Automated Fixture for Crankshaft Inspection

Final Report

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EXECUTIVE SUMMARY

Problem Description

Many of today's engines require extremely smooth crankshaft main and pin finishes due to increasingly tighter bearing clearances and the use of thinner viscosity motor oils. If the polishing of the crankshaft mains and pins are not adequate, microscopic surface peaks can cause premature bearing failure. A new method has been developed to inspect surface finish using a blue light source and a camera. Our team was tasked to take this new method and build an automated machine to prove its capabilities. With this new method, it is proven that a crankshaft can be inspected accurately for a polished or non-polished analysis in under 36 seconds. It is also proven that this new inspection method is a more efficient method since it is able to inspect each crankshaft off the manufacturing line as opposed to the current method of inspecting only one in every 50.

Specifications

The most important specification is that the entire inspection process must take less than 36 seconds. Second, each surface must be positioned with respect to the camera within a tolerance of millimeters. Lastly, due to the speed at which the crankshaft will rotate, a crankshaft weight constraint of 100 to 300 N was established.

Concepts and Selection

Several concepts were generated using a design matrix as seen in Appendix A. This was used to evaluate each concept in order to narrow down the best solution for each function, consisting of the mechanism’s movement and sensing position. Each concept was evaluated against several parameters. These involved first and foremost meeting the customer requirements, then minimizing the footprint, cost, and weight of the mechanism. The ease of manufacturing, feasibility of assembly, and the precision of the solution are other parameters we used for our evaluation. Using each of these parameters we assigned each concept a value. The concepts with the highest values were then designed further to create the Final Design.

Final Design

Following vigorous analysis of our concepts, we developed a Final Design. This design rotates the crankshaft, translates the camera beside it, and uses a rotary encoder to detect the mechanisms position. The horizontal position of the crankshaft allows the user to easily install and uninstall the crankshaft with respect to the manufacturing line. With this configuration, the design’s footprint, weight, and cost are minimized due to the use of smaller motors and fewer components. One major advantage to this design is the feasibility of manufacturing and assembly. Lastly, with the degrees of freedom split between the rotation of the crankshaft and the translation of the camera, the programming of the mechanism becomes much simpler.

Validation Results

Upon completion of our prototype fabrication, several critical tests were conducted in order to verify that all the engineering specifications were met. Many of these tests were incorporated directly into our LabVIEW user interface. Between measuring critical parameters regarding distances and angles, and visually verifying the quality of the output images, we determined that we satisfied each of the customer requirements for the machine.

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1. ABSTRACT

Many of today's engines require extremely smooth crankshaft main and pin finishes due to increasingly tighter bearing clearances and the use of thinner viscosity motor oils. If the polishing of the crankshaft mains and pins are not adequate, microscopic surface peaks can cause premature bearing failure. A new method has been developed to inspect surface finish using a blue light source and a camera. Our team was tasked to take this new method and build an automated machine to prove its capabilities. With this new method, it is proven that a crankshaft can be inspected accurately for a polished or non-polished analysis in under 36 seconds. It is also proven that this new inspection method is a more efficient method since it is able to inspect each crankshaft off the manufacturing line as opposed to the current method of inspecting only one in every 50.

2. PROBLEM DESCRIPTION

Currently, at many automobile engine crankshaft manufacturing plants, the surface finish inspection process of the pins and journals involves taking one crankshaft out of 50 made and measuring the surfaces' Ra, which is then correlated to the surface finish. This process is not only time consuming, but can also lead to a batch of 50 crankshafts having to be refinished. A new system, consisting of a camera and a light source, has been developed to inspect the surface finish. This system, instead of measuring the Ra and then correlating it to the surface finish, shines a blue light on the surface and looks at the reflection. Through the magnitude of reflected light it is possible to distinguish between an adequately finished surface and an unfinished surface [2]. Since the geometry of the crankshaft is complicated and there are several surfaces to inspect, our team was tasked by our sponsor, Dr. Hagay Bamberger of the Engineering Research Center, Reconfigurable Manufacturing Systems (ERC/RMS), to design a mechanism that would quickly and accurately move all of the pins and journals on the crankshaft in front of the camera for inspection. This process should take less than 36 seconds and allow for each crankshaft to be inspected as it comes off the line. This new process will ensure that any problems found could be fixed immediately, thus reducing time consumed and the possibility of having to refinish multiple crankshafts.

3. PROJECT REQUIREMENTS AND ENGINEERING SPECIFICATIONS

After reviewing the project description and meeting with our sponsor, we were able to identify the most important project requirements. These primary customer requirements are as follows:

- To create a universal mechanism that can inspect varying crankshaft sizes/geometries.
- To incorporate a camera and light source that both tracks and takes pictures of pin and journal surfaces.
- To design a mechanism that is both fast and accurate.

To better define the design goals, we constructed a Quality Function Deployment (QFD) chart to translate these project requirements into workable and quantifiable engineering specifications (see Appendix A). In the QFD the customer needs are listed in the left column and assigned relative importance ratings determined by our team. The top column contains the specific engineering requirements that are crucial to our design, all described by a unit of measurement and a target value or range of acceptable values. Above this column shows a correlation that exists between differing technical requirements. We then evaluated the correlation between the customer needs and the technical requirements by giving each correlation a value of 1, 3, or 9 depending on the strength of relationship. These values were then combined with the original importance ratings of the customer needs and a ranked list of technical requirements was created. These requirements will be considered while continuing to the next steps of the design process. Another important aspect of the QFD is the right column, where we analyzed how well existing competitive designs serve the customer needs and what can be improved upon. Most of the current methods of surface finish inspection involve manually testing the roughness with a stylus or laser, so the only competitive design we included in the chart was the ADCOLE 1000 Automated Roughness Average Tester [4].

The output of the QFD chart is a ranked list of the engineering requirements, with target values, and is summarized in Table 1, below:

Table 1: QFD chart results showing technical requirements with priority rankings

Priority Ranking	Technical Requirement	Units
1	Total inspection time to be less than 36 seconds	sec.
2	Camera centered with pins/journals within 10 mm	mm
3	Picture of each journal taken from same distance ±1mm	mm
3	Picture of each pin taken from same distance ±1mm	mm
5	Angle between the camera and light source fixed	degrees
6	Picture tracking	#
7	Weight of crankshaft to stay between 100 and 300 N	N

As Table 1 describes, our first priority is to keep the total inspection time to be less than 36 seconds. This time does not include set-up or breakdown of the process, but simply the time between when the start button is pressed and when the system comes to a stop. Our second priority is to keep the camera centered on the pins/journals within 10 mm. This is very important due to the fact that if the camera is not properly placed, the picture taken may be inaccurate and the test voided. Third, we must be careful to take each picture at a consistent distance from the surface. This is to keep the pictures in focus, as to allow the analysis to be done without any variations. Lastly, the angle of the camera and light source must remain fixed, we must keep track of which pictures are of which journals/pins, and we must specify the weight ranges of the crankshafts for our design.

The technical requirements above show that the most important design aspects do indeed cover the needs of the customer, which is a good indicator of a well developed QFD. These requirements will be taken into account as we continue the design process and move towards concept generation. The results of our analysis show that several aspects of the current competition can be improved upon, specifically the mechanism size, mechanism cost, and rate of inspection.

4. CONCEPT GENERATION

After we converted our customer requirements into quantifiable engineering specifications, we performed a functional decomposition for our design problem and brainstormed several preliminary concepts.

4.1 Functional Decomposition

The main function of our design is to position the distinct crankshaft main and pin surfaces in front of a camera for inspection. In order to better brainstorm the different ways of performing this task, we performed a functional decomposition to have sub-functions that are easier to deal with. Figure 1 below shows the diagram relevant to our design task. We determined that the main inputs for our system would be electricity to power the entire system, the crankshaft that is to be inspected, and specific user inputs such as the axial distance between each main and pin. The major outputs of the system are the images taken by the camera as well as the inspected crankshaft. Another output is energy loss, in the form of heat, from the motors. This heat will affect our motor mounts, as we would like to use rubber mounts to decrease vibrations, however these mounts will have to be resilient to any heat created by the motors. The main function of the design, as previously stated above, can be broken up into moving the crankshaft and/or camera to align the camera with the inspection surfaces, sensing the positions of the crankshaft and/or camera, and using the camera to take the images. In other words, we will need to first design the movement of the crankshaft and/or camera and light source, then decide how to sense when the correct position is present. Using the camera to take a picture simply involves programming, where our team will most likely use an Arduino, as this is the system we have the most experience using.

