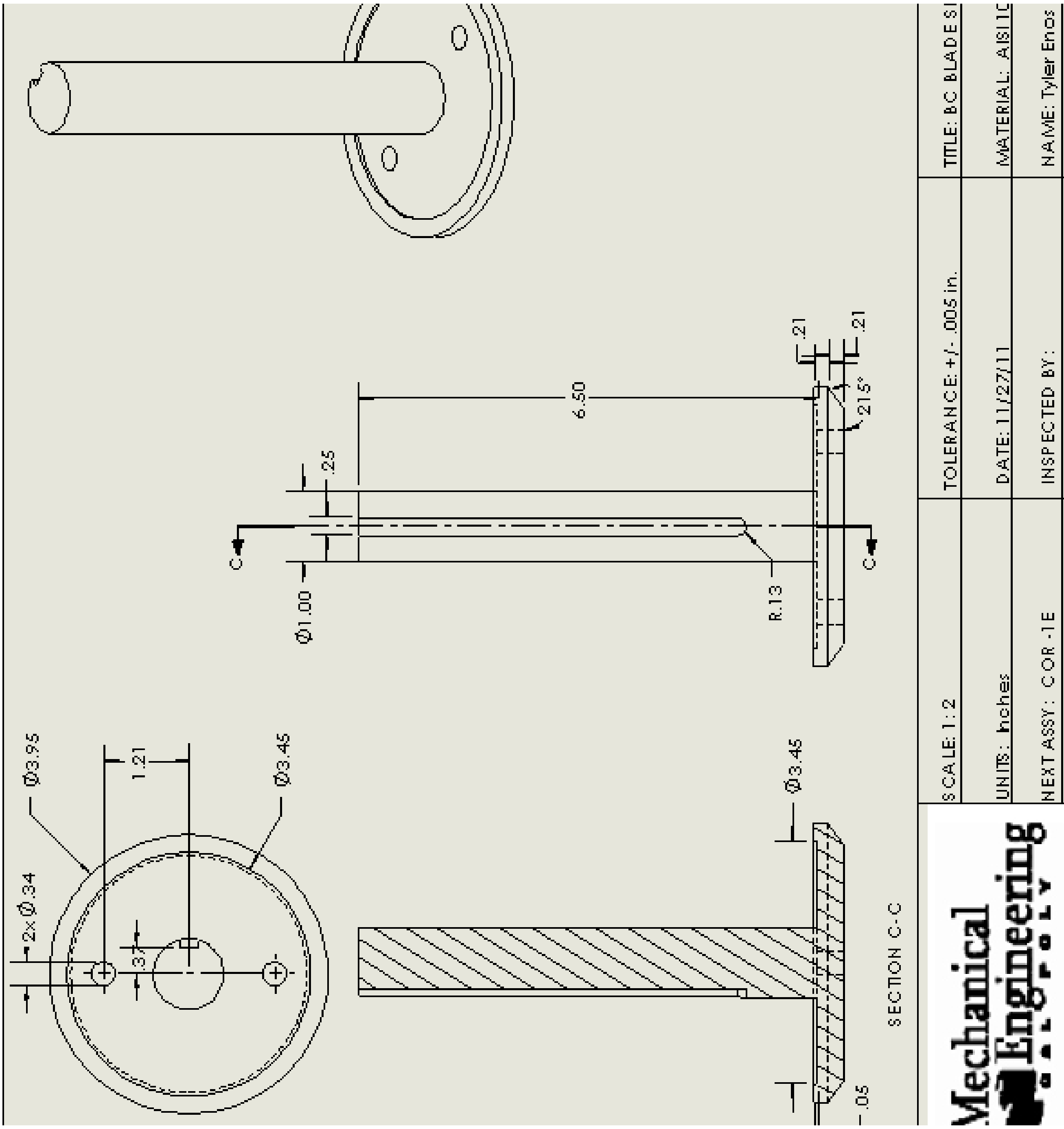


Figure B.7 Old blade shaft for the original bearing carrier.

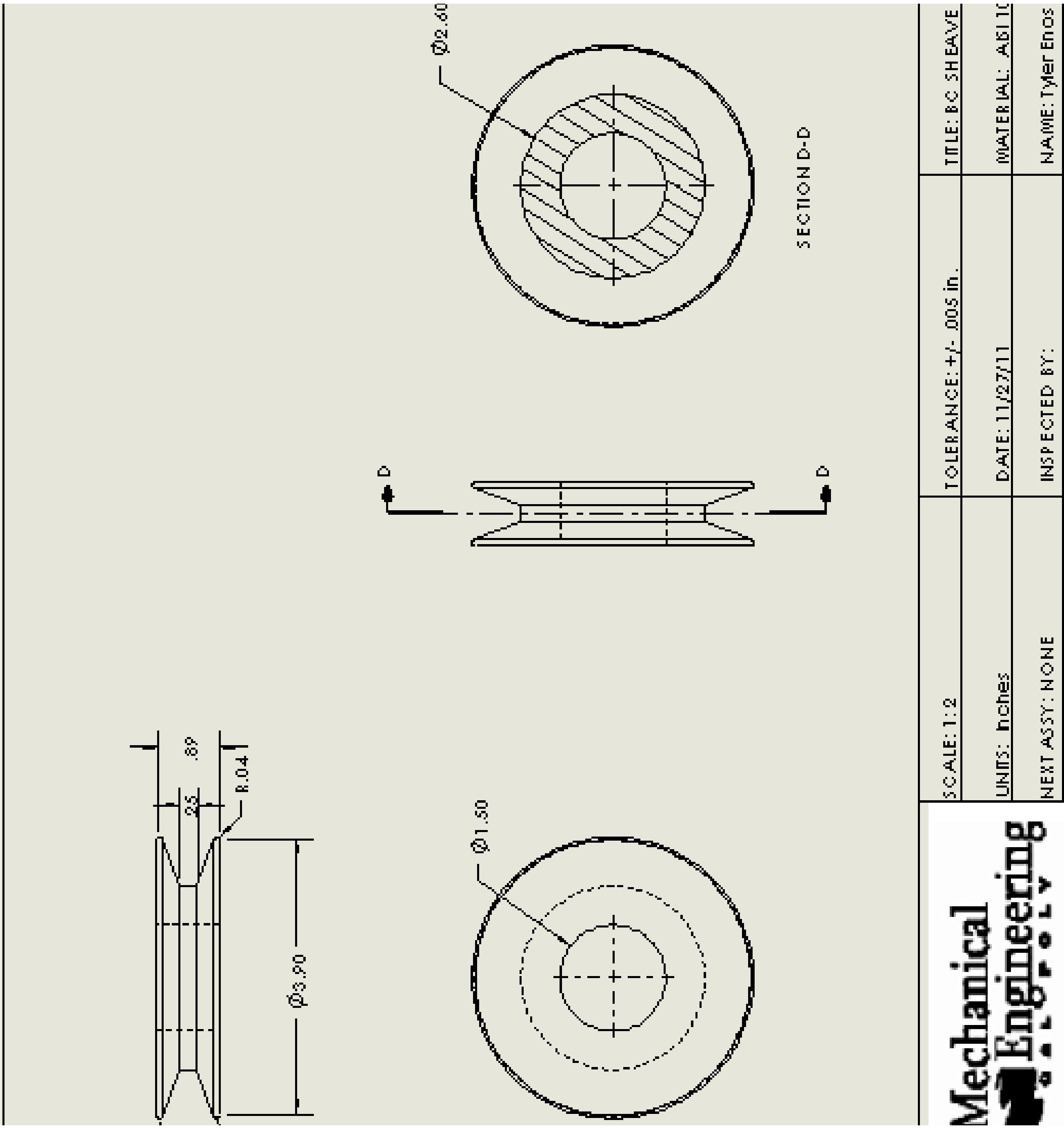


Figure B.8 Sheave which attaches to the drive shaft using set screws on the redesigned bearing carrier.

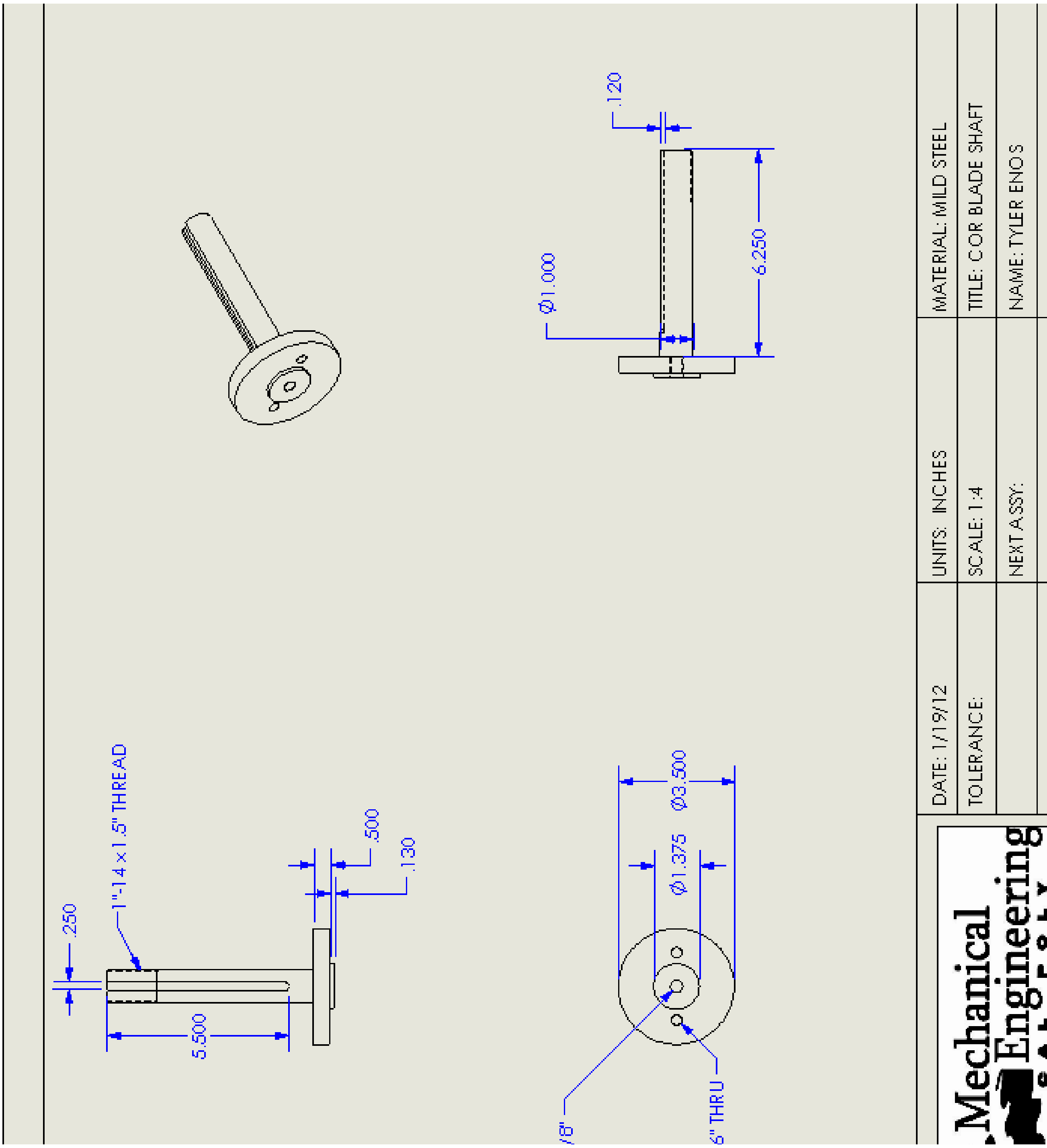


Figure B.9 New blade shaft part drawing.

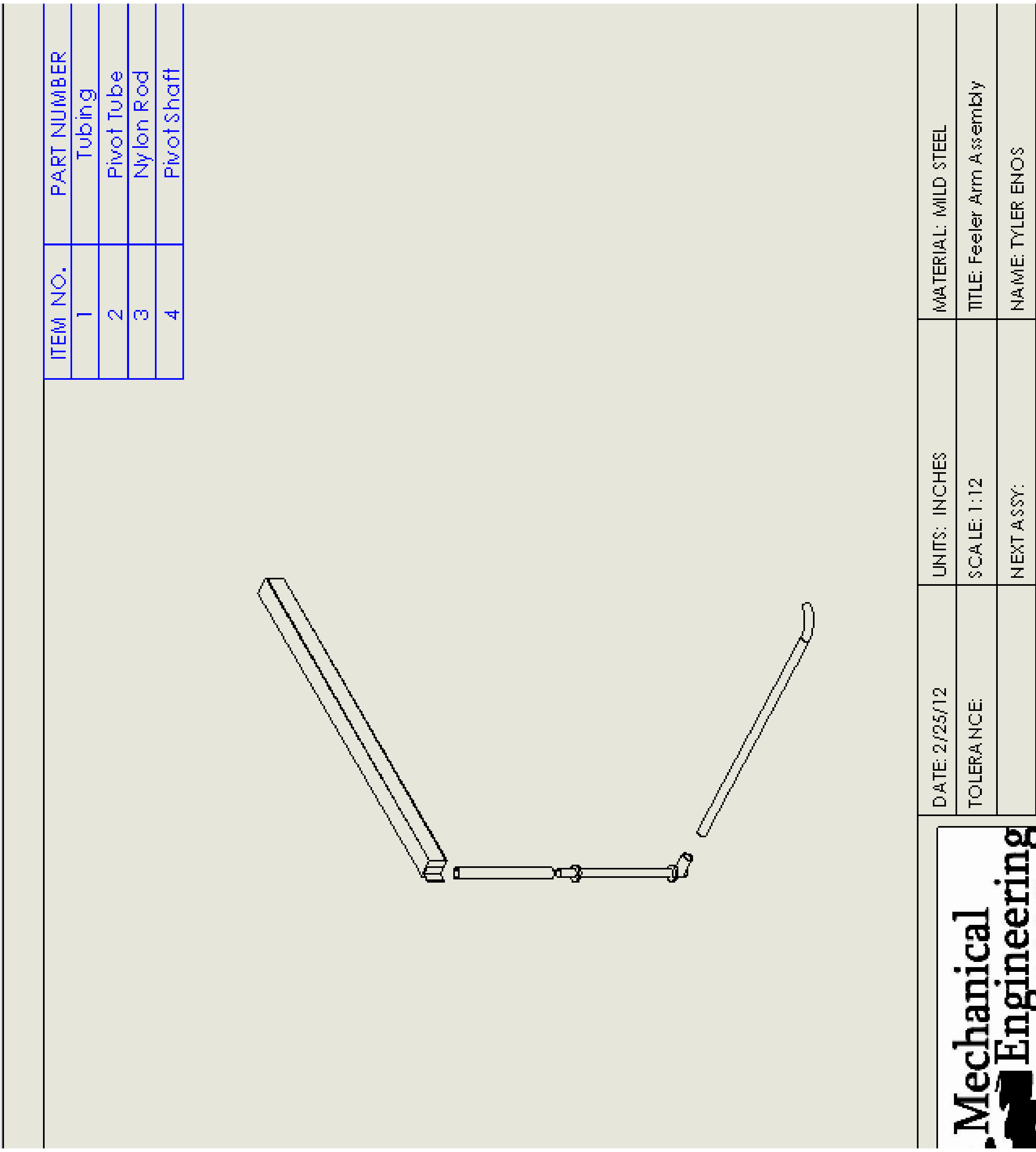


Figure B.10 Feeler arm assembly drawing

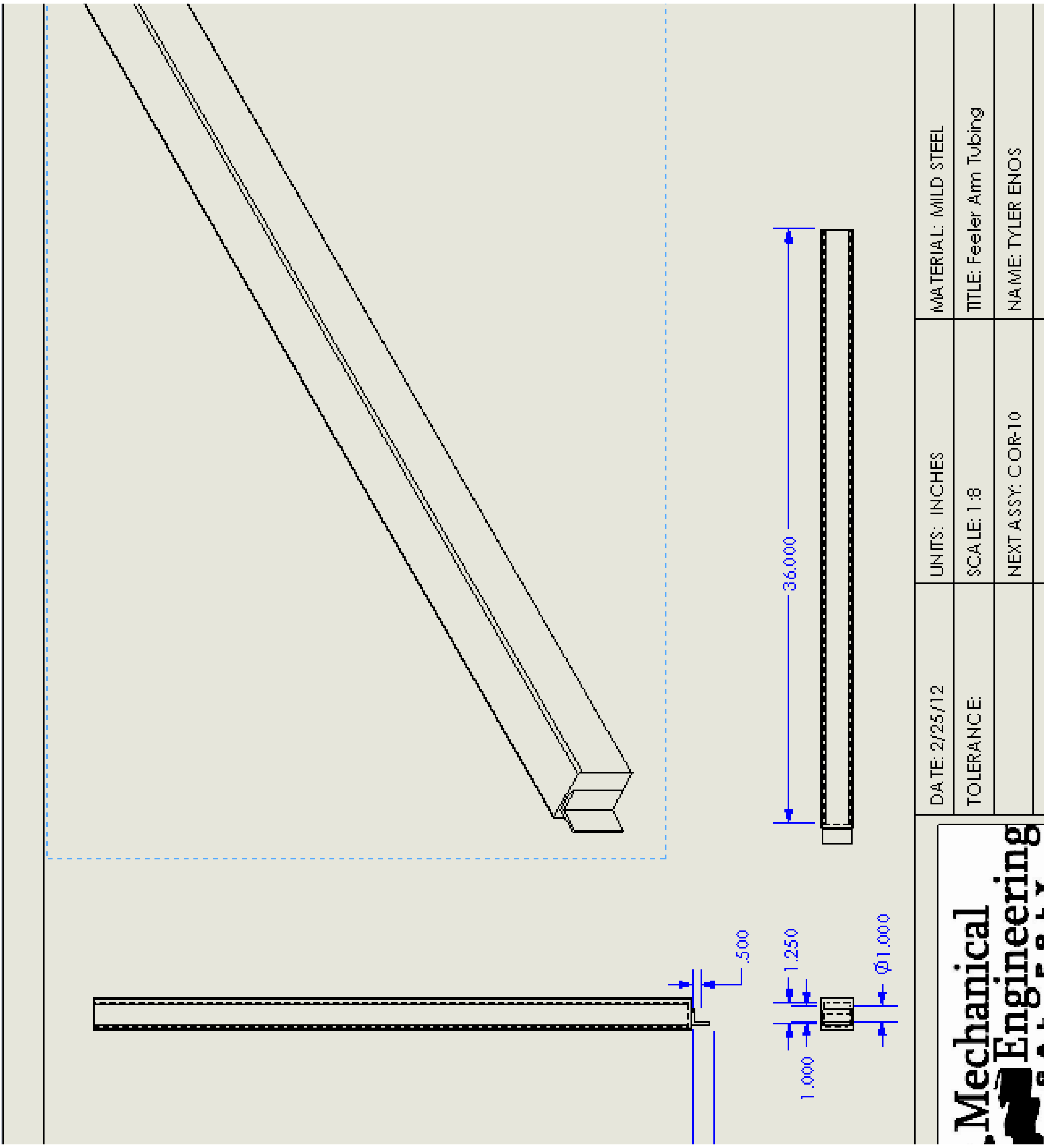


Figure B.11 Feeler arm tubing drawing

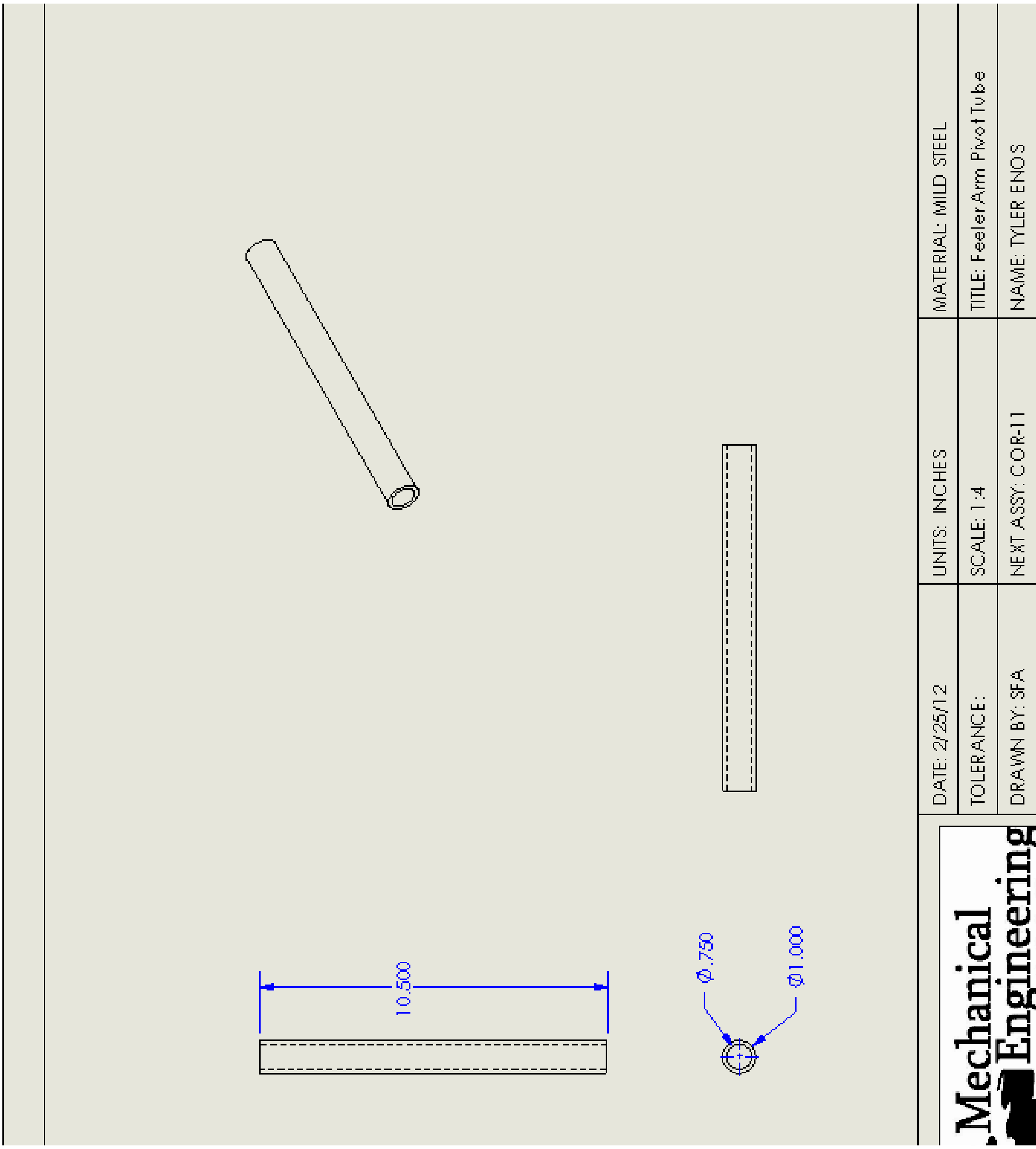


Figure B.12 Feeler Arm Pivot Tube drawing

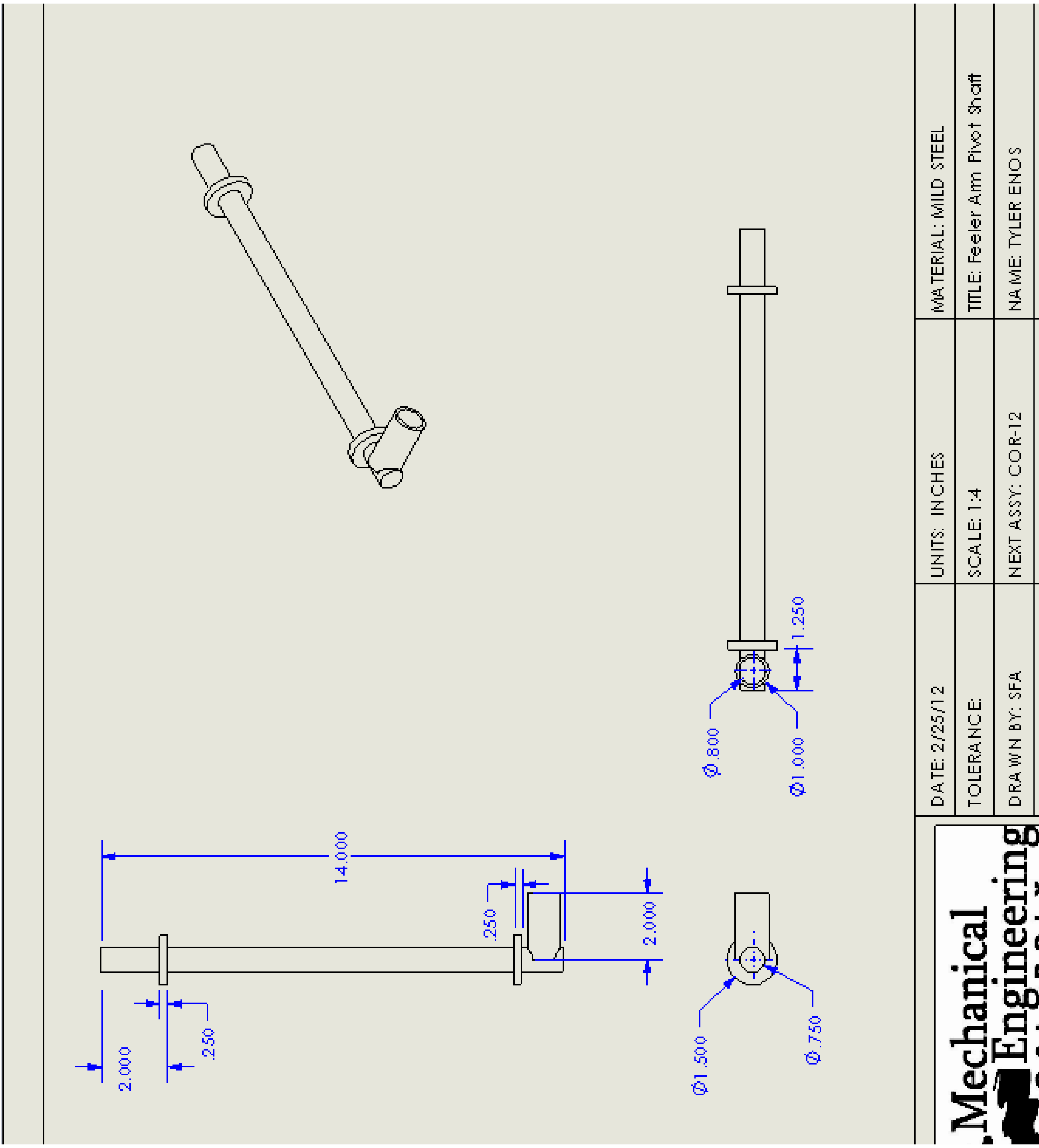


Figure B.13 Feeler Arm Pivot Shaft drawing

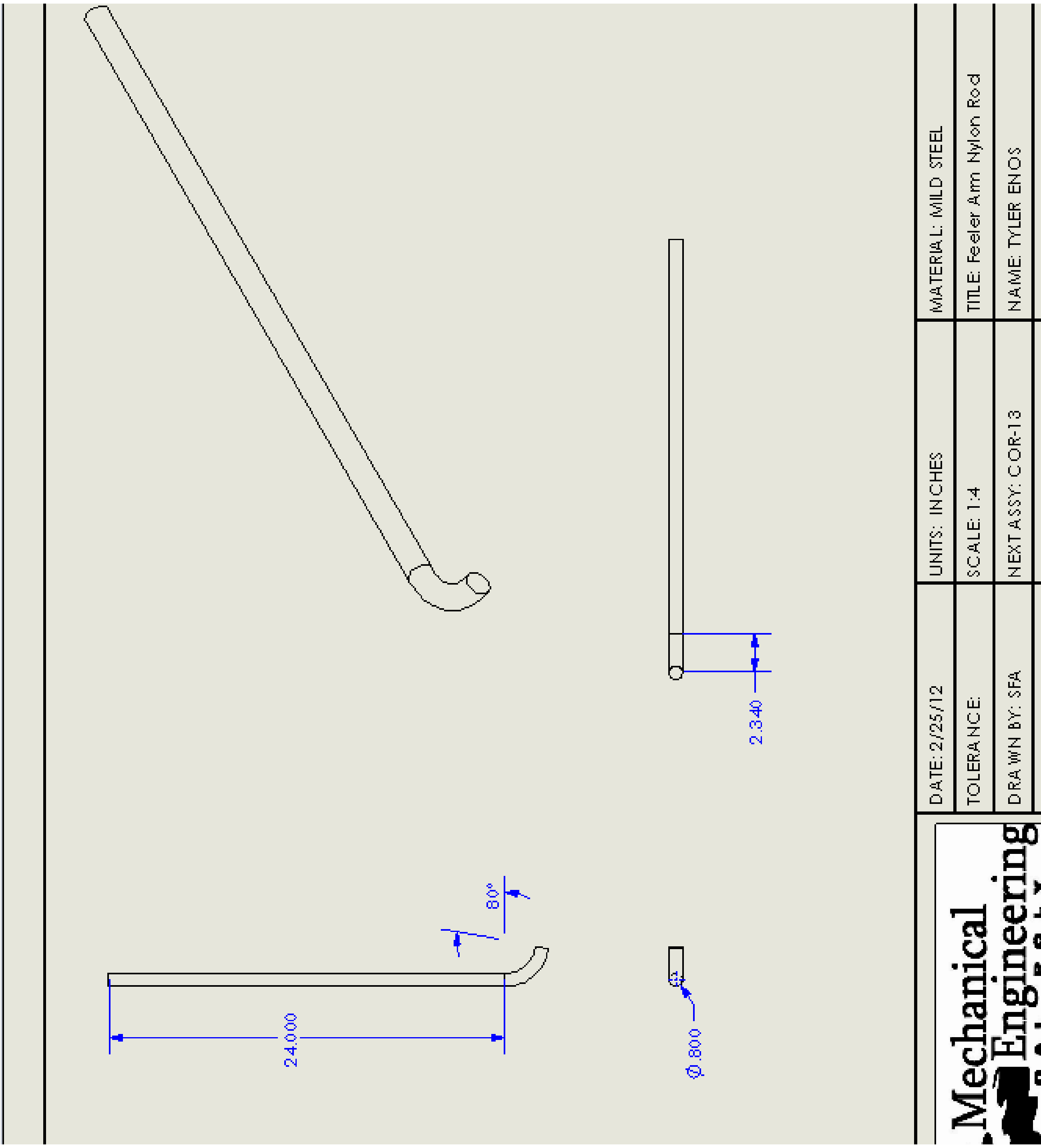


Figure B.14 Feeler Arm Nylon “bow” rod drawing

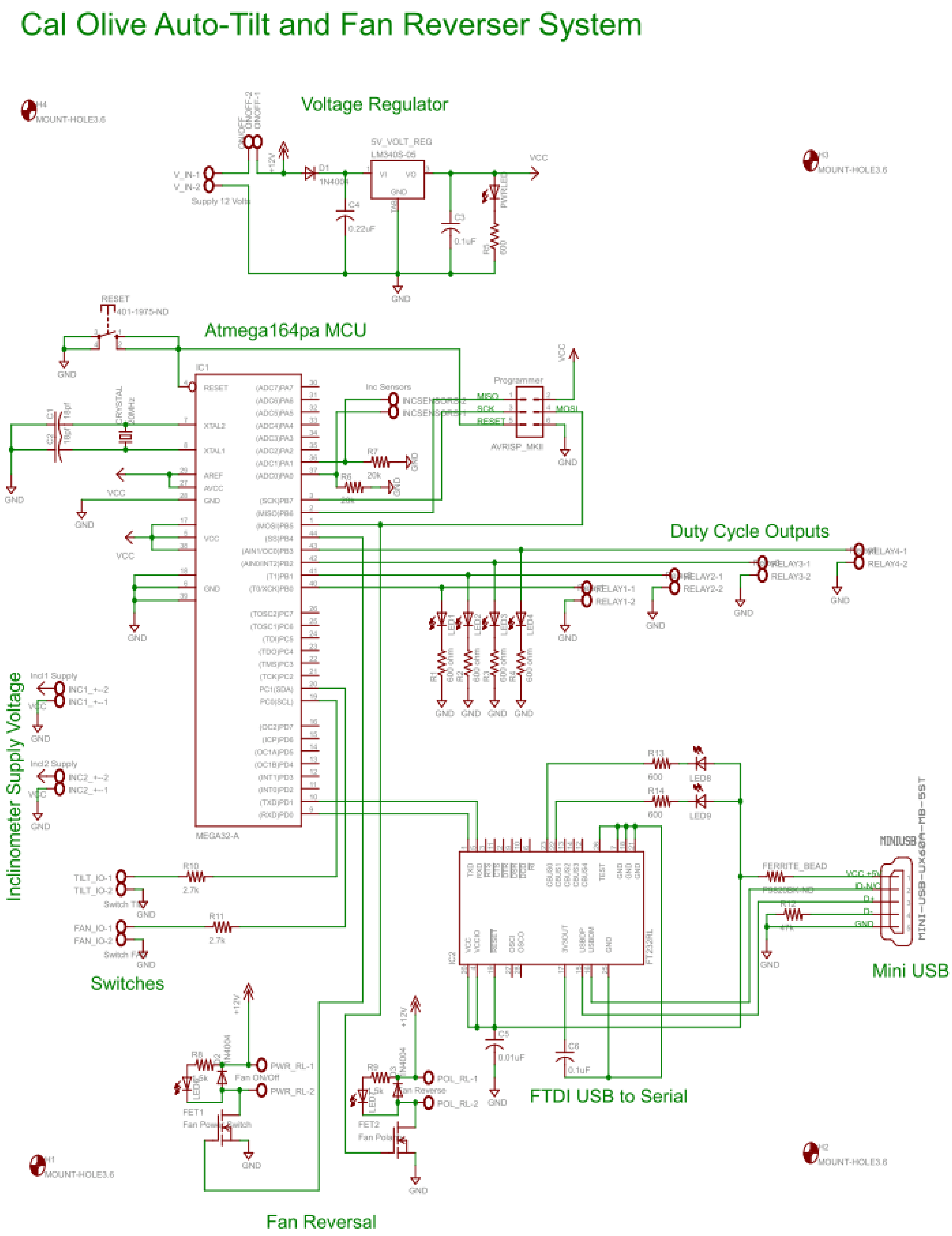


Figure B.15 Controller board schematic.

Appendix C:
Vendor Information List

Table C.1

Vendor	Part Supplied	Part Number	Quantity	Price	Contact Info
Central Coast Bearing	Oil Seals (large dia.)	550154	12	$11.60/ea.	(805) 546-9082
	Oil Seals (small dia.)	15093 (SKF)	12		
	Tapered Roller Bearings	LM78349A (Timken)	24	$25.52	
NAPA auto parts	Electrical wire & misc.	n/a	1	$322.29	(805) 543-7287
DigiKey	Inclinometers	SCA121T-D05 (mfgr.)	2	$160/ea.	digikey.com
DigiKey	Solid State Relays	CC1127-ND (digikey)	4	$28.12/ea.	digikey.com
DigiKey	Double Pole Relays	PB349-ND (digikey)	2	$13.82/ea.	digikey.com
DigiKey	Single Pole Relays	Z2868-ND (digikey)	2	$5.49/ea.	digikey.com
	Heat Exchanger	MF-60-1-4A	1	$997.00	

Table C.2

Item	Value	Description	Digi-Key P/N	Qty	Price ($)
Circuit Board	-	-	-	-	-
MicroController	164pa	IC MCU AVR 16K FLASH 44TQFP	ATMEGA164PA-AN-ND	1	5.28
UART-FT232RL	-	IC USB FS SERIAL UART 28-SSOP	768-1007-1-ND	1	4.5
Crystal	20Mhz	CRYSTAL 20.0 MHZ 20 PF FUND	CTX1106-ND	1	0.41
Voltage Regulator	5V	IC REGULATOR POSITIVE 5V TO-263	LM340S-5.0-ND	1	1.66
Screw Header	-	TERM BLOCK 5.08 2POS VERT	WM4393-ND	14	0.9
Mini USB	-	CONN RECEPT MINI-USB TYPE A SMT	ED90342CT-ND	1	1.76
Prog Header	3x2	CONN HEADER 6POS UNSHD VERT T/H	609-3710-ND	1	0.72
Reset Switch	-	SWITCH PUSH SPST-NO 0.1A 32V	401-1975-ND	1	1.03
Diode	-	DIODE RECTIFIER 1A 400V DO-41	641-1311-1-ND	4	0.25
Mosfet	N-Chan	MOSFET N-CH 60V 500MA TO-92	BS170_D27ZCT-ND	2	0.4
Ferrite Bead	-	BEAD CORE SINGLE 3.5X5MM AXIAL	P9820BK-ND	1	0.14
Ceramic Capacitor	18pF	CAP CER 18PF 100V 5% RADIAL	490-3632-ND	2	0.4
Ceramic Capacitor	0.01µF	CAP CER 10000PF 50V RADIAL	490-5396-ND	1	0.22
Ceramic Capacitor	0.1µF	CAP CER 0.1UF 50V 10% RADIAL	490-5369-ND	1	0.19
Ceramic Capacitor	0.22µF	CAP CER 0.22UF 50V RADIAL	490-3862-ND	1	0.28
Resistor	620	RES 620 OHM 1/4W 5% CARBON FILM	620QBK-ND	8	0.068
Resistor	1.5k	RES 1.5K OHM 1/4W 5% CF MINI	S1.5KQCT-ND	2	0.08
Resistor	2.7k	RES 2.7K OHM 1/4W 5% CF MINI	S2.7KQCT-ND	2	0.08
Resistor	20k	RES 20K OHM 1/4W 5% CF MINI	S20KQCT-ND	2	0.08

Resistor	47k	RES 47K OHM 1/4W 5% CARBON FILM	CF14JT47K0CT-ND	2	0.08
LED	Red	LED SS 3MM 625NM RED DIFF	754-1219-ND	4	0.14
LED	Green	LED SS 3MM 568NM GREEN DIFF	754-1210-ND	4	0.14
LED	Yellow	LED SS 3MM 588NM YLW DIFF	754-1212-ND	4	0.15
Switch	SPST	SW TOGGLE SPST BAT THR UL/CSA	M2011SS1W01/UC-ND	3	3.45
Auto-Leveling	-	-	-	-	-
SS Relay	5 Amp	RELAY SSR 5A BIPOL DC INPUT	CC1127-ND	4	28.12
High Vol Diode	-	DIODE STD REC 100V 12A DO-4	12F10-ND	6	4.82
Fan Reversal	-	-	-	-	-
Relay	DPDT	RELAY GEN PURPOSE DPDT 30A 12V	PB349-ND	2	13.82
Relay	SPDT	RELAY AUTOMOTIVE SPDT 35A 12V	Z2868-ND	2	5.49
Row Alignment	-	-	-	-	-
Switch	SPSDT	SWITCH SPDT 5A HINGED ROLLER TAB	SW872-ND	2	2.63

Table C.3

Item	Datasheet
MicroController	http://www.atmel.com/Images/8152s.pdf
UART-FT232RL	http://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_FT232R.pdf
Crystal	http://www.ctscorp.com/components/Datasheets/008-0309-0.pdf
Voltage Regulator	http://www.ti.com/lit/ds/symlink/lm340-n.pdf
Screw Header	http://www.molex.com/elqNow/elqRedir.htm?ref=http://www.molex.com/pdm_docs/sd/398800302_sd.pdf