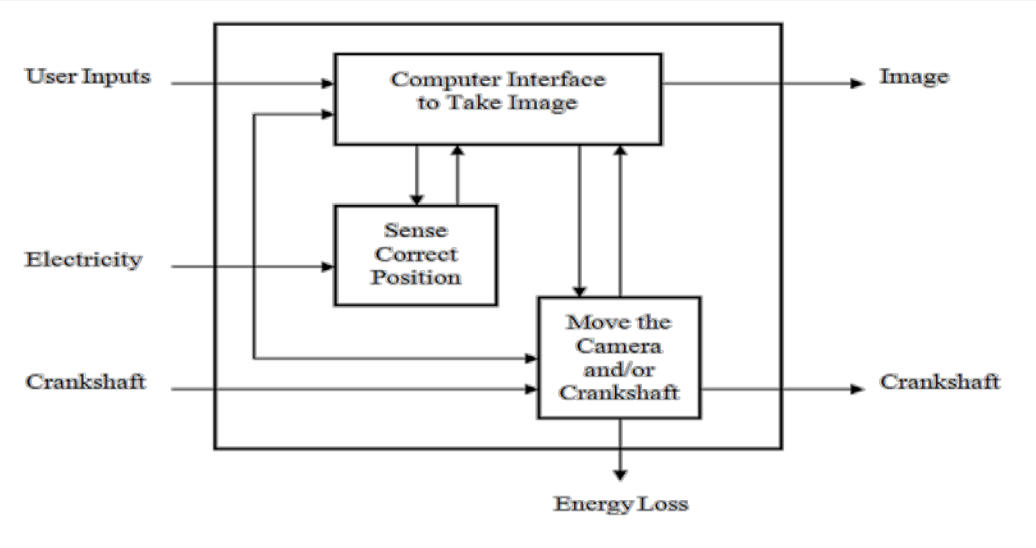


Figure 1: Functional decomposition of automated crankshaft inspection mechanism

4.2 Mechanism Movement

After we broke our main design problem into two tasks – moving the components and sensing correct positioning – we developed several preliminary design concepts. We brainstormed different ways to move the crankshaft mains and pins in front of the camera for inspection, keeping in mind the need to minimize inspection time. Three designs stood out to us as potential Alpha Design candidates, which are primarily different in the movement needed to take pictures at every inspection surface. Since two degrees of freedom (DOF's) are needed to position each main and pin in front of the camera for inspection, there are different ways to allocate them between either the crankshaft or camera and light source as summarized in Table 2 below. Concepts 1,2 and 3 are described in detail in this section.

It should be noted that our team did not pursue any mechanism designs utilizing only one motor. We believed that the cost of analysis work as well as the complexity of the programming needed greatly outweighed the cost of the second motor. One motor running both degrees of freedom would also wear out much quicker than if it were to only run one degree of freedom. Overall, a one motor mechanism is considered to be a feasible option, but not within the time constraints of our project.

Table 2: Movement needed by each mechanism concept

DOF	Concept 1	Concept 2	Concept 3	Concept 4
Translate Crankshaft	X			X
Rotate Crankshaft	X	X		
Translate Camera / Light		X	X	
Rotate Camera / Light			X	X

4.2.1 Concept 1: Shown in Figure 2, Concept 1 consists of a mechanism that has a continuously rotating crankshaft that translates horizontally in front of a fixed camera and light source for inspection. The main advantages of this design are that the crankshaft is positioned horizontally (the same as they come off of the assembly line) and that it would be very easy to install since it is simply rested on top of two supports that then rotate it. Furthermore, we would be able to guarantee that the angle between the camera and light source remains constant since they are both static in this instance. The major disadvantage of this concept is due to the horizontal translation of the crankshaft; it would require a large amount of floor space, more materials, large motors, and more general manufacturing. The inertia of the rotating crankshaft is also a safety concern that would need to be addressed.

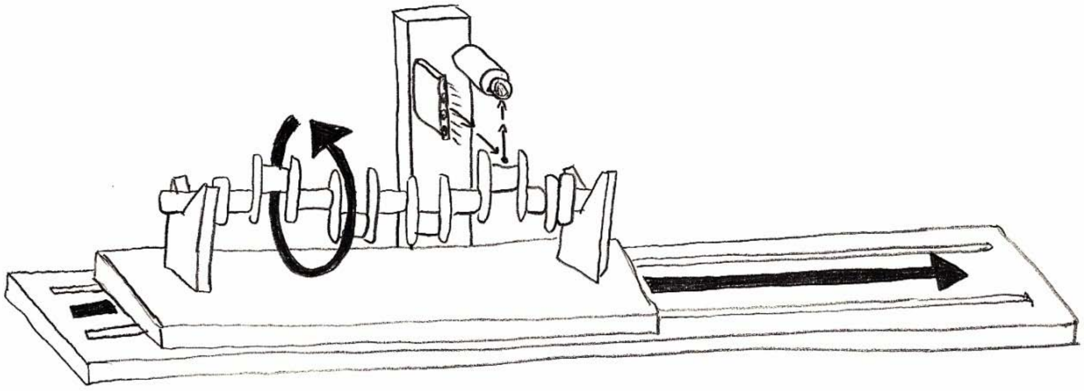


Figure 2: Preliminary sketch of Concept 1

4.2.2 Concept 2: Shown in Figure 3 (pg. 10), Concept 2 consists of a horizontally oriented crankshaft that continuously rotates while the camera and light source translate the length of the crankshaft for inspection. The main advantages of this concept are that the floor space needed for this design is half the size as Concept 1, and is positioned the same way as crankshafts come off of the assembly line for easy setup purposes. Smaller motors could be used with this design as well since translating a camera/light source would be much easier than translating the entire crankshaft and support. The main disadvantages of this concept are that the rotating crankshaft would raise a safety concern, wiring could prove to be an issue due to the movement of the camera and light source, and that the camera/light source mount could be unstable given the height of the mechanism.

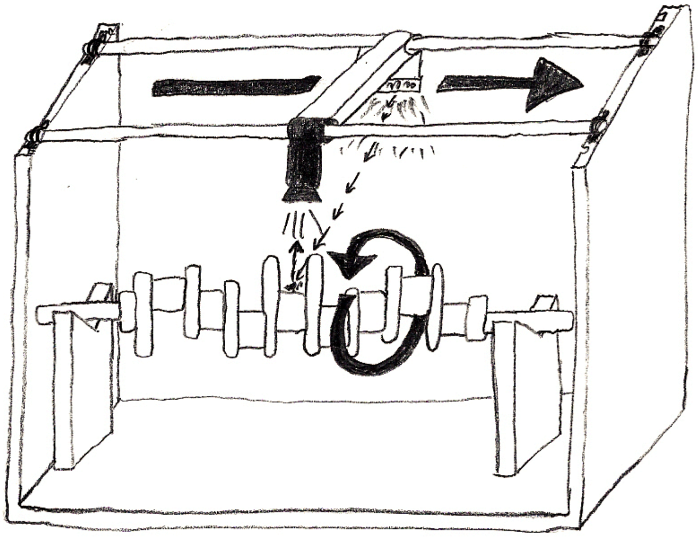


Figure 3: Preliminary sketch of Concept 2

4.2.3 Concept 3: Shown in Figure 4 (pg. 11), Concept 3 consists of the camera and light source combination both rotating and translating to each inspection surface along a stationary vertical crankshaft. The major benefit of this design is that the crankshaft can be mounted directly to the base plate, alleviating any safety concerns due to the inertia of a spinning crankshaft. The major disadvantage of this concept is manufacturing a working prototype; it is very involved and complex compared to the other designs. Furthermore, this design could not be easily integrated into the crankshaft manufacturing line and the crankshaft installation would be difficult and time consuming in comparison to simply resting a horizontal crankshaft on the supports in the previous two concepts. Due to its upright positioning, it is tall compared to its footprint. This could prove to be an unstable design, which is a safety concern. The camera mechanism would also be very heavy and would pose a need for a larger and more costly motor. Lastly, as with Concept 2, wiring could prove to be a design issue.

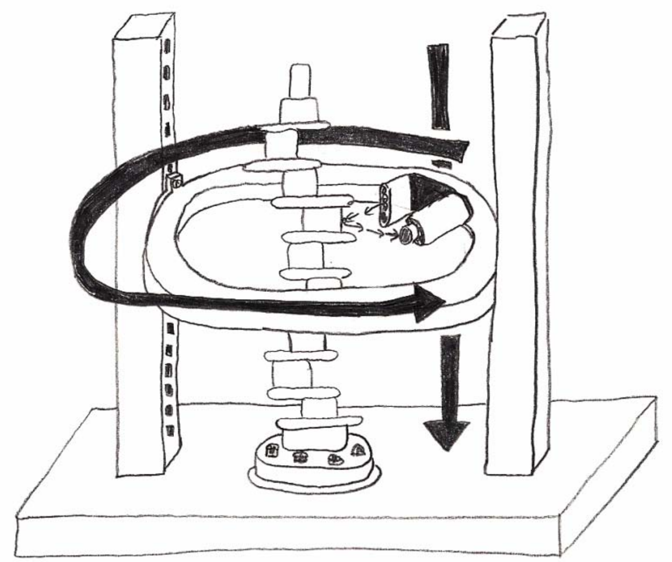


Figure 4: Preliminary sketch of Concept 3

4.3 Sensing

The other aspect necessary to execute our mechanism's function is being able to sense when the crankshaft is correctly positioned in front of the camera to take a picture. We determined two specific ways to accomplish this. One of these options deals with measuring the distance between the camera and inspection surface using a proximity sensor. The second option requires measuring the rotational orientation of the crankshaft using optical encoders. Both ways have certain advantages and disadvantages described below.

4.3.1 Proximity Sensors: There are a variety of proximity sensors that can detect the presence of objects in different ways. A few of these sensors we are considering are ultrasonic sensors, magnetic sensors, and infrared sensors shown in Figure 5. These sensors have two important characteristics we will be looking for. One, they must have a narrow beam width, which will be necessary to detect the position of each pin and journal bearing without being affected by the counterweights on either side. This width is about an inch so we will be looking for beam widths less than one inch. The second important characteristic is beam resolution. We need to have a beam that accurately detects the position of the rotating surfaces when they come within a specified distance of the camera. Each type has advantages and disadvantages that will be discussed in the following paragraph.

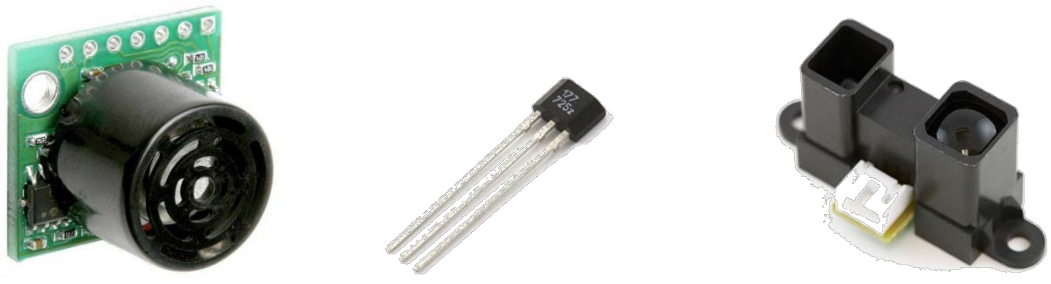


Figure 5: Ultrasonic (Left), Magnetic (Middle), and Infrared (Right) Proximity Sensors [14]

Ultrasonic sensors, like the one shown above, emit a sound wave and based on the reflected response can precisely determine the distances to objects [13]. There is generally a positive linear correlation between cost and range resolution for these objects. Beam width varies between each product according to cost and should not pose as much of a concern as even a $30 USD sensor has a width in the range we need. Regardless of the environment, these devices will accurately predict an object's distance within a reasonable price at a variable range.

Magnetic sensors, similar to the Hall-effect sensor shown above, output a voltage in response to a change in the magnetic field surrounding them. These sensors tend to have a small detection range (less than 2 cm) and require another magnet attached to the inspection surface for the field perturbation. These sensors have high resolution and inexpensive characteristics (about $1 USD). However, for the purpose of our project we feel that they would be disadvantageous for sensing the bearing surface location due to their small detection range. Placement would require additional components and interference would be another issue due to the small detection range.

Infrared sensors, similar to the one shown above, emit infrared light to detect distances to objects. There are a number of positive as well as negative characteristics associated with these sensors. Some negative qualities include inaccurate ranges, poor surface reflectivity, and ambient light interference. However, these sensors are low cost, have an extremely narrow beam width, and have a large detection range.

4.3.2 Optical Encoders: Optical encoders, specifically rotary encoders like the one shown below in Figure 6, utilize a light source and photo detector to determine an objects rotational position. These encoders are reliable, inexpensive (about $50 USD), and very accurate. For this idea to work we would somehow need to integrate the encoder onto each crankshaft that is input into the system. This process would require exact placement of each shaft relative to the encoder to develop an initial position. This could prove to be a problem concerning the 36 second inspection time.

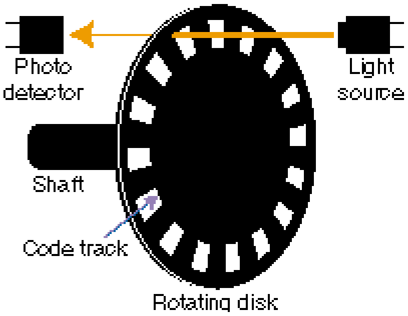


Figure 6: Absolute Optical Encoder [15]

5. CONCEPT SELECTION

In order to select the best design concept for our Alpha Design our team first looked at all the customer requirements to ensure that our design concepts meet all of them. While looking at the customer requirements we realized the need for a way to quantify the mechanics and sensors of each concept. To meet this need we created a design matrix (Appendix A) listing the two main systems in our design, the mechanism and the sensing. These systems were then broken down into lists of all of the ways to accomplish the system. Once each system was broken down into a specific set of options to perform each task we needed a set of parameters to weigh them against. The parameters involved meeting the customer requirements as well as meeting our own requirements in order to create a working prototype within the allotted time frame. These parameters included minimizing the footprint of the mechanism, minimizing the total cost, minimizing the total weight, the ease of manufacturing, the feasibility of assembling the mechanism, and the precision of the solution. Using each of these parameters we gave each option a value then we calculated a final value for each design solution.

Table 3 below gives an idea of how the mechanism design concepts stacked up against the parameters and each other. The values are based on a magnitude scale, the higher the value, the better the system. Since the camera translating and the crankshaft rotating scored a lot higher than all of our other design options our Alpha Design is based on these characteristics.

Table 3: Mechanism Concept Selection Results

System Mechanism	Value of Mechanism
Camera translate – Crankshaft rotate	96
Crankshaft translate – Crankshaft rotate	58
Camera translate – Camera rotate	54
Crankshaft translate – Camera rotate	46

The other part of our Alpha Design that we needed to select was how to sense if the camera and light source are lined up correctly with the surfaces we need to take an image of. Our team came up with five kinds of sensors that might work with this type of mechanism and again scored each sensor against all of the same selection parameters, excluding ease of manufacturing since we will purchase the sensors already manufactured. Our results, summarized in Table 4, show that the best type of sensor is a sonar sensor.

Table 4: Sensor Concept Selection Results

System Sensor	Value of Mechanism
Sonar	45
Infrared	39
Magnetic	27
Optical Encoder	27

With our mechanism selected and our sensor determined, we created our Alpha Design as described in the next section.

6. ALPHA DESIGN

Following some basic analysis of our concepts, we designed a preliminary Alpha Design. Using Appendix A we chose a concept that not only met the customer requirements as we were told, but also one that best met the parameters set up for concept selection. Seen in Figure 7 (page 14), it can be observed that the design is more closely related to Concept 2 as described above in Concept Generation. This design rotates the crankshaft, while translating the camera above it. The horizontal position of the crankshaft allows the user to easily install and uninstall the crankshaft with respect to the manufacturing line. With this configuration the footprint of the entire design is also minimized, as well as weight and cost due to the minimization of the number of components and the ability to use smaller motors. One major advantage to this design is the feasibility of manufacturing and assembly. This concept lends itself to simplicity and should take a minimal amount of machining and assembly time compared to other concepts. Lastly, with the degrees of freedom split between the rotation of the crankshaft and the translation of the camera, the programming of the mechanism also becomes much simpler.