Mini USB	http://www.mill-max.com/images/products/pdf/metric/121M.pdf
Prog Header	http://portal.fciconnect.com/res/en/pdffiles/doc_search/20021111.pdf
Reset Switch	http://www.ck-components.com/index.php?module=media&action=Display&cmpref=13327&lang=en&width=&height=&format=&alt=
Diode	http://61.219.227.171/cms/UserFiles/QW-BG013%201N4001%20Thru454875.%201N4007%20REV.A.pdf
Mosfet	http://www.fairchildsemi.com/ds/BS/BS170.pdf
Ferrite Bead	http://industrial.panasonic.com/www-data/pdf/AEH0000/AEH0000CE7.pdf
Ceramic Capacitor	http://www.murata-northamerica.com/murata/murata.nsf/promo_rde_handout.pdf
Ceramic Capacitor	http://www.murata-northamerica.com/murata/murata.nsf/promo_rde_handout.pdf
Ceramic Capacitor	http://www.murata-northamerica.com/murata/murata.nsf/promo_rde_handout.pdf
Ceramic Capacitor	http://www.murata-northamerica.com/murata/murata.nsf/promo_rde_handout.pdf
Resistor	http://www.yageo.com/documents/recent/Leaded-R_CFR_2011.pdf
Resistor	http://www.seielect.com/catalog/SEI-CF_CFM.pdf
Resistor	http://www.seielect.com/catalog/SEI-CF_CFM.pdf
Resistor	http://www.seielect.com/catalog/SEI-CF_CFM.pdf
Resistor	http://www.seielect.com/catalog/SEI-CF_CFM.pdf
LED	http://www.us.kingbright.com/images/catalog/SPEC/WP132XYD.pdf
LED	http://www.us.kingbright.com/images/catalog/SPEC/WP132XYD.pdf
LED	http://www.us.kingbright.com/images/catalog/SPEC/WP132XYD.pdf
Switch	http://www.nkkswitches.com/pdf/MtogglesBushing.pdf
Auto-Leveling	

SS Relay	http://www.crydom.com/en/Products/Catalog/d_c60.pdf
High Vol Diode	http://www.vishay.com/doc?93487
Fan Reversal	
Relay	http://documents.tycoelectronics.com/commerce/DocumentDelivery/DDEController?Action=showdoc&DocId=Data+Sheet%7F1308242_T92%7F0910%7Fpdf%7FEnglish%7FENG_DS_1308242_T92_0910.pdf
Relay	http://components.omron.com/components/web/pdflib.nsf/0/39018354E59A56C985257201007DD68C/$file/G8JN_0607.pdf
Row Alignment	
Switch	http://components.omron.com/components/web/pdflib.nsf/0/80FC48E7A8A557A885257201007DD493/$file/SS_1110.pdf

Table C.4

Precision Machine Co. Order Form			
Item	**Description**	**Qty**	**Price (single unit)**
Bearing Carrier Housing	Turn down bearing shoulder 1.25" from top edge	12	$24
New blade shafts	Build shafts with keyway, threads, and bottom flange	12	$63
1" ID spacers	spacer 1" long	12	$10
1.5" OD Spacers	Spacer 1.5"long	12	$10
Metal Order			
2.5" x .25" square tubing	8 ft. long	1	$40
2.5" x .25" square tubing	6 ft. long	1	$30
1.5" x .12" Pipe	3 ft. long	1	$10
2' x 3' - sheet metal	16 gauge	1	$20
2' x 3' - expanded metal	.5" diamond, flat	1	$20
Miscellaneous			
extra Labor and Bonus	Bonus for completing emergency work on time	NA	$300
			Total
			$1,700

Appendix D:
Data Sheets

SKF *	**Product Datasheet**

Stock Number	**15093**
Description	**LDS & SMALL BORE SEAL**
Lip Code	**Nitrile (Lip Code: R)**
Type/Style	**CRWA1** 

	Inches
Shaft	**1.5**
Bore	**2.441**
OD	**2.445**
Width	**0.313**
Weight	**0.053**

UPC	**00085311015226**
Speedi-Sleeve	**99149**
Bore-Tite on O.D.	**Y**

Product Images: Note: photos are representative of construction.

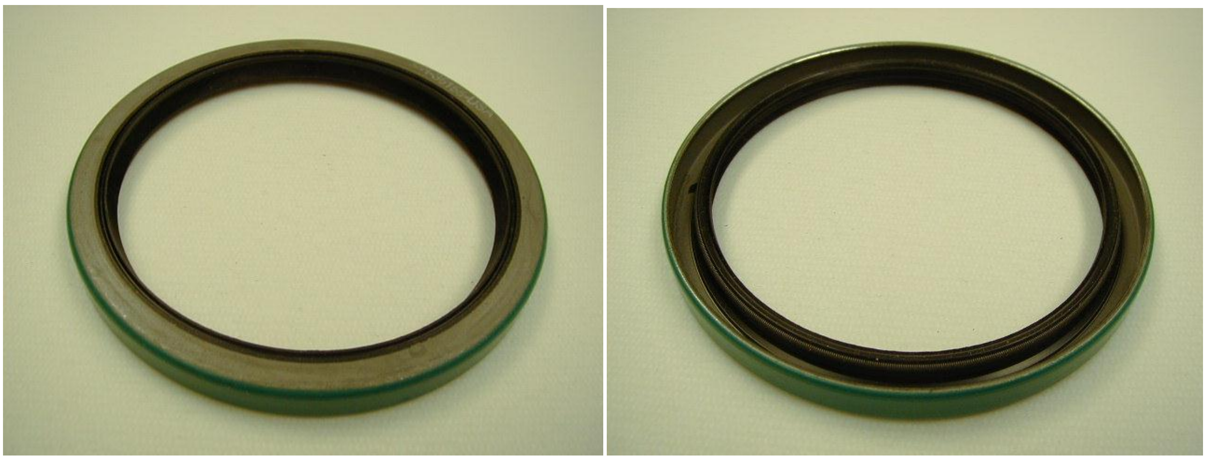


Figure D.1 Product Datasheet for small diameter bearing housing seal.

SKF*

Product Datasheet

Stock Number	**550154**
Description	**LDS & SMALL BORE SEAL**
Lip Code	**Nitrile (Lip Code: R)**
Type/Style	**CRWA1** 

	Inches
Shaft	**1.75**
Bore	**2.441**
OD	**2.445**
Width	**0.313**
Weight	**0.055**

UPC	**00085311048637**
Speedi-Sleeve	**99174**
WastWatcher	**17315**
Bore-Tite on O.D.	**Y**

Product Images: Note: photos are representative of construction.