As will be described in later sections, between Design Review #2 and #3, a new customer requirement was introduced. This prohibited us from supporting the crankshaft by its mains. For this reason, the design had to be reevaluated and redesigned. Although the final design is visually very different from the Alpha Design, the concept of the mechanism is the same. It is for this reason that the Alpha Design is described here.

6.1 Overall Design

Figure 7 below shows the overall Alpha Design. The crankshaft (A) is rotated in place while the camera and light source (B) is translated left to right. The camera and light source translation system is held up by four half-inch steel rods (C) threaded into aluminum block joints (D) at the top and put though the aluminum base plate (E), and then threaded into individual aluminum stands (F). The base plate supports the crankshaft rotation system as well as the crankshaft itself. Plexiglass (G) is then bolted to each side of the mechanism in order to provide rigidity as well as safety. This structure provides ample support for the camera and light source translation and the crankshaft rotation systems. Each system is explained further below.

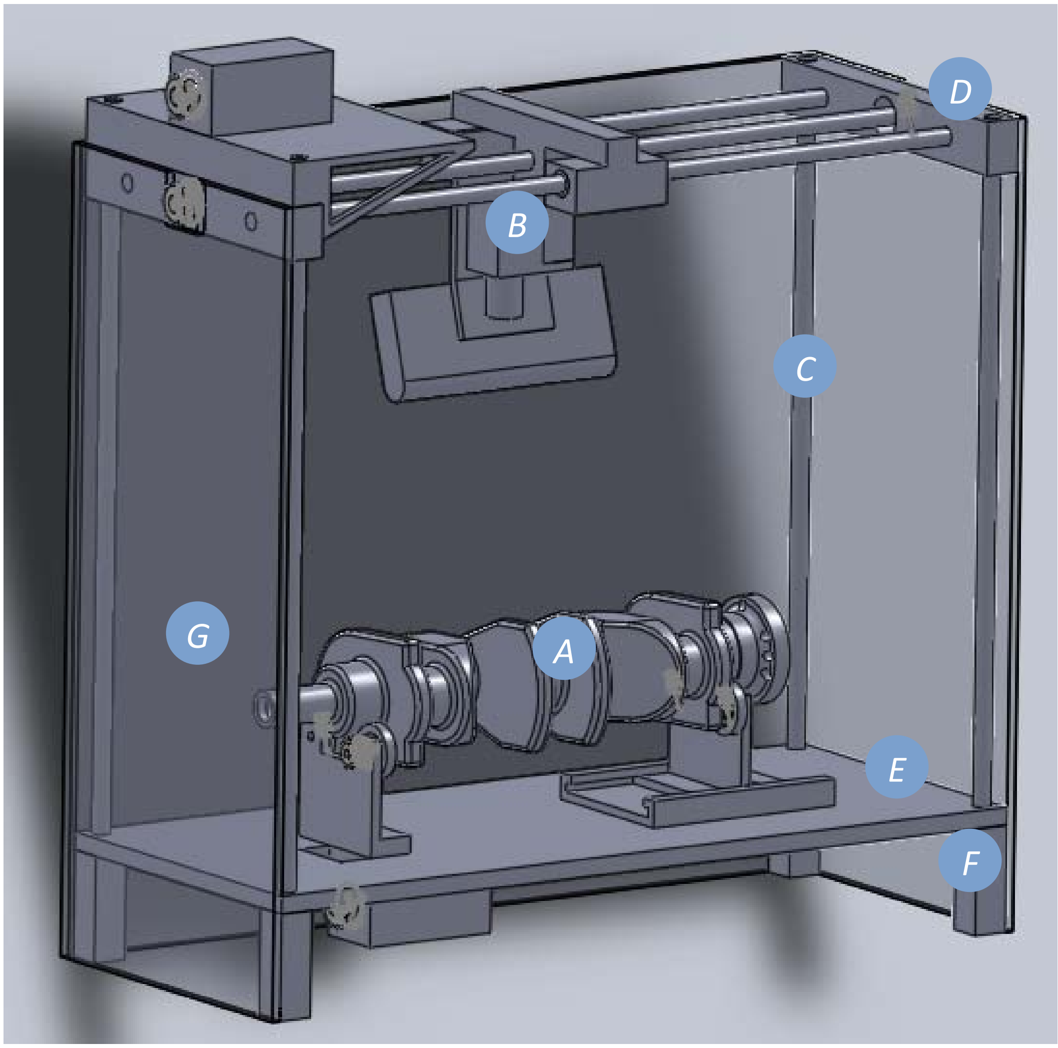


Figure 7: A full view of our Alpha Design

6.2 Camera Translation Drivetrain

Figure 8 (page 16) is a close up view of the drivetrain used to translate the camera. Though not obvious, it should be noted that the dowel attached to the lower gear (1) below is actually a screw. This screw is turned by a DC stepper motor (2) through a chain. The camera and light support (3) is fixed with a mated nut that allows the support to translate back and forth along the screw. Brass bushings, press fit into the support, slide along steel rods (4) to assist in this translation. Due to the fact that a stepper motor is used, each "step" can be interpreted into a translation distance of the camera/light support. Using these steps the position of the camera/light will be tracked. To ensure that the stepper motor torque does not affect the system a quarter inch thick aluminum plate (5) is used. This plate will allow enough rigidity to support the motor and any torque spikes.

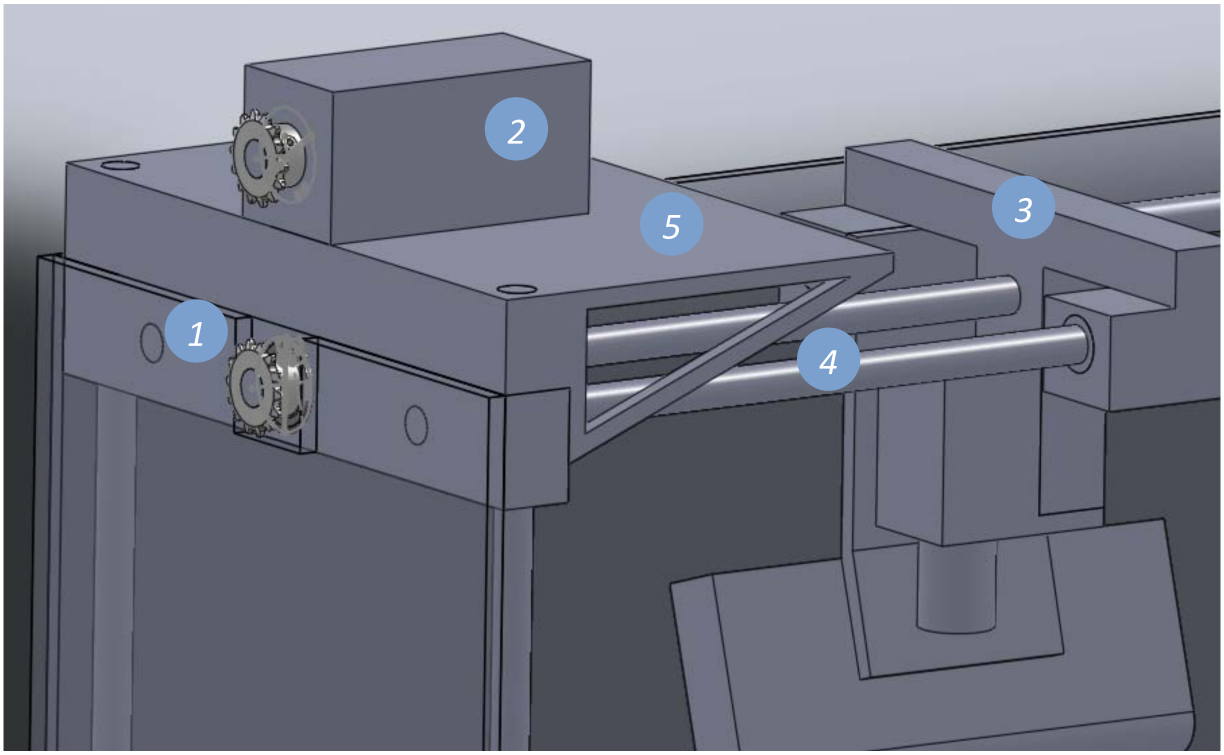


Figure 8: View of drivetrain used to translate camera

6.3 Camera and Light Source Mount

Figure 90 (page 17) below shows the mounting of the camera (6) and light source (7) themselves. The camera is attached to the center of the camera/light support (1) in order to be centered with the crankshaft surfaces. Next to the camera is also where the sonar sensor will be mounted. This will be used to track the position of the crankshaft. When the camera is to take a picture of a pin, the sonar sensor will wait until the pin is at its farthest position from the camera to tell the computer to take a picture. This positioning will ensure that no oil holes will be in the picture, which could skew the results, as oil holes are always drilled radially inward and are not seen on the inner side of the pins. The light source is mounted to a plate, which is then fastened to the far end of the camera/light support. The light source mounting plate is bent in a way that aligns the light source at the correct angle (approximately 20 degrees) to the camera and crankshaft surface. This mounting allows this angle to stay constant no matter where the camera is moved. Another possible design could be to purchase a longer light source that will cover the entire length of the crankshaft. This will simplify this aspect of the design and will allow for less moving parts, thus simplified wiring.

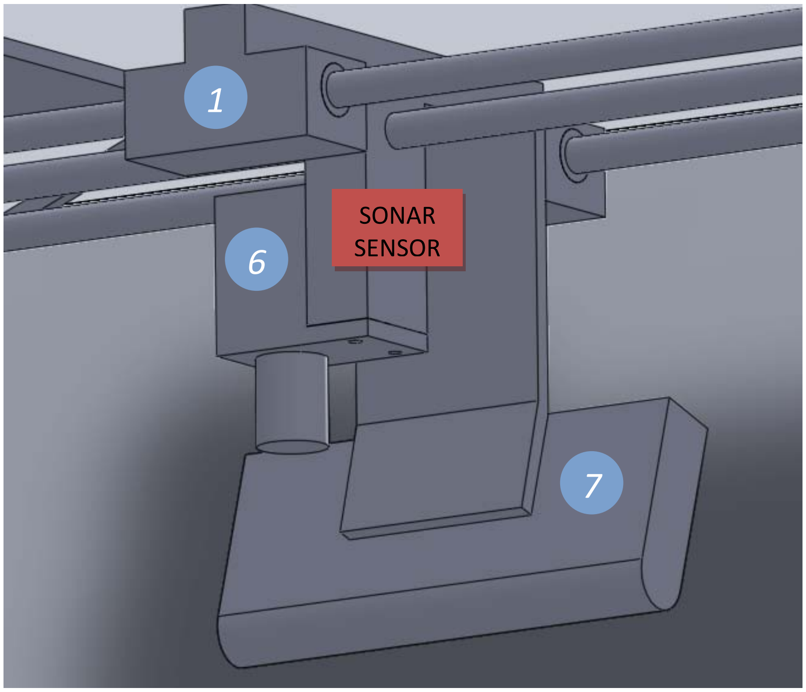


Figure 9: Mounting of camera and light source

6.4 Right Side Crankshaft Support

Figure 10 below shows how the crankshaft is supported on its right side. The outer main (8) of the crankshaft is supported by two bearings (9). The weight of the crankshaft is sufficient enough to keep it stable between the two bearings while spinning at less than 80 RPM. Each of these bearings has a rubber ring around them in order to avoid scratching of the mains and their surfaces.

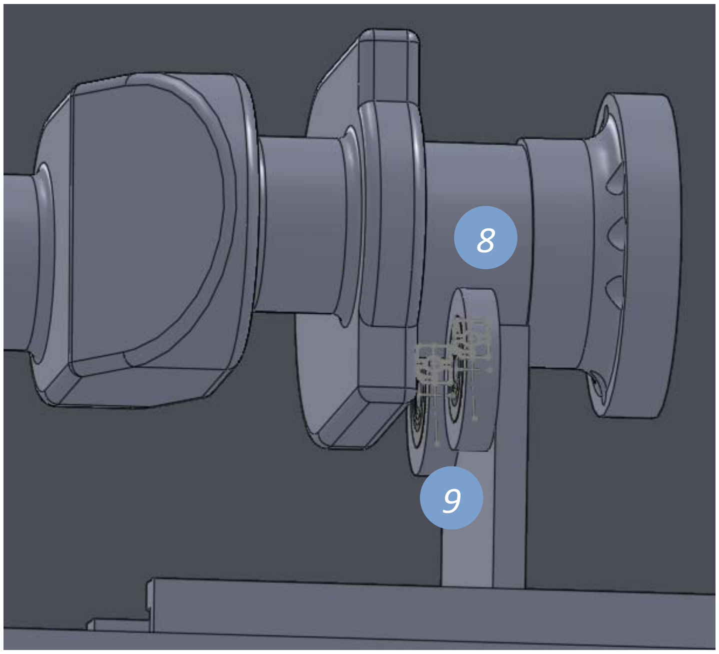


Figure 10: Right side of crankshaft support

6.5 Crankshaft Support Adjustment

Figure 11 below shows another angle of the right support as seen in Figure 10 (page 17). This aluminum support (10) is able to slide up or down the length of the shaft in order to receive various types of crankshafts. The support slides within an aluminum track (11) and is locked in place with set screws. With this type of adjustment nearly any crankshaft between the lengths of 0.4 meters and 0.8 meters can be inspected.

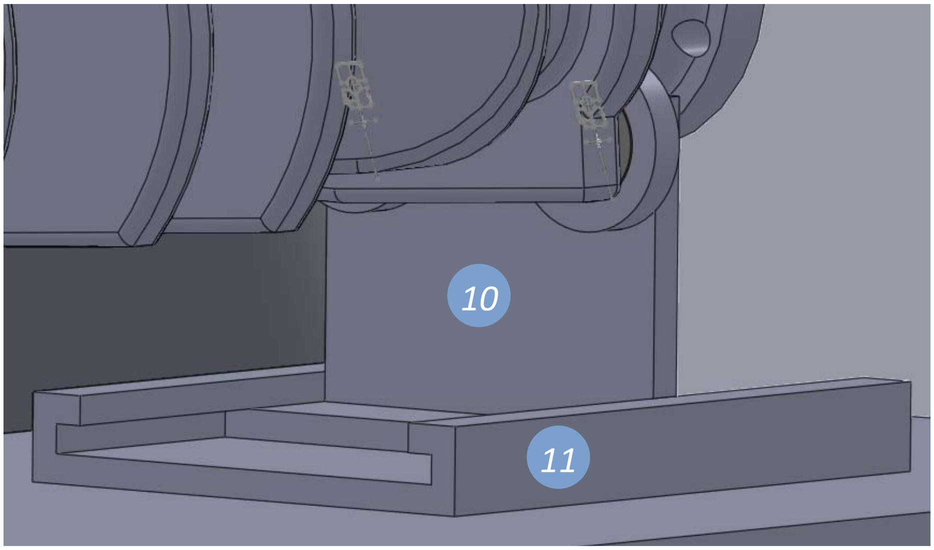


Figure 11: Second view of right side support

6.6 Left Side Crankshaft Support and Drivetrain

Figure 12 (page 19) shows how the left side of the crankshaft is supported, as well as how the crankshaft is rotated. The crankshaft is supported on the left side in the same way that it is supported on the right side (Figure 10 page 17); however, the left side has a driven bearing (12) instead of a free rolling bearing. A motor (13) is mounted to the bottom of the base plate (14) through rubber mounts to decrease vibrations. This motor spins a gear (15), which connects to the gear (16) on the driven bearing (12) through a chain. This driven bearing then translates the torque from the motor to the outer main (17) of the crankshaft and the crankshaft begins to spin. The free rolling bearing and driven bearing are held at the same width apart as the right side rolling bearings as well as through a similar support (18). As with the right side, the weight of the crankshaft is sufficient enough to keep it stable under 80 RPM. Because this design uses a sonar sensor to detect the position of the pins, the system used to rotate the crankshaft is much simpler and needs no feedback controls. Thus a simple DC motor can be used for this application.