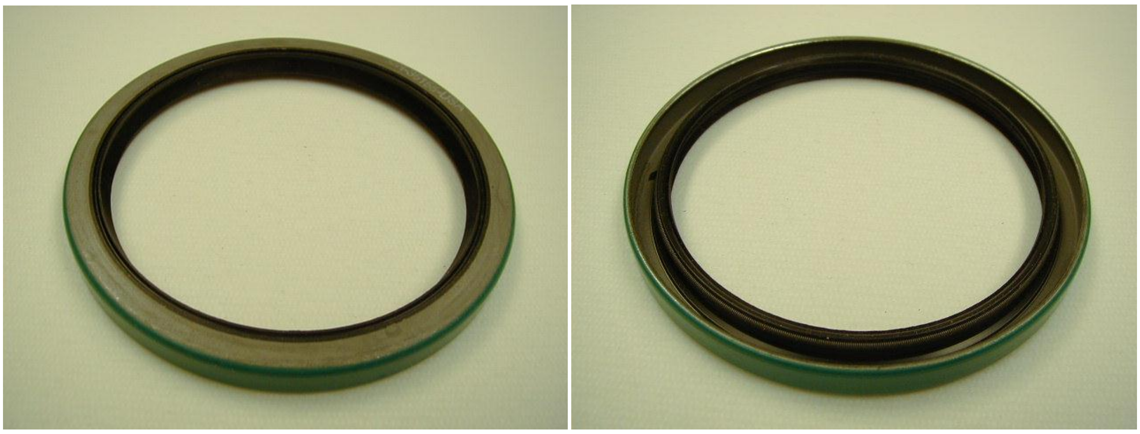


Figure D.2 Product Datasheet for large diameter bearing housing seal.

FLUID COOLING | Mobile MF Series

AIR COOLED MF

Features

- Same as M Series with DC Fan or Hydraulic Motor
- 3/8" Tube Size
- Aluminum Fins
- Low AMP Draw 12 or 24 Volt DC Motor
- Heavy Duty Construction
- Optional Serviceable Relief Bypass Valve
- Optional Fan Control Switch
- Long Life Hydraulic Motors
- Heat Removal TO 50,000 BTU/Hr.
- Oil Flows to 150 GPM
- Mounting Brackets Included
- SAE, NPT or 37° Flare Oil Connections
- Rugged Steel Manifolds

Ratings

Operating Pressure 300 psi

Operating Temperature 350° F

Materials

Tubes Copper

Fins Aluminum

Turbulators Steel

Manifolds Steel

Fan Assembly High Impact Plastic

Motor Displacement .22in³/Rev. (Hydraulic)

Maximum Pressure 2000 PSI (Hydraulic)

Allowable Backpressure 1000 PSI (Hydraulic)

Relief Bypass Valve Option

MODEL	DESCRIPTION
MFR-15	3/4", external, all steel valve. Available in either 30 PSI or 60 PSI settings. May be removed for servicing.
MFR-30 MFR-60	1-1/2", external, all steel valve. Available in either 30 PSI or 60 PSI settings. May be removed for servicing.

Number of Fans	DC current required		Hydraulic Motor Data		
	12 Volt	24 Volt	Oil Flow Required (GPM)	Minimum Operating Pressure (PSI)	Maximum Fan Speed (RPM)
1	12.5 amps	6.3 amps	2.1	300	2200
2	25 amps	12.6 amps	4.2	300	2200

How to Order

[ ] - [ ][ ] - [ ] - [ ] - [ ]

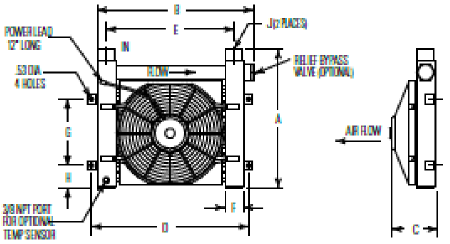
- **Model Series**: MF; MFR - Relief Bypass Included
- **Model Size Selected**
- **Connection Type***: 1 - NPT; 2 - SAE; 3 - BSPP; 7 - 37° Male Flare
- **Motor Specification**: NM - No Motor; 4A - 12 Volt DC; 4B - 24 Volt DC; 9 - Hydraulic Motor
- **Relief Bypass**: Blank - No Bypass; 30 - 30 psi; 60 - 60 psi — ADD FOR MFR MODELS ONLY

*Other connection types available. Please consult factory for assistance.

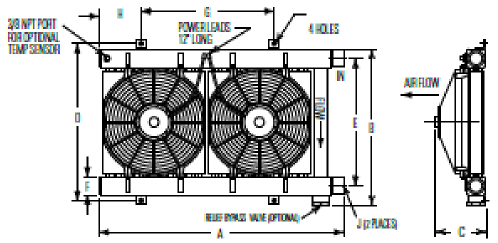
TTPSales@thermasys.com 262.554.8330 www.thermaltransfer.com

Dimensions - 12 & 24 Volt DC Motors

Models MF-15 and MF-30



Model MF-60



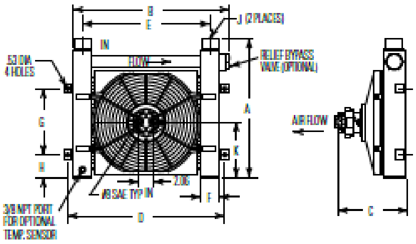
Units shown with optional bypass valve

MODEL	A MF	A MFR	B MF	B MFR	C	D	E	F	G	H	J NPT	J SAE	SHIPPING WEIGHT
MF-15	13.88	15.88	15.75	17.41	4.99	17.25	14.25	1.50 SQ	9.00	1.88	1.00	#16	27
MF-30	16.58	18.83	19.75	21.12	6.10	21.25	17.25	2.50 SQ		3.06	1.50	#24	41
MF-60	30.83	33.08							18.00	5.68			78

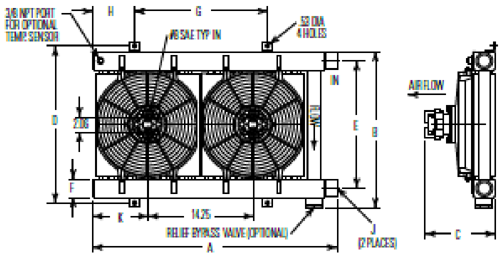
*Note: All dimensions are in inches. We reserve the right to make reasonable design changes without notice. *Inlet and outlet oil connections can be reversed when the bypass valve is not used.*

Dimensions - Hydraulic Motors

Models MF-15 and MF-30



Model MF-60

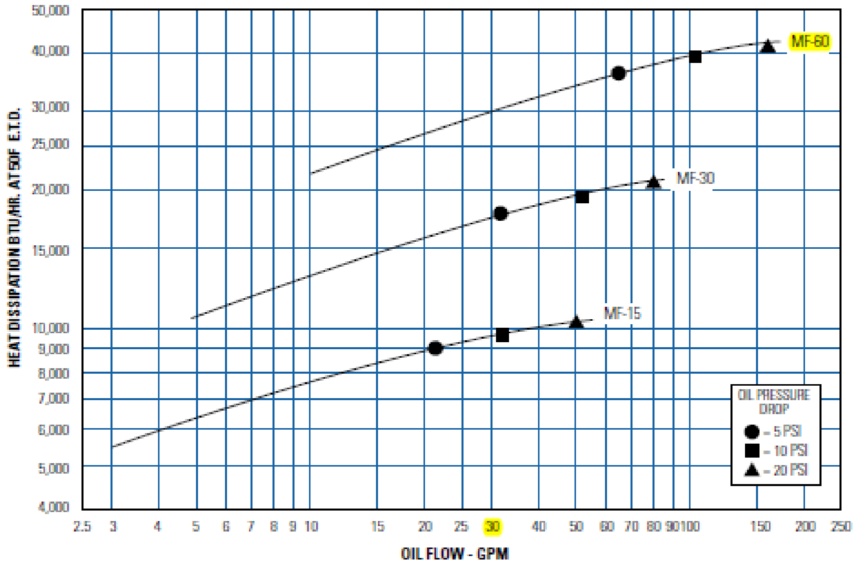


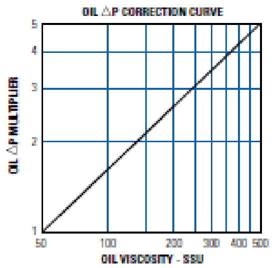
Units shown with optional bypass valve

MODEL	A MF	A MFR	B MF	B MFR	C	D	E	F	G	H	J NPT	J SAE	SHIPPING WEIGHT
MF-15	13.88	15.88	15.75	17.41	7.87	17.25	14.25	1.50 SQ	9.00	1.88	1.00	#16	27
MF-30	16.58	18.83	19.75	21.12	8.96	21.25	17.25	2.50 SQ		3.06	1.50	#24	41
MF-60	30.83	33.08							18.00	5.68			78

*Note: All dimensions are in inches. We reserve the right to make reasonable design changes without notice. *Inlet and outlet oil connections can be reversed when the bypass valve is not used.*

Performance Curves





Selection Procedure

Performance Curves are based on 50 SSU oil entering the cooler 50°F higher than the ambient air temperature used for cooling. This is referred to as a 50°F E.T.D.

Step 1 **Determine the Heat Load.** Heat load may be expressed as either horsepower or BTU/Hr. To convert horsepower to BTU/Hr.:
BTU/HR = Horsepower x 2545

Step 2 **Determine Entering Temperature Difference.** The entering oil temperature is generally the maximum desired oil temperature.
Entering oil temperature – Ambient air temperature = E.T.D.

Step 3 **Determine the Corrected Heat Dissipation to use the curves.**

Corrected Heat Dissipation = BTU/HR heat load x $\frac{50°F \times Cv}{E.T.D.}$

Step 4 **Enter curves** at oil flow through cooler and curve heat dissipation. Any curve above the intersecting point will work.

Step 5 **Determine Oil Pressure Drop from Curves:**
● = 5 PSI; ■ = 10 PSI; ▲ = 20 PSI. Multiply pressure drop from curve by correction factor found in oil △ P correction curve.

Oil Temperature

Typical operating temperature ranges are:

Hydraulic Motor Oil	120°F - 180°F
Hydrostatic Drive Oil	160°F - 180°F
Engine Lube Oil	180°F - 200°F
Automatic Transmission Fluid	200°F - 300°F

C_V Viscosity Correction

	OIL				
Average Oil Temp °F	SAE 5 110 SSU at 100°F 40 SSU at 210°F	SAE 10 150 SSU at 100°F 43 SSU at 210°F	SAE 20 275 SSU at 100°F 50 SSU at 210°F	SAE 30 500 SSU at 100°F 65 SSU at 210°F	SAE 40 750 SSU at 100°F 75 SSU at 210°F
100	1.14	1.22	1.35	1.58	1.77
150	1.01	1.05	1.11	1.21	1.31
200	.99	1.00	1.01	1.08	1.10
250	.95	.98	.99	1.00	1.00

Figure D.3 Heat Exchanger Specification Sheet

Data Sheet

SCA121T DUAL AXIS INCLINOMETER MODULES

The SCA121T Series contain 3D-MEMS-based dual axis inclinometer modules that provide instrumentation grade performance for leveling applications in harsh environment. The measuring axes of the sensing elements are parallel to the mounting plane and orthogonal to each other. Low temperature dependency, high resolution and low noise, together a with robust sensing element design, make the SCA121T the ideal choice for leveling instruments. The VTI inclinometers are insensitive to vibration, due to their over damped sensing elements, and can withstand mechanical shocks of up to 20000 g.

Features

- Dual axis inclination measurement (X and Y)
- Measuring ranges ±30° and ± 90°
- 0.0035° resolution (10 Hz BW, analog output)
- Sensing element controlled over damped frequency response (-3dB 18Hz)
- Robust design, high shock durability (20000g)
- High stability over temperature and time
- Single +5 V supply and unregulated 7…35V supply
- RoHS compliant

Applications

- Platform leveling and stabilization
- 360° vertical orientation measurement
- Leveling instruments
- Cabin leveling
- Solar panel control systems

1 Electrical Specifications

The SCA121T product family comprises three versions, the SCA121T-D03, the SCA121T-D05 and the SCA121T-D07 that differs in measurement range and supply voltage. The product version specific performance specifications are listed in the table SCA121T performance characteristics below.

1.1 Absolute Maximum Ratings

Supply voltage SCA121T-D05(V_{DD})	Regulated -0.3 V to +5.5V
Supply voltage SCA121T-D03 and D07	Unregulated -0.3 V to +35V
Voltage at input / output pins	-0.3V to 5.3
Storage temperature	-55°C to +85°C
Operating temperature	-40°C to +85°C
Mechanical shock	Drop from 1 meter onto a concrete surface (20000g). Powered or non-powered

1.2 Performance Characteristics

Parameter	Condition	SCA121T-D03	SCA121T -D05	SCA121T -D07	Units
Measuring range	Nominal	±90	±90	±30	°
		±1	±1	±0.5	g
Supply Voltage		7…35	5±0.25	7…35	V
Offset (Output at 0g)		2.5	Vdd/2	2.5	V
Offset calibration error	Max deviation	±1.5	±1.5	±1.5	°
Sensitivity		2	2	4	V/g
	between 0…1° [1]	35	35	70	mV/°
Sensitivity calibration error		±1.5	±1.5	±1.5	%
Offset temperature dependency	-25…85°C	±1	±1	±1	°
	0…70°C	±0.5	±0.5	±0.5	°
Sensitivity temperature dependency	-25...85°C	-1.5...+0.5	-1.5...+0.5	-1.5...+0.5	%
	0…70°C	-0.8...+0.3	-0.8...+0.3	-0.8...+0.3	%
Typical non-linearity	Measuring range			±0.57	°
Frequency response	–3dB LP [2]	8-28	8-28	8-28	Hz
Ratiometric error	Vdd = 4.75...5.25V		±2		%
Cross-axis sensitivity	Max.	4	4	4	%

Note 1. The angle output has SIN curve relationship to voltage output.

Note 2. The frequency response is determined by the sensing element's internal gas damping.

1.3 Electrical Characteristics

Parameter	Condition	Min.	Typ	Max.	Units
Current consumption	No load		5	8	mA
Operating temperature		-40		+85	°C
Analog resistive output load	Vout to Vdd or GND	10			kOhm
Analog capacitive output load	Vout to Vdd or GND			20	nF
Start-up delay	Reset and parity check			10	ms

1.4 Electrical Connection

Wire Color	Name	Function
Blue	GND	Ground
Red	Vdd	Power supply
Yellow	Out X	X-axis output
Green	Out Y	Y-axis output
White	NC	Not Connected

2 Functional Description

2.1 Measuring Directions

Figure 1. The measuring directions of the SCA121T

2.2 Voltage to Angle Conversion

Analog output can be transferred to angle using the following equation for conversion:

$$\alpha = \arcsin\left(\frac{V_{out} - Offset}{Sensitivity}\right)$$

Where: Offset = output of the device at 0° inclination position, Sensitivity is the sensitivity of the device and V_{Dout} is the output of the SCA121T. The nominal offset is 2.5 V and the sensitivity is 4 V/g for the SCA121T-D07 and 2 V/g for the SCA121T-D03 and SCA121T-D05.

Angles close to 0° inclination can be estimated quite accurately with straight line conversion but for the best possible accuracy, arcsine conversion is recommended to be used. The following table shows the angle measurement error if straight line conversion is used.

Straight line conversion equation:

$$\alpha = \frac{V_{out} - Offset}{Sensitivity}$$

Where: Sensitivity = 70mV/° with SCA121T-D07 or Sensitivity= 35mV/° with SCA121T-D03 and SCA121T-D05

Tilt angle [°]	Straight line conversion error [°]
0	0
1	0.0027
2	0.0058
3	0.0094
4	0.0140
5	0.0198
10	0.0787
15	0.2185
30	1.668

2.3 Ratiometric Output

Ratiometric output means that the zero offset point and sensitivity of the sensor are proportional to the supply voltage. If the SCA121T-D05 supply voltage is fluctuating the SCA121T-D05 output will also vary. When the same reference voltage for both the SCA121T-D05 sensor module and the measuring part (A/D-converter) is used, the error caused by reference voltage variation is automatically compensated for.

3 Mechanical Specifications

Cable length:	-D03,-D07 30cm
	-D05 110cm
Cable type:	UL/CSA listed, PUR black
Cable diam.:	6±0.2mm
Leads:	5 x 0.14mm^2
Total weight:	Approx. 60 grams
Protection class:	IP66
Housing:	Zinc casting with passivation
Mounting:	The sensor module is to be mounted on a flat and smooth surface with 2 screws, dimension M4. Mounting torque 5 ±1Nm

3.1 Sensor dimensions

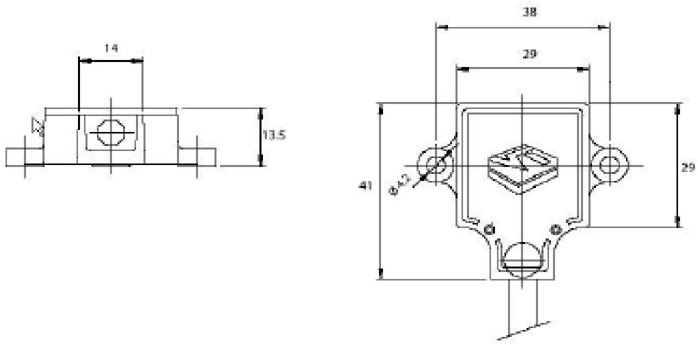


Figure 2. Mechanical dimensions of the SCA121T (dimensions in mm)

Figure D.4 Inclinometer Specification Sheet

- **30A, 2 form A (NO) and 2 form C (CO) switching capability**
- **Designed to control compressor loads to 3.5 tons, 110LRA / 25.3FLA**
- **Meets requirements of UL 508 and UL 873 spacings - 8mm through air, 9.5mm over surface**
- **Meets requirements of VDE 8mm spacing, 4kV dielectric coil-to-contact**
- **Meets requirements of UL Class F construction**
- **UL approved for 600VAC switching (1.5HP)**
- **New screw terminal version (consult factory for availability, ratings)**

Typical applications
HVAC, residential / commercial appliances, industrial controls

Approvals

UL E58304 (Recognized and Listed); CSA LR48471; VDE 40019600
Technical data of approved types on request

Contact Data

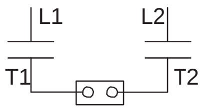
Contact arrangement	2 form A (NO), 2 form C (CO)
Rated voltage	277VAC
Max. switching voltage	600VAC
Limiting continuous current	30A NO; 3A NC
Limiting making current	30A NO; 3A NC
Limiting breaking current	30A NO; 3A NC
Contact material	AgSnOInO, AgCdO
Min. recommended contact load	500ma (NO)/ 100ma (NC), 12VAC
Frequency of operation, with load	360hr
Operate/release time max., including bounce	15/15ms

Contact ratings 1)

Type	Load	Cycles
UL508		
AgCdO		
NO	40A, 277VAC, resistive	$6x10^3$
NO	30A, 120/277VAC, resistive	$100x10^3$
NO	10A, 600VAC, general purpose	$100x10^3$
NO	1HP, 120VAC	$100x10^3$
NO	3HP, 240VAC	$1x10^3$
NO	1.5HP, 480 or 600VAC	$100x10^3$
NO	110LRA/25.3FLA, 240VAC (DC coil only)	$100x10^3$
NO	60LRA/14FLA, 240VAC (AC coil only)	$100x10^3$
NO	3A, 240VAC, pilot duty	$100x10^3$
NO	20A, 28VDC, resistive	$100x10^3$
NO	TV10, 120VAC	$100x10^3$
NC	3A, 277VAC	$100x10^3$
NC	2A, 480VAC	$100x10^3$
NC	1A, 600VAC	$100x10^3$
AgSnOInO		
NO	30A, 120/277VAC, resistive (DC coil only)	$200x10^3$
NO	30A, 120/277VAC, resistive (AC coil only)	$100x10^3$
NO	20A, 480VAC, resistive	$100x10^3$
NO	1.5HP, 120VAC, 2 pole making/breaking (Fig.1)	$100x10^3$
NO	3HP, 240VAC, 3 phase (DC coil only)	$100x10^3$
NO	3HP, 480VAC, 3 phase (DC coil only)	$100x10^3$
NO	2HP, 600VAC, 3 phase (DC coil only)	$100x10^3$
VDE		
AgCdO, flange mount relays		
NO	20A, 400VAC	$100x10^3$
NC	3A, 400VAC	$30x10^3$
CO	20A NO / 3A NC, 400VAC	$30x10^3$
AgCdO, PC mount relays		
NO	30A, 400VAC	$100x10^3$
NC	3A, 400VAC	$30x10^3$

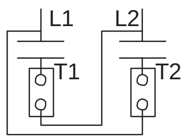
Contact ratings 1) (continued)

ARI 780-86 Endurance Test (section 6.6):
HVAC Definite Purpose Contactor Standard
Normally Open Contacts
Single Phase/Two Pole (Both poles together switching a single load)
110 LRA, 25.3 FLA, 200K operations (DC Coil)



Single Phase Per Pole (Single load per pole)
110 LRA, 18 FLA, 200K operations (DC Coil).
60 LRA, 14 FLA, 200K operations (AC Coil).

Figure 2



1) Contact ratings at 25°C (unless otherwise noted) with relay properly vented. FLA, LRA ratings are compatible with 3.5 ton compressor applications.

Mechanical endurance	$10x10^6$ ops.

Coil Data

Coil voltage range	5 to 110VDC; 12 to 240VAC
Max. coil power	1.7W; 4.0VA
Max. coil temperature	155°C
Coil insulation system according UL	Class F

Coil versions, DC coil

Coil code	Rated voltage VDC	Operate voltage VDC	Release voltage VDC	Coil resistance Ω±10%	Rated coil power W
6	6	4.5	0.6	22	1.7
9	9	6.75	0.9	48	1.7
12	12	9	1.2	86	1.7
18	18	13.5	1.8	197	1.7
24	24	18	2.4	350	1.7
48	48	36	4.8	1390	1.7
CO	30A NO / 3A NC, 400VAC				$30x10^3$

110	110	82.5	11	7255	1.7

Coil versions, AC coil

Coil coil code	Rated voltage	Frequency	Operate voltage	Release voltage	Coil resistance	Rated power
	VAC	Hz	VAC	VAC	Ω±10%	VA
12	12	60	9.6	1.2	9.1	4
24	24	60	19.2	2.4	36.6	4
120	110/120	50/60	96	12	950	4
240	220/240	50/60	192	24	3800	4
277	250/277	50/60	222	28	5485	4

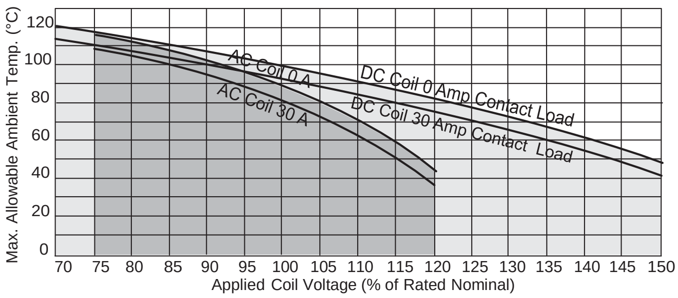
All figures are given for coil without preenergization, at ambient temperature +23°C.

Coil Data (continued)

Ambient temperature vs. coil voltage

Assumptions:

1. Thermal resistance = 35°C per Watt (DC only.)
2. Still air.
3. Nominal coil resistance.
4. Max. mean coil temperature = 155°C (change of resistance method).
5. Coil temperature rise due to load = 6.3°C @ 30 amps.
6. Curves are based on 1.7W at 25°C (DC only.).



Insulation Data

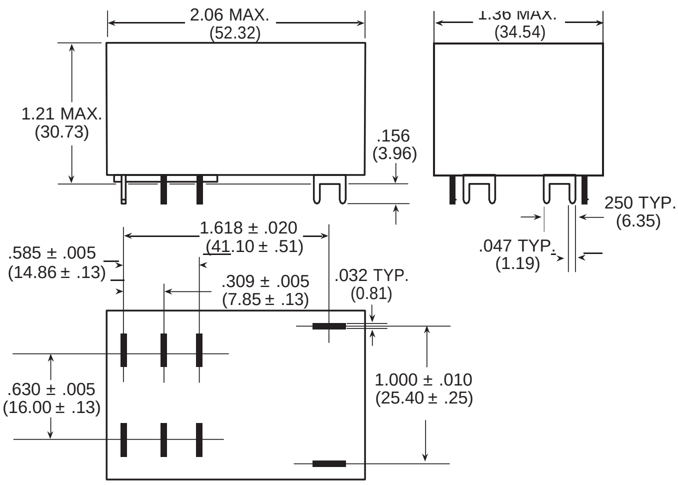
Initial dielectric strength	
between open contacts	1500V rms
between contact and coil	4000V rms
between adjacent contact	2000V rms
Initial surge withstand voltage	
between contact and coil	6kV
Initial insulation resistance	
between insulated elements	$1x10^9 \Omega$
Clearance/creepage	
between contact and coil	8mm clearance/9.5mm creepage

Other Data

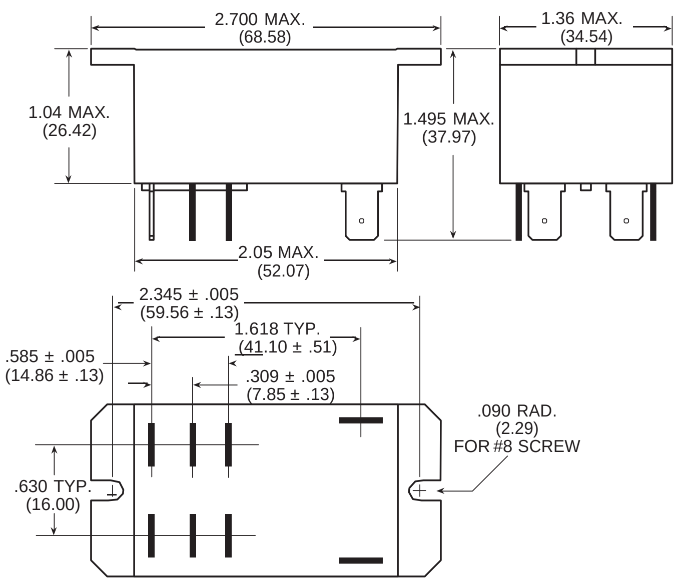
Material compliance:	EU RoHS/ELV, China RoHS, REACH, Halogen content refer to the Product Compliance Support Center at www.te.com/customersupport/rohssupportcenter
Ambient temperature	
DC coil	-55ºC to 85ºC
AC coil	-55ºC to 65ºC
Category of environmental protection	
IEC 61810	RTI - dust protected, RTII - flux proof, RTIII - wash tight
Vibration resistance (functional)	1.65mm max excursions, 10-55 Hz
Shock resistance (functional)	10g for 11msec
Shock resistance (destructive)	100g
Terminal type	pcb-tht or quick connect
Weight	86g
Resistance to soldering heat THT	
IEC 60068-2-20	250°C
Packaging/unit	tray/30 pcs., box/120 pcs.

Dimensions

T92 – Mounting and termination code 1

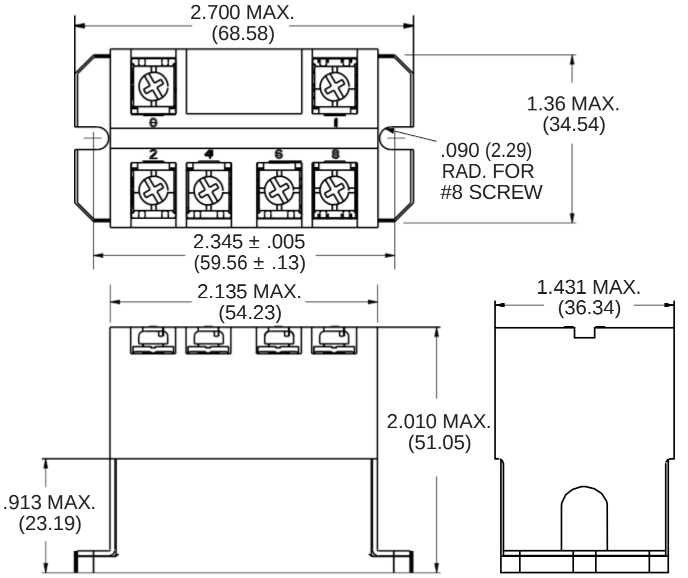


T92 – Mounting and termination code 2, 3 and 4



Dimensions

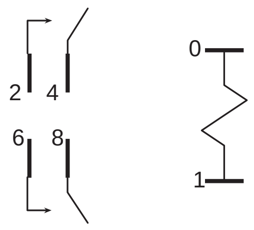
T92 – Mounting and termination code 5



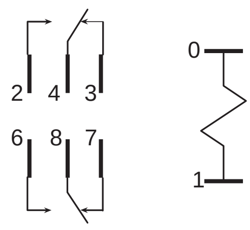
Terminal assignment

Bottom view on pins

2 Form A



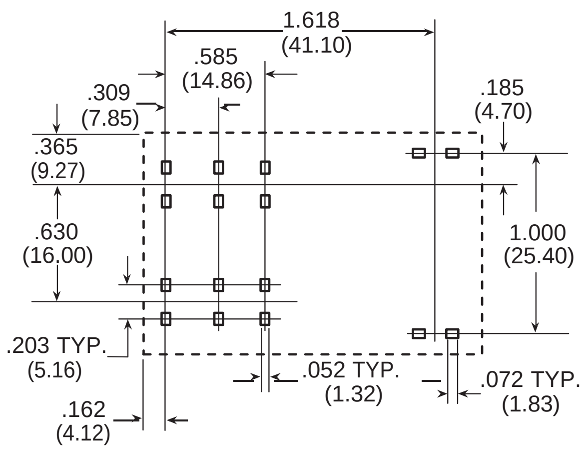
2 Form C



PCB layout

Bottom view on pins

T92 - Mounting and termination code 1



An alternate PC board layout utilizes .076 ± .003 (1.93 ± .076) diameter holes on the same center-to-center spacing shown above. Use of the rectangular holes is recommended for improved solderability.

Only necessary terminals are present on single throw models. Consequently, some holes will be unnecessary for single throw models.

Product code structure

Typical product code	T92	S	11	D	2	2	-24

Type
- **T92** Printed circuit board / panel mount power relay T92

Enclosure
- **P** Dust protected plastic case
- **S** Wash-tight, tape sealed, plastic case (Mounting and termination code 1)
  Top sealed, not wash-tight, not tape sealed on bottom (Mounting and termination codes 2, 3 & 4)

Contact arrangement
- **7** 2 form A (2 NO)
- **11** 2 form C (2 CO)

Coil Input
- **A** AC voltage, 60Hz or 50/60 Hz (consult coil versions table)
- **D** DC voltage

Mounting and termination
- **1** Printed circuit board mount; printed circuit board terminals.
- **2** Panel mount via flanged cover; .250” (6.35mm) x .032” (.81mm) QC terminal
- **3** Panel mount via flanged cover; .187” (4.75mm) x .032” (.81mm) QC terminals for coil and .250” (6.35mm) for contacts
- **4** Panel mount via flanged cover, .187” (4.75mm) x .020” (.51mm) QC terminals for coil and .250” (6.35mm) for contacts.
- **5** Panel mount via flanged cover, M4 screws w/ captive pressure plates. Requires Enclosure P and Contact arrangement 7.