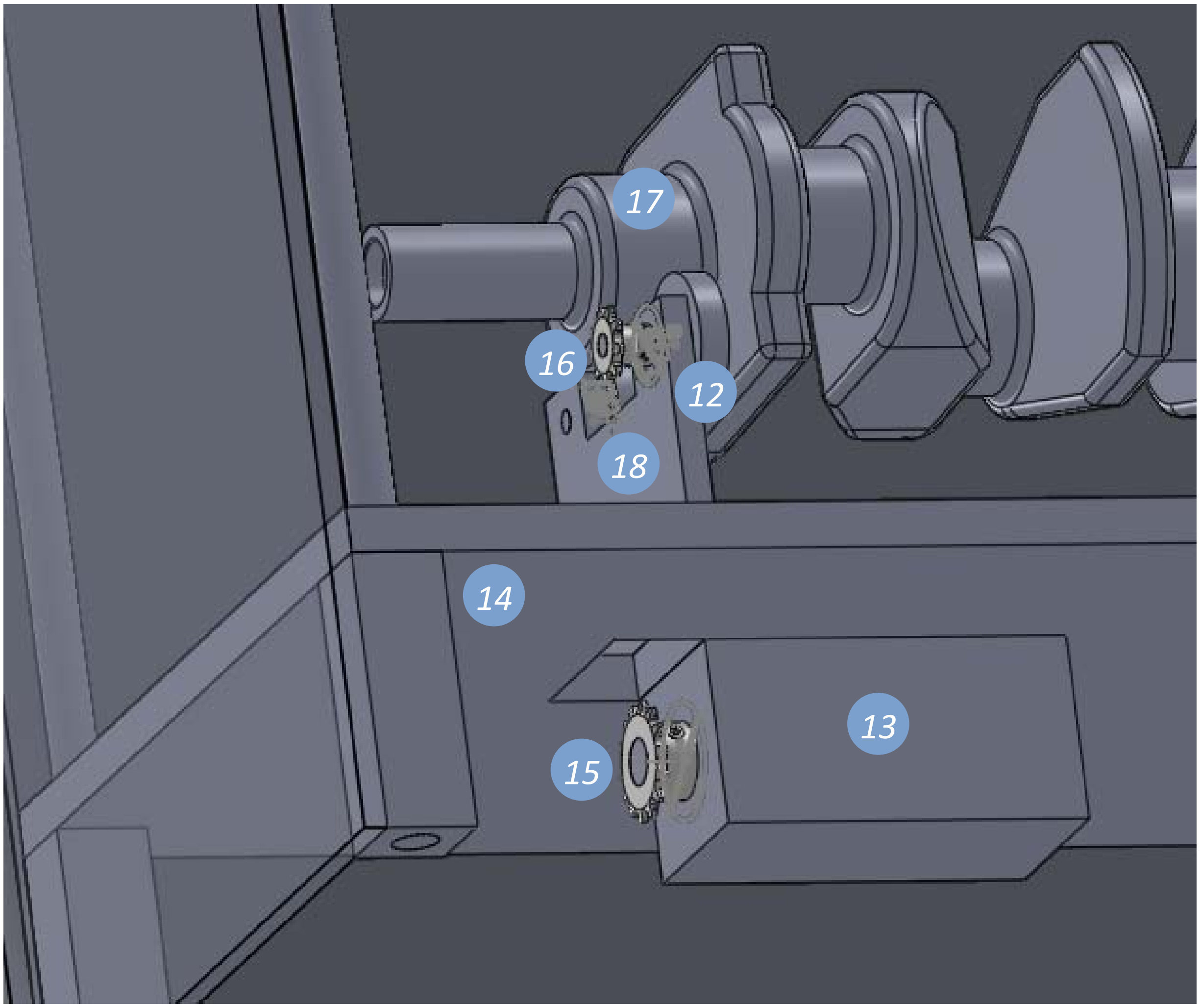


Figure 12: Left side support and drivetrain for crankshaft

7. ENGINEERING DESIGN PARAMETER ANALYSIS

The engineering analysis we decided to use after Design Review #2 to evaluate, refine, and optimize our alpha design for Design Review #3 has been implemented. The improved design has changed considerably since our alpha design but nevertheless still required important engineering logic as the basis of our decisions. This section will describe the steps and analysis we took to arrive at our final design. In particular, we will mention how we selected components such as motors and the encoder as well as how we knew the provided components (donated by our sponsor and outside resources) would meet engineering specifications.

7.1 Initial Analysis

A simple analysis was conducted as to ensure that our mechanism could easily execute its inspection process in the allotted time of 36 seconds. For 30 RPM and a camera translation time from surface to surface of 0.5 seconds we can meet the required time constraint. With this RPM, one full rotation of the crankshaft will occur in 2 seconds. This is the maximum time the camera will wait to take a picture assuming a surface had just passed the optimal position. There are approximately 10 to 12 bearing surfaces on a crankshaft. At maximum it will take 2 seconds for each surface rotation, plus the 0.5 seconds for each surface translation. For 10 crankshaft surfaces, it will take a total of 25 seconds for rotation and translation. An added spin up time of approximately 2 seconds and spin down time of 4 seconds gives us a total time of 31 seconds. During the reset time of 4 seconds the camera and light source will have ample time to return to its home position; thus, this “homing” time does not affect the total inspection time. With the largest possible crankshaft, a V-8 crankshaft with 12 surfaces, two more surfaces are added. This requires us to take two more pictures and move two extra translations for an additional 5 seconds. The total inspection time for a 12 surface crankshaft is then 36 seconds. This is the maximum time for our inspection process and is how we determined the minimum rotational speed of 30 RPM. This analysis can be seen below in Table 5:

Table 5: Sample time analysis for a 12 surface crankshaft

	Spin Up	**Take 12 pictures**	**Reset**	**TOTAL TIME**
Time	2 sec	30 sec	4 sec	36 sec

This analysis is extremely conservative, using the slowest possible RPM speed of the crankshaft to see the worst-case scenario. Should any unexpected issues arrive, we will be able to increase the RPM’s substantially in order to meet the time constraint.
Crankshaft inertias as well as other energy losses are other important factors that will be analyzed prior to Design Review #3. From this analysis we will be able to select a motor that meets the required torque and speed specifications we have determined.

7.2 Selected Components

Engineering analysis formed the basis of our component selection. These components include the crankshaft motor, camera and light source motor, encoder, and other mechanical accessories. For each component analysis we first looked at our engineering requirements to meet customer demands. In Table 1 on p. 9 the technical requirements show our highest priority is meeting the 36 second inspection time. Using this 36 seconds we determined in Table 5 that the worst case scenario requires us to spin the crankshaft at a minimum of 30 RPM. This value as well as the other allotted times were used as a standard to select components. We also made sure to design for the largest crankshaft, which according to Table 1 would be 300 N (or about 30 kg). In each analysis we took a conservative approach and designed for a safety factor of at least two. In the following sections we will state all assumptions we have made and support our decisions for selecting each component.

7.2.1 Mechanical Accessories: First and foremost we need to support the selected mechanical accessories that would be used by the motors. Some of these accessories important to the analysis of motor selection include the power screw components (nut, screw, slides, support) and head/tail stock components. The head and tail stock components were provided by QPAC micropolishing and analysis of these provided components can be found in section 9.2.1. Based on prior machining fundamentals, experience, and availability we selected our materials, nuts, and screws. We supported our selections through use of free body diagrams as shown in Figure

13, 14, and 15, below. Materials were also selected through use of the Cambridge Engineering Selector and MSC ADAMS. Each component will provide the structural support we need for each loaded crankshaft. Analysis has been completed on the maximum deflection of each sliding rod support and can be shown in Figure 18. Derivation 1 in Appendix B provides how we calculated a maximum deflection of 1 mm for each sliding rod.