Contact material
- **2** AgCdO
- **4** AgSnOInO

Coil voltage

Coil code: please refer to coil versions table

Product Code	Enclosure	Contacts	Coil	Mounting	Contact Material	Coil	Part Number
T92P7A22-24	Plastic dust cover	2 form A, 2 NO	AC	Panel mount + quick conn.	AgCdO	24 VAC	6-1393211-0
T92P7A22-120						120 VAC	5-1393211-7
T92P7A22-240						240 VAC	6-1393211-2
T92P7A22-277						277 VAC	6-1393211-3
T92P7A24-240					AgSnOInO	240 VAC	3-1423008-3
T92P7A52-120				Panel mount + screw term.	AgCdO	120 VAC	1423008-8
T92P7A52-240						240 VAC	1-1423008-2
T92P7D12-12			DC	PCB terminals		12 VDC	6-1393211-5
T92P7D12-24						24 VDC	6-1393211-6
T92P7D22-12				Panel mount + quick conn.		12VDC	6-1393211-9
T92P7D22-24						24 VDC	7-1393211-1
T92P7D22-48						48 VDC	7-1393211-2
T92P7D24-12					AgSnOInO	12VDC	2-1423008-2
T92P7D24-24						24 VDC	1423008-9
T92P7D42-24					AgCdO		7-1393211-5
T92P7D52-12				Panel mount + screw term.		12 VDC	1-1423008-0
T92P7D52-24						24 VDC	1423967-1
T92P11A12-120		2 form C, 2 CO	AC	PCB terminals		120 VAC	3-1393211-8
T92P11A22-12				Panel mount + quick conn.		12 VAC	3-1393211-9
T92P11A22-24						24 VAC	4-1393211-3
T92P11A22-120						120 VAC	4-1393211-0
T92P11A22-240						240 VAC	4-1393211-4
T92P11A22-277						277 VAC	4-1393211-6
T92P11A24-240					AgSnOInO	240 VAC	3-1423008-7
T92P11A42-120					AgCdO	120VAC	4-1393211-8
T92P11D12-12			DC	PCB terminals		12 VDC	5-1393211-0
T92P11D22-12				Panel mount + quick conn.			5-1393211-3
T92P11D22-24						24 VDC	5-1393211-4
T92P11D24-12					AgSnOInO	12 VDC	3-1423008-5
T92P11D24-24						24 VDC	3-1423008-6
T92S7A12-24	Wash tight	2 form A, 2 NO	AC	PCB terminals	AgCdO	24 VAC	9-1393211-8
T92S7A12-120						120 VAC	9-1393211-7
T92S7A12-240						240 VAC	9-1393211-9
T92S7A22-24	Top sealed			Panel mount + quick conn.		24 VAC	1393212-4
T92S7A22-120						120 VAC	1393212-2
T92S7A22-240						240 VAC	1393212-5
T92S7D12-12	Wash tight		DC	PCB terminals		12 VDC	1393212-8
T92S7D12-24						24 VDC	1-1393212-0
T92S7D12-48						48 VDC	1-1393212-1
T92S7D12-110						110 VDC	1393212-7
T92S7D14-24					AgSnOInO	24 VDC	1-1423008-8
T92S7D22-12	Top sealed			Panel mount + quick conn.	AgCdO	12 VDC	1-1393212-4
T92S7D22-18						18 VDC	1-1393212-5
T92S7D22-24						24 VDC	1-1393212-7
T92S7D22-110						110 VDC	1-1393212-3
T92S11A12-24	Wash tight	2 form C, 2 CO	AC	PCB terminals		24 VAC	8-1393211-1
T92S11A12-120						120 VAC	8-1393211-0
T92S11A12-240						240 VAC	8-1393211-2
T92S11A22-12	Top sealed			Panel mount + quick conn.		12 VAC	8-1393211-3
T92S11A22-24						24 VAC	8-1393211-6
T92S11A22-120						120 VAC	8-1393211-4
T92S11A22-240						240 VAC	8-1393211-7
T92S11D12-12	Wash tight		DC	PCB terminals		12 VDC	8-1393211-9
T92S11D12-24						24 VDC	9-1393211-0
T92S11D12-48						48 VDC	9-1393211-1
T92S11D12-110						110 VDC	8-1393211-8
T92S11D22-12	Top sealed			Panel mount + quick conn.		12 VDC	9-1393211-3
T92S11D22-24						24 VDC	9-1393211-4

Figure D.5 Double Pole Double Throw Relay Data Sheet

G8JN

General Purpose Automotive Power Relay

- Wide temperature range: -40° C to 125° C.
- Standard ISO terminal footprint.
- Handles heavy automotive load; inrush current 100 A.
- High current path fully welded; reduces heat buildup at full load.
- Made in North America.

Ordering Information

Terminal type	Contact form	Cover	Resistor	Bracket	Model
Plug in	SPDT	Standard	---	---	**G8JN-1C7T-DC12**
			---	Molded plastic	**G8JN-1C7T-MF-DC12**
			680 Ω	---	**G8JN-1C7T-R-DC12**
			680 Ω	Molded plastic	**G8JN-1C7T-MF-R-DC12**
		Weatherproof	---	---	**G8JN-1C6T-DC12**
			680 Ω	---	**G8JN-1C6T-R-DC12**
			680 Ω	Metal	**G8JN-1C6T-F-R-DC12**
			---	Metal	**G8JN-1C6T-F-DC12**

Specifications

■ Contact Data

Max. resistive load	SPDT	35 A (NO) / 20 A (NC)
Contact voltage drop (Initial value at 23° C)		≤200 mV (NO) / ≤100 mV (NC)
Max. inrush current	Inductive load	100 A (NO) / 40 A (NC)

■ Coil Data

Rated voltage	12 VDC
Operating voltage	10-16 VDC
Coil resistance (see note)	74 Ω ± 15%
Pick-up voltage	8 V (23°)
Dropout voltage	1 V at 23° C

Note: Coil resistance specified is without the suppression resistor.

■ Characteristics

Operate time at 23° C	20 ms max @ 12 VDC
Release time at 23° C	10 ms max @ 12 VDC
Insulation resistance	> 20 MΩ @500 VDC
Shock resistance	10G min.
Vibration resistance	9G min.
Duty cycle at rated load [16V at 80° C]	Up to 100%
Mechanical life	1,000,000 operations min.
Electrical life (resistive load)	100,000 operations minimum (14V / 35A)
Operating ambient temperature	-40° to 125° C
Weight	Approx. 34g

Note: Data shown are of initial value.

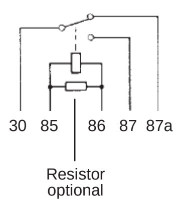
Dimensions

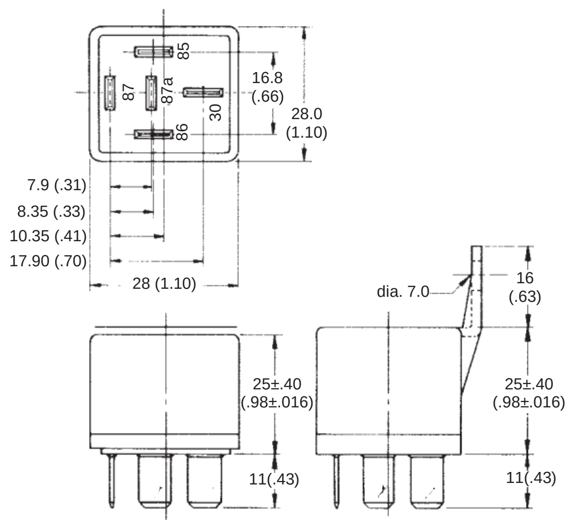
Unit: mm (inch)

■ SPDT Plug-in Type

G8JN-1C7T- @@@

Circuit Diagram

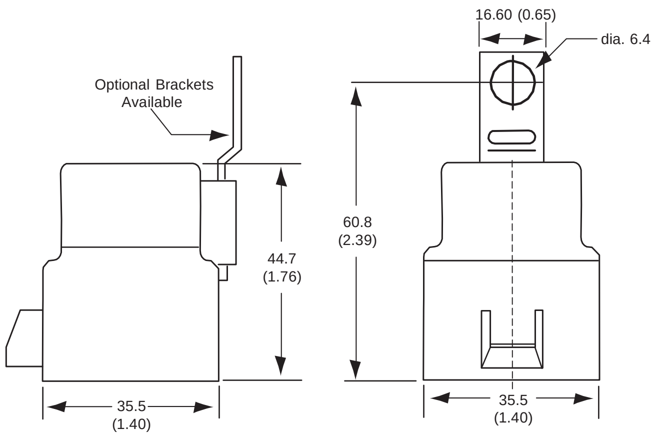


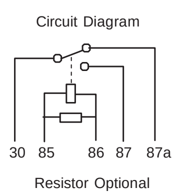


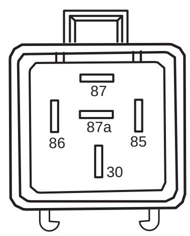
Standard Package **Plastic Bracket Optional**

■ SPDT Plug-in Weatherproof Type

G8JN-1C6T- @@@







Note: In the interest of product improvement, specifications are subject to change.

Figure D.6 Single Pole Relay Data Sheet

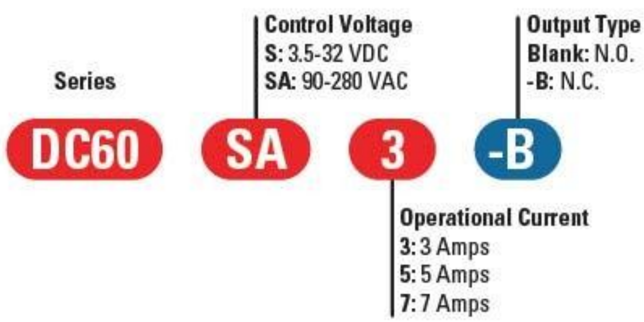
DC60 Series

- Bi-polar transistor output
- Ratings from 3A to 7A @ 60 VDC
- AC or DC control
- UL and cUL Recognized (E116950)

PRODUCT SELECTION

Control Voltage	3A	5A	7A
3.5-32 VDC	DC60S3	DC60S5	DC60S7
90-280 Vrms/VDC	DC60SA3	DC60SA5	DC60SA7

AVAILABLE OPTIONS



OUTPUT SPECIFICATIONS (1)

Description	3A	5A	7A
Operating Voltage [VDC]	3-60	3-60	3-60
Maximum Off-State Leakage Current @ Rated Voltage [mA]	0.1	0.1	0.1
Maximum Load Current [ADC] (2)	3	5	7
Minimum Load Current [mA]	20	20	20
Maximum Surge Current [Adc] (10ms)	6	10	14
Maximum On-State Voltage Drop @ Rated Current [Vdc]	1.3	1.5	1.7
Thermal Resistance Junction to Case (Rjc) [°C/W]	2.2	2.2	2.2

INPUT SPECIFICATIONS (1)

Description	DC Control	AC/DC Control
Control Voltage Range	3.5-32 VDC	90-280 Vrms/VDC
Minimum Turn-On Voltage	3.5 VDC	90 Vrms/VDC
Minimum Turn-Off Voltage	1.0 VDC	10 Vrms/VDC
Typical Input Current	2.2 mA @ 5 VDC	2 mA @ 120 V, 4 mA @ 240 V
Nominal Input Impedance	1500 Ohm	60K
Maximum Turn-On Time [msec] (3)	0.1	10
Maximum Turn-Off Time [msec] (4)	0.3	40

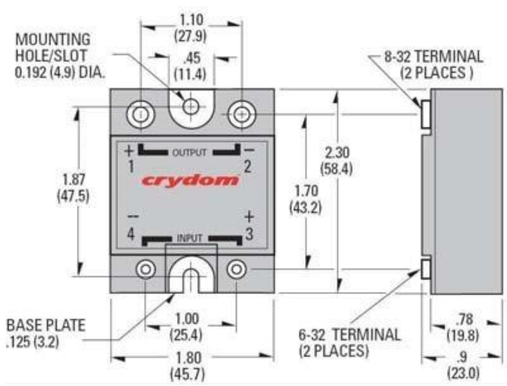
GENERAL SPECIFICATIONS

Description	Parameters
Dielectric Strength, Input/Output/Base (50/60Hz) [Vrms]	4000
Minimum Insulation Resistance (@ 500 V DC)	10^9 Ohm
Maximum Capacitance, Input/Output	8 pF
Ambient Operating Temperature Range	-30 to 80°C
Ambient Storage Temperature Range	-40 to 125 °C
Weight (typical)	3.0 oz (86.5g)
Encapsulation	Thermally conductive Epoxy
Terminals	Screws and Saddle Clamps Furnished, Unmounted
Recommended Terminal Screw Torque Range:	6-32 Screws - 10 in lbs. 8-32 and 10-32 Screws -20 in. lbs. (Screws dry without grase)

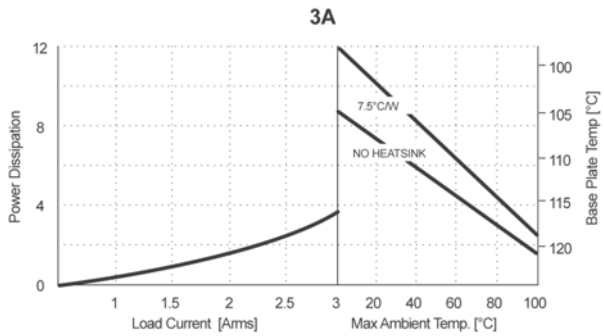
GENERAL NOTES

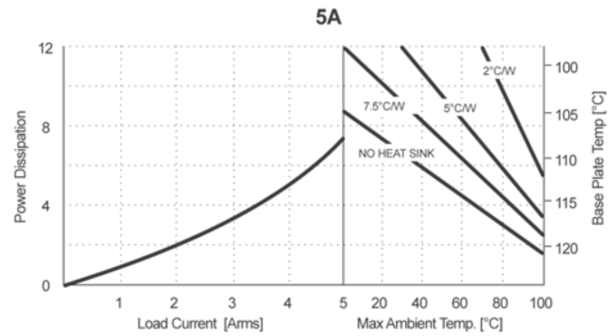
1) All parameters at 25°C unless otherwise specified.
2) Heat sinking required, see derating curves.
3) Turn-on time for –B version is 300 µs
4) Turn-off time for –B version is 100 µs.

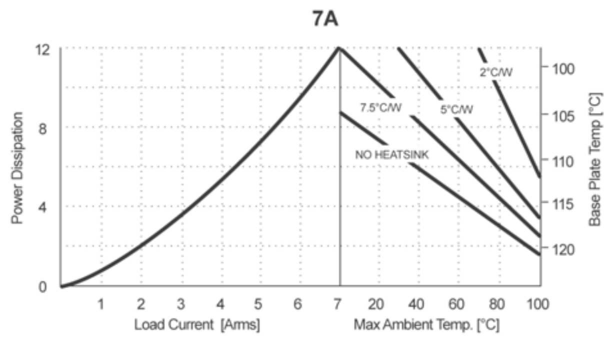
MECHANICAL SPECIFICATIONS



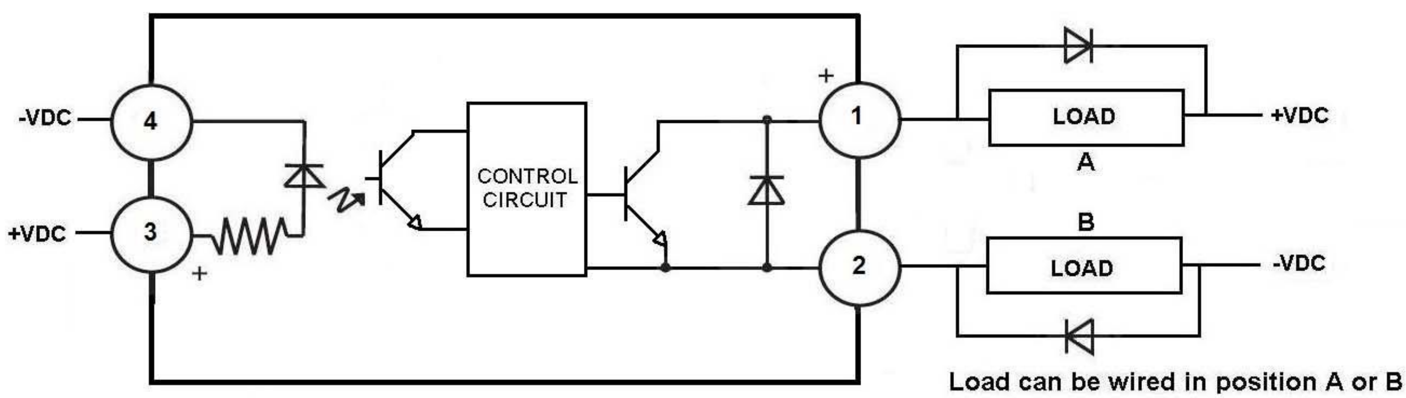
THERMAL DERATE INFORMATION







WIRING DIAGRAM



DC Inductive loads must be diode suppressed to prevent damage to SSR

AGENCY APPROVALS

Designed in accordance with the requirements of IEC 62314

E116950

Rev. 120711

⚠ DANGER / PELIGRO / DANGER /GEFAHR / PERICOLO / PERIGO					
HAZARD OF ELECTRIC SHOCK, EXPLOSION, OR ARC FLASH. • Disconnect all power before installing or working with this equipment. • Verify all connections and replace all covers before turning on power. **Failure to follow these instructions will result in death or serious injury.**	**RIESGO DE DESCARGA ELECTRICA O EXPLOSION.** • Desconectar todos los suministros de energia a este equipo antes de trabajar con este equipo. • Verificar todas las conexiones y colocar todas las tapas antes de energizer el equipo. **El incumplimiento de estas instrucciones puede provocar la muerte o lesiones serias.**	**RISQUE DE DESCHARGE ELECTRIQUE OU EXPLOSION** • Eteindre toutes les sources d'énergie de cet appareil avant de travailler dessus de cet appareil • Vérifier tous connections, et remettre tous couverts en olace avant de mettre sous **De non-suivi de ces instructions provoquera la mort ou des lésions sérieuses sérieuses.**	**GEFAHR EINES ELEKTRISCHE N SCHLAGES ODER EINER EXPLOSION.** • Stellen Sie jeglichen Strom ab, der dieses Gerät versorgt, bevor Sie an dem Gerät Arbeiten durchführen • Vor der Inbetriebnahme alle Anschlüsse überprüfen und alle Gehäuseteile montieren. **Unterlassung dieser Anweisungen können zum Tode oder zu schweren Verletzungen führen.**	**RISCHIO DI SCOSSA ELETTRICA O DELL'ESPLOSI ONE.** • Spenga tutta l'alimentazion e che fornisce questa apparecchiatu ra prima del lavorare a questa apparecchiatu ra • Verificare tutti i collegamenti e sostituire tutte le coperture prima della rotazione sull'alimentazi one **L'omissione di seguire queste istruz ioni provocherà la morte o di lesioni serie**	**RISCO DE DESCARGA ELÉTTRICA OU EXPLOSÃO** • Desconectar o equipamento de toda á energia antes de instalar ou trabalhar com este equipamen to • Verificar todas as conexões e recolocar todas as tampas antes de religar o equipamento **O não cumprimento destas instruções pode levar á morte ou lesões sérias.**

⚠ WARNING / AVERTISSEMENT / WARNUNG /ADVERTENCIA / AVVERTENZA / AVISO		
RISK OF MATERIAL DAMAGE AND HOT ENCLOSURE • The product's side panels may be hot, allow the product to cool before touching. • Follow proper mounting instructions including torque values. • Do not allow liquids or foreign objects to enter this product. **Failure to follow these instructions can result in serious injury, or equipment damage.**	**RISQUE DE DOMMAGE MATERIEL ET DE SURCHAUFFE DU BOITIER** • Les panneaux latéraux du produit peuvent être chauds. Laisser le produit refroidir avant de le toucher. • Respecter les consignes de montage, et notamment les couples de serrage. • Ne pas laisser pénétrer de liquide ni de corps étrangers à l'intérieur du produit. **Le non-respect de cette directive peut entraîner, des lésions corporelles graves ou des dommages matériels.**	**GEFAHR VON MATERIALSCHÄDEN UND GEHÄUSEERHITZUNG** • Die Seitenwände können heiß sein. Lassen Sie das Produkt abkühlen, bevor Sie es berühren. • Beachten Sie die Montageanweisungen, • Führen Sie keine Flüssigkeiten oder Fremdkörper in das Produkt ein. **Die Nichtbeachtung dieser Anweisung kann Körperverletzung oder Materialschäden zur Folge haben.**
RIESGO DE DAÑOS MATERIALES Y DE SOBRECALENTAMIENTO DE LA UNIDAD • Los paneles laterales del producto pueden estar calientes. Esperar que el producto se enfríe antes de tocarlo. • Respetar las instrucciones de montaje, y en particular los pares de apretado. • No dejar que penetren líquidos o cuerpos extraños en el producto. **Si no se respetan estas precauciones pueden producirse graves lesiones, daños materiales.**	**RISCHIO DI DANNI MATERIALI E D'INVOLUCRO CALDO** • I pannelli laterali dell'apparecchio possono scottare; lasciar quindi raffreddare il prodotto prima di toccarlo. • Seguire le istruzioni di montaggio corrette. • Non far entrare liquidi o oggetti estranei in questo apparecchio. **La mancata osservanza di questa precauzione può causare gravi rischi per l'incolumità personale o danni alle apparecchiature.**	**RISCO DE DANO MATERIAL E DE AQUECIMENTO** • Os painéis laterais do produto podem estar quentes; dê tempo ao produto para arrefecer antes de lhe tocar. • Siga devidamente as instruções de montagem. • Não permita a entrada de líquidos e de objectos estranhos no produto. **A não observância destas precauções pode provocar a morte, ferimentos graves ou danos materiais.**

Figure D.7 Solid State Relay Data Sheet

Table D.1 Tapered Roller Bearing Specifications

Bearing Type	TRB	
Bearing Subtype	TS	
Cone (Inner)	LM78349A	
Cup (Outer)	LM78310A	
d - Bore	1.3775	in
D - Outer Diameter	2.4399	in
T - Width	0.658	in
C1 - Dynamic Radial Load Rating - 1 M revs	8850	lbf
C90 - Dynamic Radial Load Rating - 90 M revs	2290	lbf
Ca90 - Dynamic Axial Load Rating - 90 M revs	1750	lbf
C0 - Static Load Rating	11800	lbf
K = 0.39 / Tan (contact angle)	1.31	
e = 1.5 * Tan (contact angle)	0.44	
Y = 0.4 / Tan (contact angle)	1.35	
Cg - Geometry constant for lubrication adjustment to bearing life	0.0678	
B - Inner Ring Width	0.6693	in
R - Max Shaft Fillet Radius	0.06	in
db - Shaft Backing Shoulder Diameter	1.65	in
da - Shaft Backing Shoulder Diameter	1.56	in
Aa - Cone Back Face (BF) to Cage distance	0.03	in
Ab - Cone Front Face (FF) to Cage distance	0.05	in
C - Outer Ring Width	0.5354	in
r - Max Housing Fillet Radius	0.06	in
Db - Housing Backing Shoulder Diameter	2.13	in
Da - Housing Backing Shoulder Diameter	2.32	in
a - Effective Center Location	-0.10	in
Assembly Weight	0.46	lb

Figure 1. Sources:
Left: http://vinetechequipment.com/Vine%20Tech%20Hedger%20002.jpg
Middle: http://www.bubco.com/images/bpics/hedgetrim.jpg
Right: http://mjr.superapple.com/img/newsletter//The%20Hedger.jpg

Figure 10. source:
http://bearingstore-shop.com/2011/01/04/bearing-2/

Appendix E:
Controller Setup Procedure

Auto-Leveling System

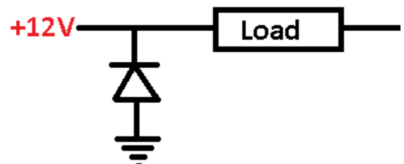
Each Side Independent: • (4x) 5 amp solid state relays • (2x) Inclinometer	(*Figure 2*)
One Side Dependent • (2x) 7 amp solid state relays ✓ Make sure combined current of both solenoids is less than 7 amps. • (1x) Inclinometer	(*Figure 3*)

Note: No software setup is needed for dual independent or single independent action.

- Mount the Inclinometer(s) at the appropriate angle.
- Connect the appropriate actuator solenoid to the appropriate relay terminal
- Make sure cables from inclinometers to the controller are well connected and not to tight, no pinching areas.
- Spin long distance wires to reduce noise.
- Connect voltage spike protection diodes for the solid state relays
- Find good location for controller with minimal vibrations.

Fan Reversal Controller:

- Use Single Pole Double Throw (Normally Closed) Relay for the fan power. This ensures so that if the relay fails it will still run.
- Use Double Pole Double Throw Relay for the Fan reversal.
- Make sure Voltage Spike Diodes are connected.

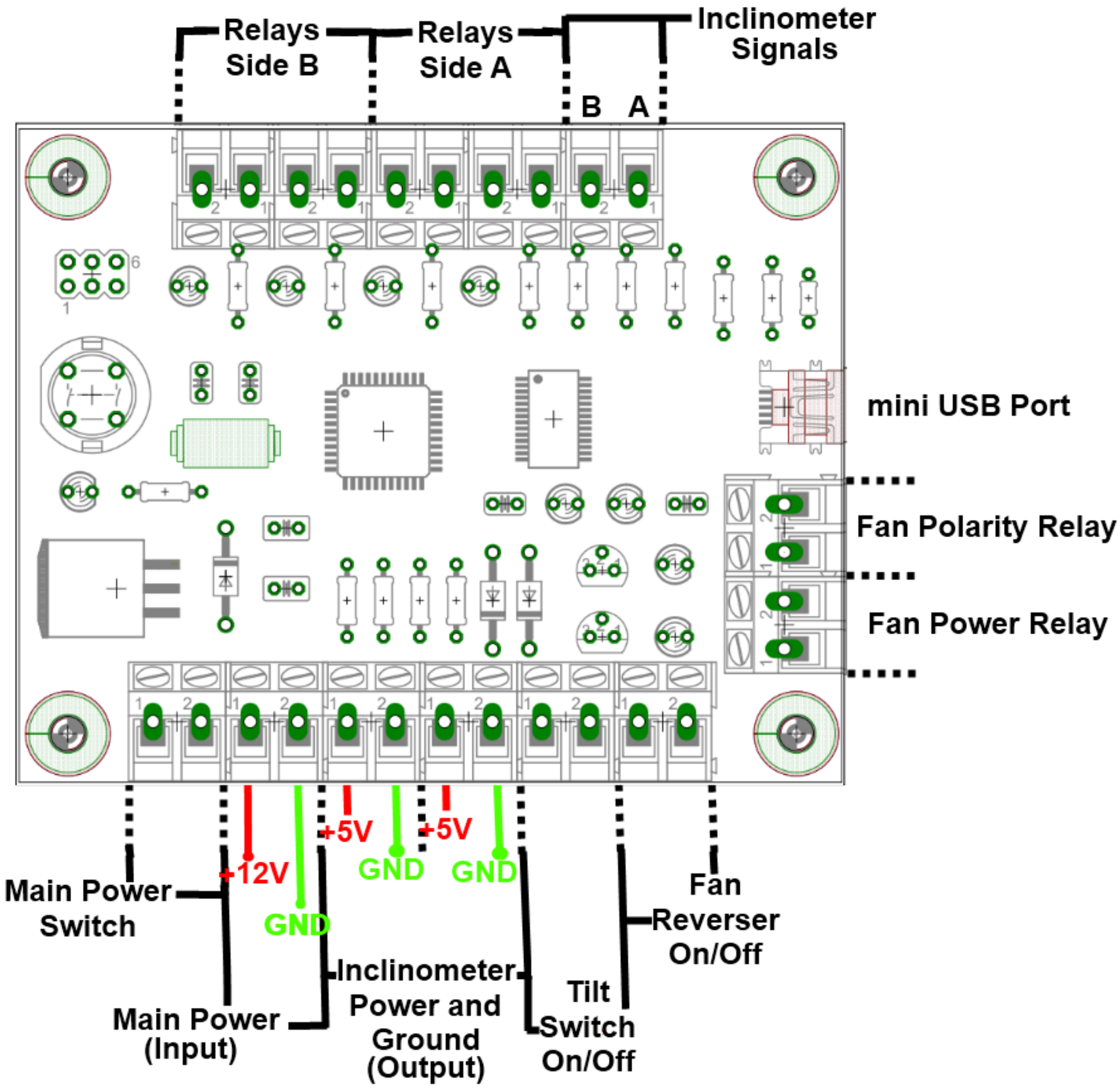


USB Interface

- Use Mini USB cable to a PC or Linux device.
- Use Terminal Communication Device such as Tera Term and connect to appropriate port. Usually COM4 or USB0.

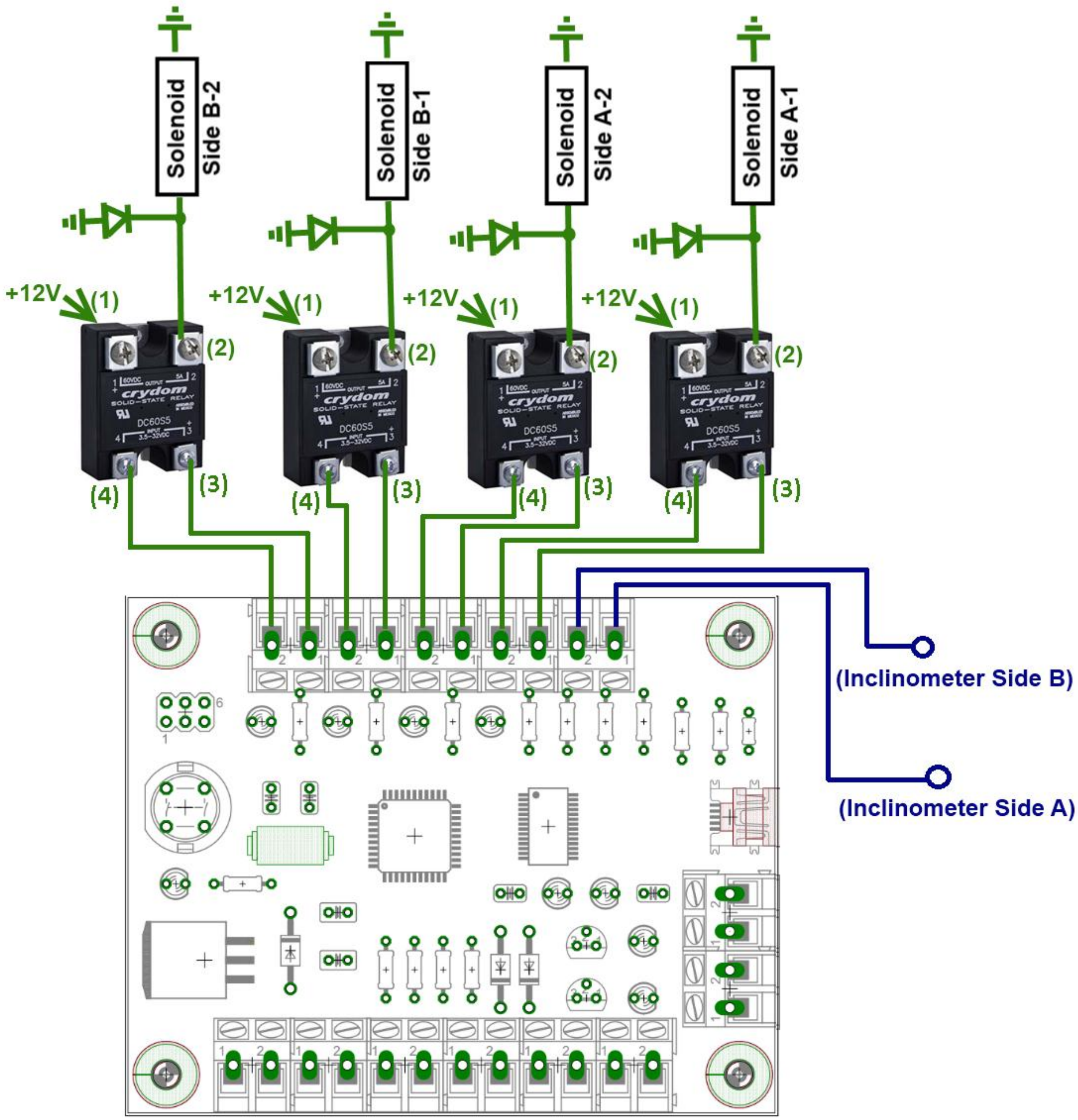
Controller Layout

(Figure 1)