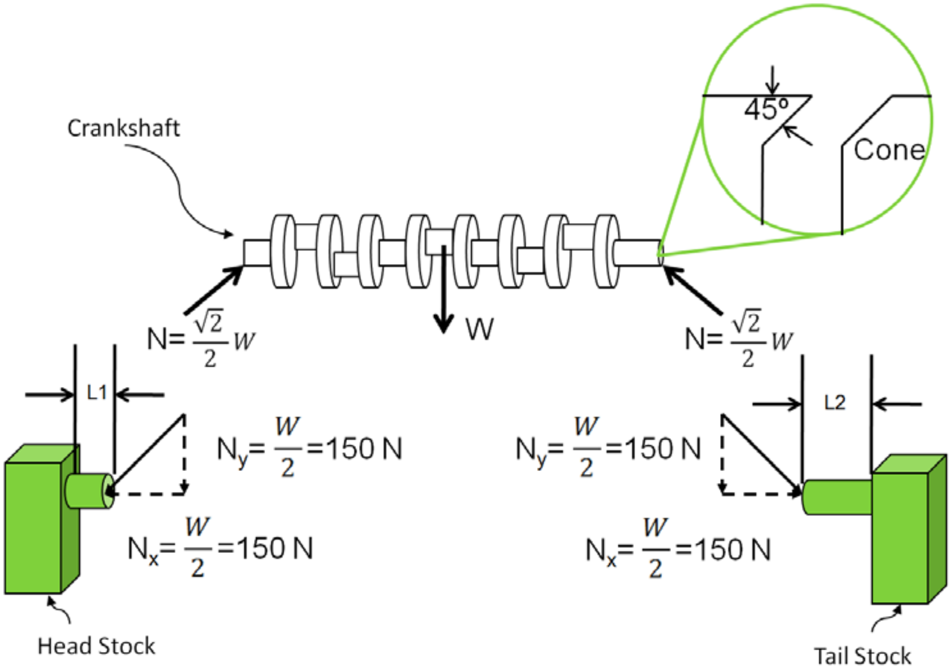


Figure 13: Free Body Diagram of a Crankshaft in Static Equilibrium

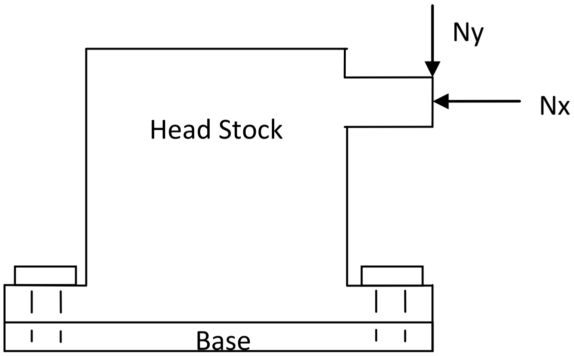


Figure 14: Head and Tail Stock Structural Analysis

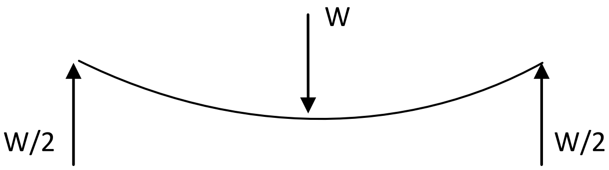


Figure 15: Free Body Diagram of Power Screw Mechanism at Position of Max. Deflection

7.2.2 Motor Selection: From our alpha design we have determined there are two important kinematic mechanisms that need to be met. One degree of freedom involves rotating the crankshaft and the other entails translating the camera and light source. Given the load specifications for each degree of freedom we can determine the minimum torque and speed required to meet our technical requirements. We will show how we determined these requirements for each motor. Then we will discuss final parameters we used to make a selection from the list of acceptable motors.

7.2.2.1 Crankshaft Rotation-A minimum torque of 3.35 Nm (29.7 inlbs) is needed to rotate the crankshaft so that we meet the design parameters discussed. Originally, we designed to allow for rotation on two of the crankshaft's main bearings. However, since speaking with our sponsor we have learned this is not acceptable. As you will see in our final design we have decided to rotate the crankshafts through axially tensioned cones. Regardless, we need to select a motor that will meet the 2 second spin-up time, overcome the crankshaft inertia, and bearing friction.

Determining the moment of inertia of a crankshaft can be very complex. For our analysis we decided to simplify the crankshaft's geometry to be a hollow cylinder with a mass of 30 kg (66.1 lbs). We used the crankshaft provided by our sponsor and measured an outer diameter of about 0.1524 m (6 inches) and used an inner diameter of 0.0508 m (2 inches). The purpose for simplifying the crankshaft as a hollow cylinder rather than a solid one is to be conservative in our approach. Using the equations from Derivation 2 in Appendix B we determined the crankshaft's mass moment of inertia to be at most 0.097 kgm^2 (331 in^2lbs).

Using the crankshaft's moment of inertia we used the equations provided in Derivation 3 in Appendix B to determine the minimum torque required to accelerate just the crankshaft. From our analysis we determined a minimum torque of 0.152 Nm (1.35 inlbs) to overcome the crankshaft's inertia assuming no friction.

Bearing friction torque plays an important role in rotating the crankshaft. Two important types of bearings to consider in our design are the radial ball bearings, and the thrust bearing. Each radial bearing produces a maximum torque of about 0.0076 Nm (0.067 inlbs). This analysis as seen in Derivation 4 in Appendix B is based on the 150 N axial load analyzed in Figure 16 for a 300 N crankshaft. The frictional coefficient of 0.004 is based on a common single row radial ball bearing reference. The thrust bearing plays the most significant effect on the total torque required to rotate the crankshaft. Given that we exert the maximum amount of axial force from our pneumatic cylinder (444 N) and that the frictional coefficient of a dry ball bearing is 0.4 the maximum friction torque produced is 3.35 Nm (29.7 inlbs). Then using these values and the fact that we have 3 radial ball bearings within our support mechanism we determined a minimum torque of 3.54 Nm (31.3 inlbs) is required to rotate the crankshaft while axially loaded.

Using this minimum torque value and a minimum of 30 RPM we began looking at a variety of motors that met our requirements. In Table 6 on page 23 a list of motors, their respective torque/speed characteristics, safety factor, cost, part number, and supplier can be found.

Table 6: Motors that meet minimum requirement of 30 RPM and 31.3 inlbs of torque

Motor Type	Torque (inlbs)	RPM	Safety Factor	Cost	Part #	Supplier
DC Gearmotor	62	43	2	$258.71	016-101-0037	Bison
DC Gearmotor	56	60	1.8	$297.96	6470K72	McMaster
AC Gearmotor	32	35.1	1.0	$48.48	6142K48	McMaster
Stepper Motor	31.7	100	1.0	$95.00	SM60-86	Excitron
DC Gearmotor	**106**	**82**	**3.4**	**FREE**	**FPG-6004PA1001**	**Auto Parts**

As you can see in Table 6 we selected the DC gearmotor that is found at any AutoParts store (generally about $62). Thanks to another contributor we were able to acquire this motor as a donation. However, we would have still purchased this motor because it meets our minimum specifications with the largest factor of safety. Had we found another motor that met the requirements with a similar factor of we would have used cost to differentiate the two. Finally, the last parameter used to select a motor would be availability. Fortunately, each motor in Table 6 was available and in stock for a delivery within one week of purchasing. The selected Bosch 12V FPG DC Gearmotor can be seen in Figure 16 below. The engineering drawing, characteristic curve, and connection diagram of this motor can be found in Appendix B.

Figure 16: Bosch 12V FPG DC Gearmotor

7.2.2.2 Camera and Light Source Translation- A minimum torque of 0.23 Nm (2.06 inlbs) is required to translate the camera and light source each step. The analysis for this mechanism depends greatly on the load we are translating as well as the mechanical accessories we selected. The camera, light source, and plates are the load (F) which is being translated by a power screw mechanism. Figure 17 on p. 24 shows a free body diagram demonstrating the force required to move this load using a power screw.

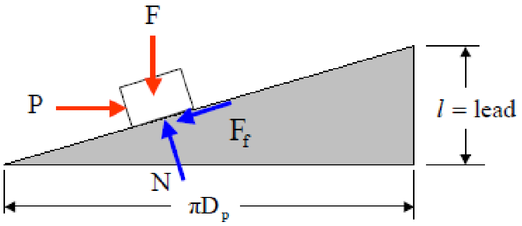


Figure 17: Power Screw Free Body Diagram

Each translation must move the load approximately 1.5 inches in about 0.5 seconds as we determined in Table 5 on p. 20. To achieve this translation, we determined that our motor must provide 1800 RPM. Based on our selection of a 0.5 inch diameter, 32 inch length, 0.1 inch threaded screw and two 0.5 inch diameter, 32 inch length, AISI 1566 Steel camera slider supports we determined the minimum torque required to move our estimated load of 10lbs. We also assumed a coefficient of friction of 0.25 between a steel screw and nut. First, we determined how much torque the screw required to overcome its inertia. Then using our load characteristics and power screw analysis we found how much torque is required to move the load. Finally, we added the two torques together and came up with a minimum torque requirement of 0.23 Nm (2.06 inlbs). Our in depth analysis can be found in Derivation's 5 and 6 in Appendix B.