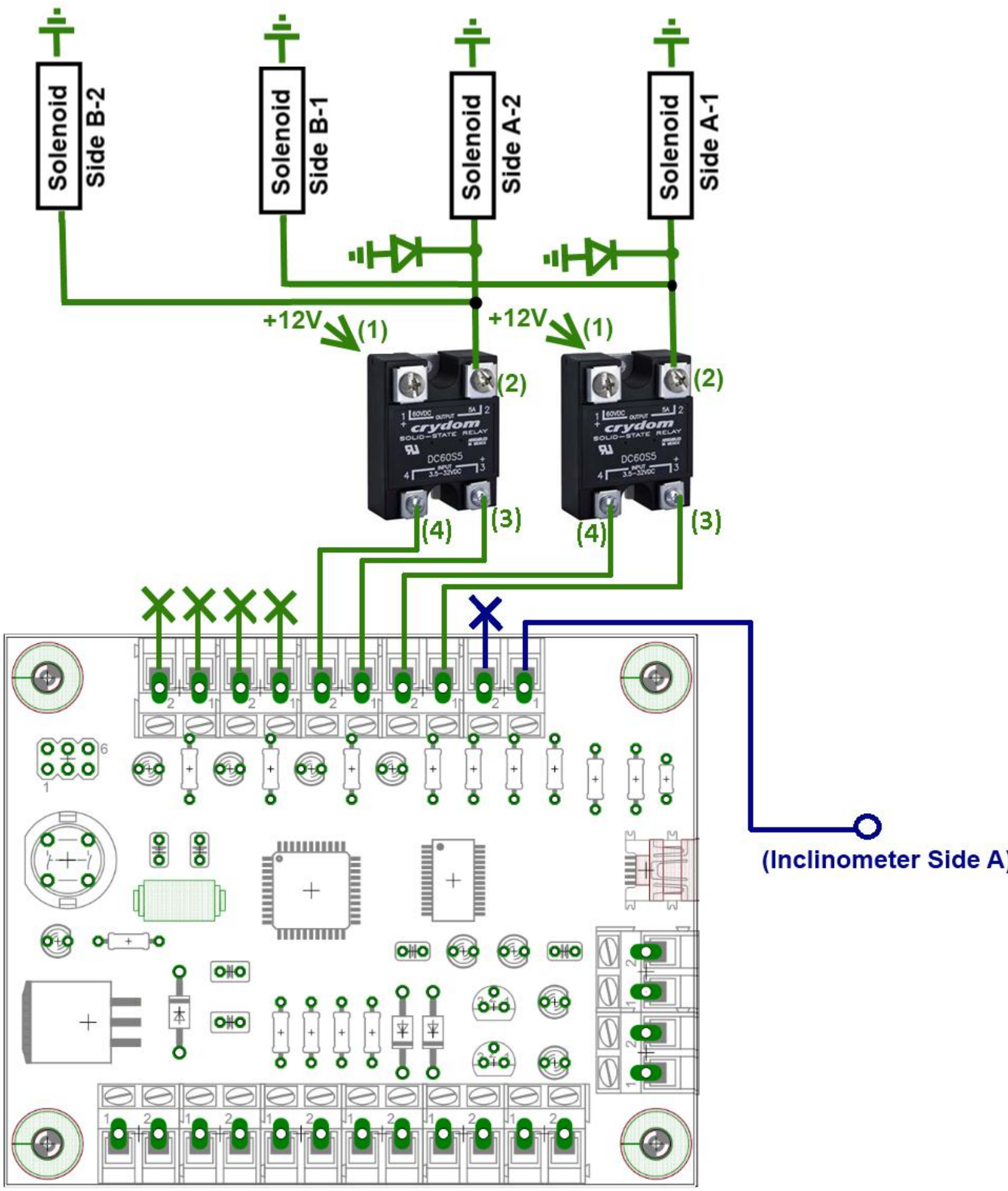
Dual Independent Leveling Layout

(Figure 2)



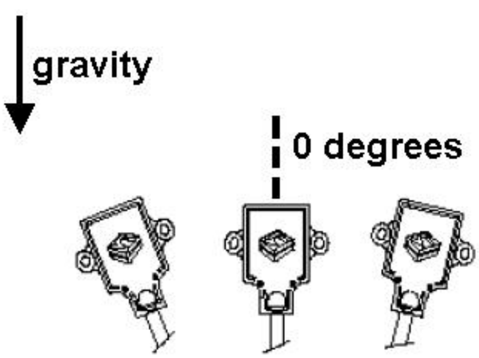
Single Independent Leveling Layout

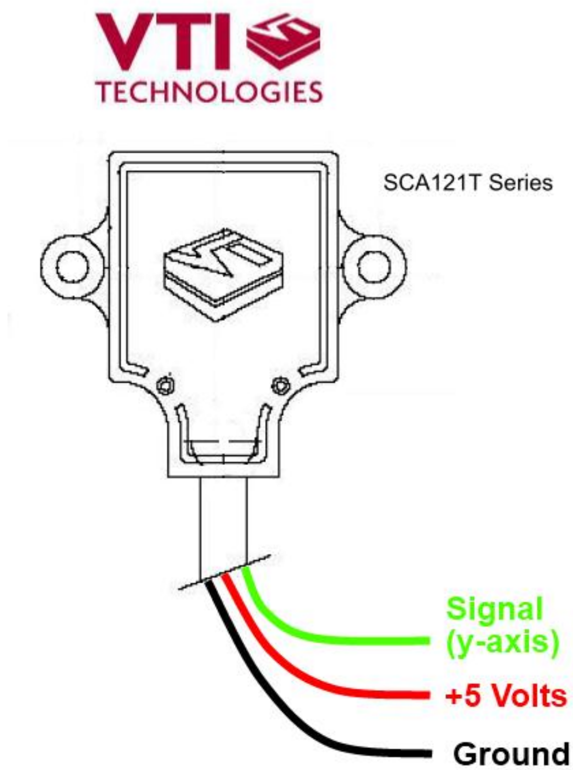
(Figure 3)



Inclinometer Layout

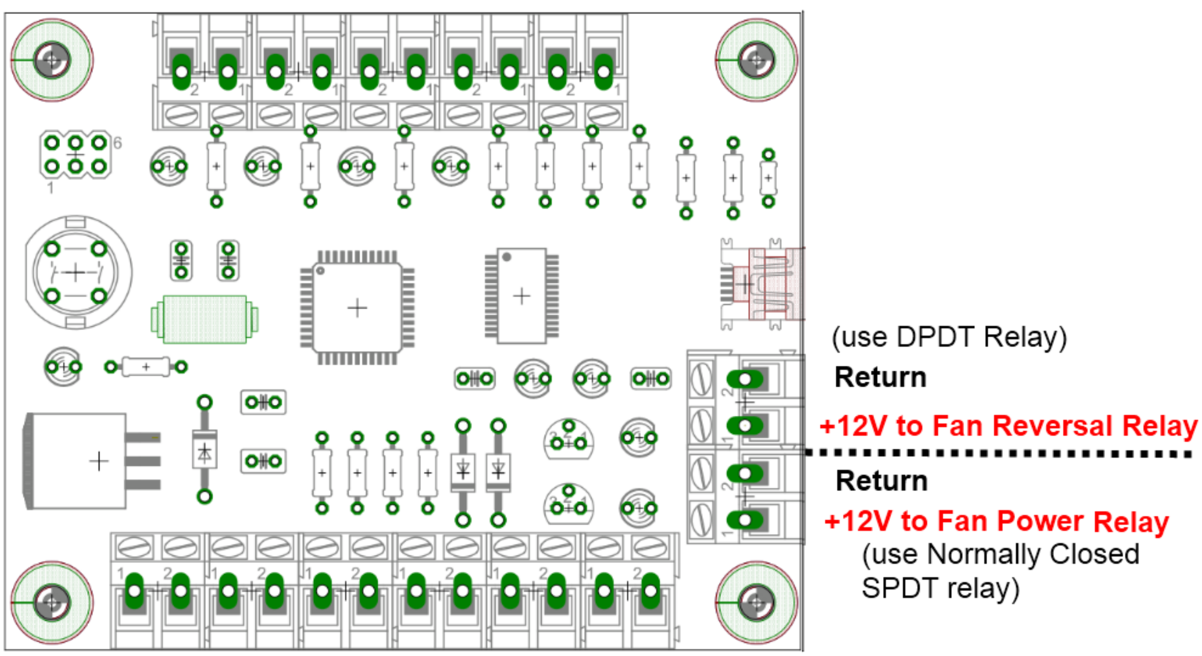
(Figure 4)





Fan Reversal Layout

(Figure 5)



Appendix F:

Controller Debugging Procedure

#1: Check connections!

<u>Nothing Works</u>

1) Check Power
    a. Is LED lit?
        i. (NO) → No input voltage. Connect source
        ii. (YES) → next step…
    b. Constant 5 Volts at voltage regulator output?
        i. (NO) → Too Much Noise. Next step…

    → Use external Voltage Regulator
2) Check Connections

<u>Tilt Doesn't Work</u>

1) Tilt switch ON?
2) Relay lights go on and off?
    a. (NO) → No Signal Communication from Inclinometers
    b. (YES, Random Flicker) → Bad signal connection. Too much noise.
    c. (YES, Proportionally to Angle) → Bad connection to Solenoid
    d. (YES, Proportionally to Angle) → Tilt Gain is set too low. Increase.

<u>Tilt Works But Not Correctly</u>

1) Oscillating and Unstable?
    → Tilt Gain is set too high.
2) Not going in the correct direction?
    → Switch Solenoid Wires from Solid State Relay.
3) Correcting Opposite Side?
    → Switch Inclinometer Signal Wires.

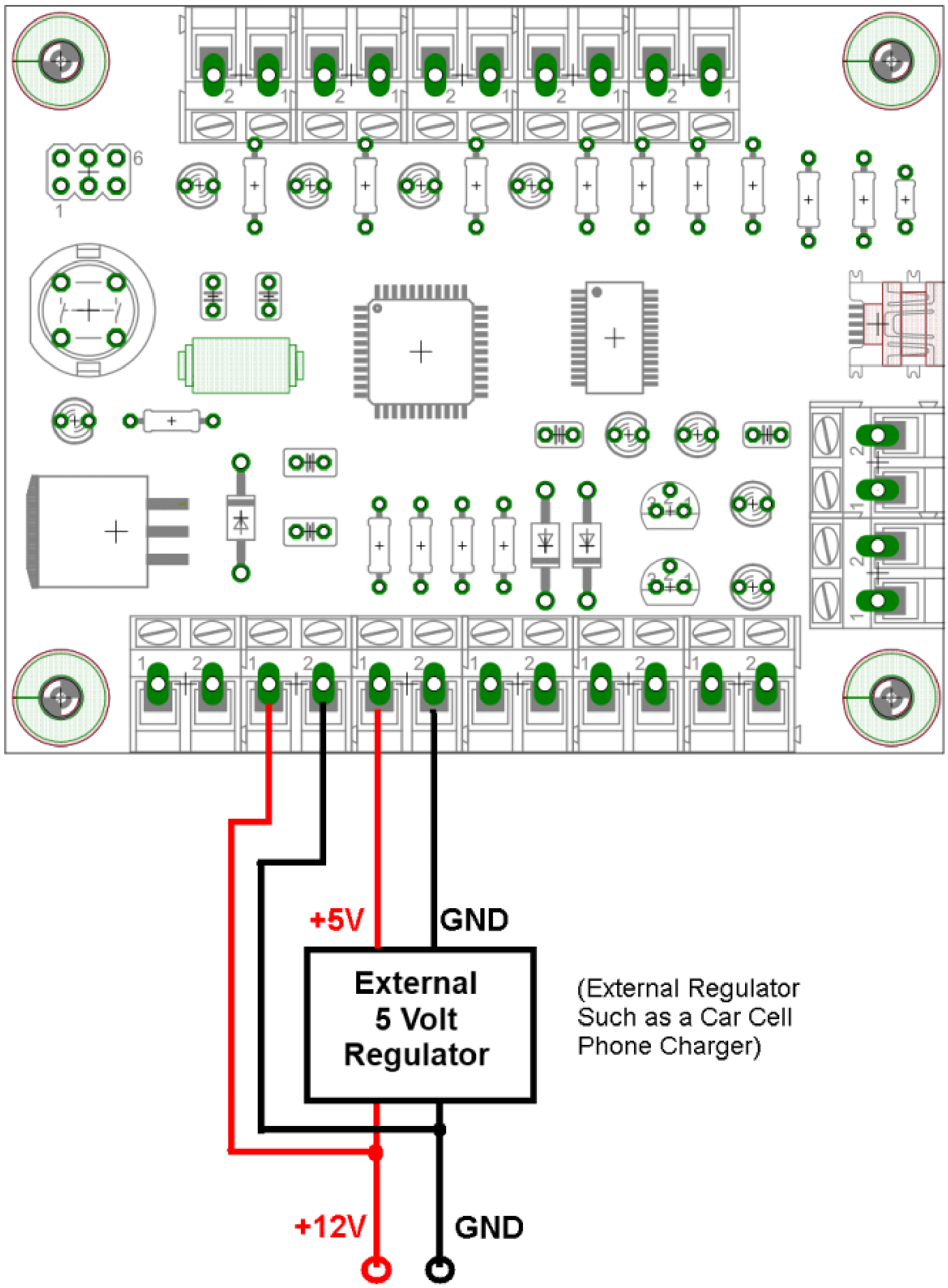
<u>Fan Reversal System Not Working</u>

1) Fan Reversal Program Switch ON?
2) Controller LED Lights up?
    a. (NO) → Blown Controller Component.
        i. Is Diode OK? Measure continuity.
            1. (NO) → Replace Diode
            2. (YES) → Bad Transistor. Replace with N-channel MOSFET
    b. (YES) → Bad connection to relay. Or blown relay.

<u>USB Connectivity Doesn't Work</u>

1) LED flicker when connect?
    a. (NO) → bad USB connection
    b. (YES) → next step
2) Using Terminal Communication Program such as **Tera Term**?
3) Cycle through available connections. Usually COM4.
4) Does nothing show on the terminal window?
    → Hit reset switch.

External Voltage Regulator Diagram



Appendix G:
Controller USB Interface

Plug In USB cable for User Control

- Press 'ENTER' for user control interface. This stops operation of everything.
- Press 'Q' to quit and resume normal operation.

Menu:

- Reset All
- Pulse Width
    - See Value
    - Set Value
- Tilt Gain
    - See Value
    - Set Value
- Zero Angle Degrees
    - Read Current Zero Angle Value
    - Read Current Angle Value
    - Set Zero Angle Value
- Read Current Angle
- Set Fan Time Values
    - Off 1
    - Reverse Polarity
    - On
    - Off 2
    - Normal Polarity
    - On
    - Repeat Time