Just as we did for our motor selection process for the crankshaft application, we compared different stepper motors using torque and rpm as key parameters and summarized our findings in Table 7 below:

Table 7: Stepper Motors that meet requirement of 1800 RPM and 2.06 inlbs of torque

Torque (inlbs)	RPM	Steps/Rev	Safety Factor	Cost	Part #	Supplier
4.69	3000	200	2.3	$198.70	6134K82	McMaster[19]
7.81	3000	200	3.8	$216.53	6134K84	McMaster
4.1	1725	200	2	$39.00	SM42-47	Excitron [20]
8.75	**6900**	**200**	**4.2**	**$69.00**	**SM60-45**	**Excitron**

The motor option displayed in bold in the table above shows the motor we determined to be the best option for translating the camera and light source. This Excitron SM60-45 stepper motor's torque requirement has a safety factor of more than 4 and also meets the speed requirement. A picture of our selected motor is shown in Figure 21 on p. 29. In order for us to properly control the motor and ensure that it syncs with our LabVIEW user interface, we also decided to purchase the motor controller/driver shown in Figure 18 and 19 on p. 25. An engineering drawing of the selected stepper motor and driver connection diagrams can be seen in Appendix B.

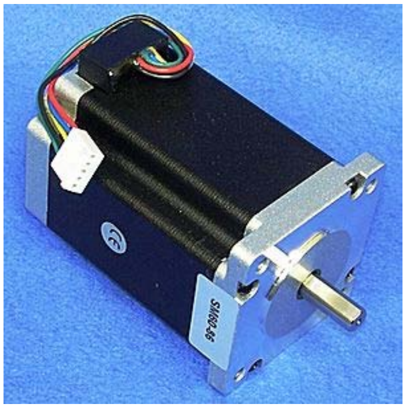


Figure 18: Excitron SM60-45

Figure 19: 10A-TTL-3SW Driver/Controller

7.2.3 Encoder and DAQ Selection:

We selected our optical encoder based on two conditions. First, that we should not produce more samples than what can be recorded. Second, that the resolution of encoder be enough to accurately predict the position of the crankshaft bearings within 0.5°. Based on these conditions we needed to first determine the sampling rate of our Data Acquisition unit (DAQ). Our sponsor, through the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS), was able to provide our team with a National Instruments NI USB-6251 BNC DAQ. This DAQ is essential for us to control the crankshaft dc motor and take inputs from the optical encoder through our LabVIEW user interface. We determined the DAQ has two 80 MHz counters. A picture of the donated DAQ unit is displayed in Figure 20 below:

Figure 20: Picture of the donated NI USB-6251 BNC DAQ unit

To meet our requirement of a 0.5° resolution we needed to have an encoder with at least 720 counts per revolution (cpr). US digital provides incremental encoders that have 500, 552, and 1000 cpr. Thus, we selected the 1000 cpr incremental encoder. The reason for selecting an incremental encoder is because we only want to know the relative positioning of crankshaft after we hit start. We will use one of the counters on the provided DAQ to count each rising edge of the pulse train sent to it by the optical encoder. Based on the 1000 cpr and the basis that we will rotate the crank at close to 30 rpm this translates into 500 Hz. This sampling rate is approximately a factor of 10^3 Hz less than the amount we will be producing. A picture of our selected optical encoder from US Digital can be seen in Figure 21 below.

Figure 21: Optical Encoder

7.3 Provided Components

Including the DAQ already mentioned, the following components have been provided. The following sections will support each donated component's function and show the engineering logic that would have been completed had we needed to select them.

7.3.1 Head and Tail Stock:

The head and tail stock was donated by QPAC Micropolishing and is the basis of our crankshaft support redesign. It is responsible for locking the crankshaft into place using a pneumatic cylinder as well as by rotating the crankshaft actuated by the DC motor. The head and tail stock are industrial grade equipment and their structural integrity was confirmed by our main contact at QPAC. This equipment is used for the same functionality as needed by our project in industry, so we are confident that it will withstand all loads from our tests.

7.3.2 Pneumatic Cylinder:

Attached to our donated tail stock we have a Festo Pneumatic Cylinder. Unfortunately, a part number is not provided with the supplied component. However, based on the approximate dimensions as well as certain characteristics we are able to analyze the potential axial load. Provided the two air flow hoses protruding from the cylinder we can assume it is double-acting. This mean that air must be supplied in the direction you want to move the piston. In Figure 22 on p. 27 is a 2-D diagram of a double-acting pneumatic cylinder. Attached to these tubes we have a mechanical actuator or flow switch. This mechanism says it is rated to 175 psi. Provided this parameter and the assumptions that we have a 1inch bore, and a ½ inch rod we can determine the maximum axial load to be 458 N (103 lbf). The equations used to produce this result can be seen in Appendix B Derivation 8. Using the free body diagram shown in Figure 16 we know that all we need is 150 N (33.7 lbf) axial load to keep the crankshaft in a stable configuration. Provided this load we can calculate the minimum pressure needed to be 394.4 kPa (57.2 psi). This calculation can also be seen in Appendix B Derivation 9. To avoid needless compression we will only supply 620.5 kPa (90 psi) to the cylinder which correlates into a safety factor of 1.5.

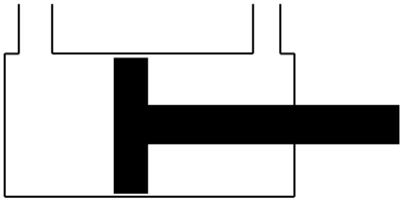


Figure 22: Double-Acting Pneumatic Cylinder

7.3.3 Camera:

We were fortune to have been donated a Pulnix TM4200 CL camera from our sponsor to use as our inspection camera. A photograph of this the provided component can be seen below in Figure 23.

Figure 23: Pulnix TM4200 CL Camera

One critical assumption our team made when incorporating a continuously rotating crankshaft into our final design was that the camera's shutter speed was sufficient to take clear pictures of the inspection surfaces. If the shutter speed was too slow, there would be blurry pictures that might affect the surface roughness readings, thus making our design inadequate. The camera that we will be using has a shutter speed of 1/16,000 sec, however, which is twice as fast as production cameras used to take sharp photographs of very fast subjects, such as hummingbirds, planes, and sporting events [17]. Our crankshaft will only be spinning at a rotational speed of 30 rpm (180°/sec), and after multiplying this by the camera's shutter speed we determined that the crankshaft will only rotate 0.01° during the shutter time. Therefore, we are confident that this will not present a problem when inspection each journal and pin surface.

7.4 Design Analysis:

While looking at some of the design parameters for our project we went to a few programs for additional assistance. We used the CES software provided by The University of Michigan to help narrow down what materials we should build some of our important components from. Using this software we were able the use engineering means to choose the right material rather than just our teams combined knowledge from past experience. We also used another program called SimaPro to gain a better understanding about how our design will affect the environment and its surroundings. This program asked us to look at more than just our project but how our project will affect others in the future. One final feature that was explored during our analysis was the safety of our design and how safe others will be when using it. We looked at all aspects of the design to ensure a safe and effective approach to designing our machine. For more details of the computer results see Appendix D.

8. FINAL DESIGN DESCRIPTION

After meeting with our sponsor and presenting our design, a new customer requirement was given: there is to be absolutely no contact with any of the main or pin surfaces. This new requirement presented a huge problem for us since most of our current design concepts were using the mains as our means of support. Our Concept Three was then our only option but our team decided to come up with a new design that used some of our previous alpha design ideas and still met all of the customer requirements. Our newest design concept started like this:

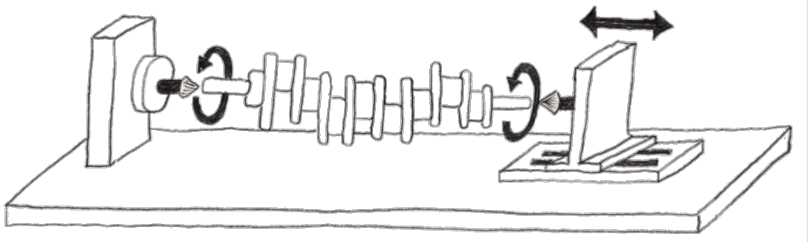


Figure 24: Our newest design concept

Once we had made sure our sponsor was ok with this method of rotating the crankshaft we then adapted our camera slider and support system to work into our full design of our prototype.

8.1 The Design of our Prototype

Figure 25 below shows the final design we will be using to build our prototype. Given our new method of supporting the crankshaft by its ends we designed our system to have a driven support shaft. This allowed us to both support the shaft and rotate it without touching any of the mains or pins. With our new design we found it to be smarter to place the camera next to the crankshaft rather than above it. We are still able to use the same camera slide support system that we designed for our alpha design. Finally with the new design we changed from a solid steel plate to a platform of boxed steel tube frame. This was mostly due to weight of the components and ease of manufacturing. Next we can get a more detailed look at each of the system components.

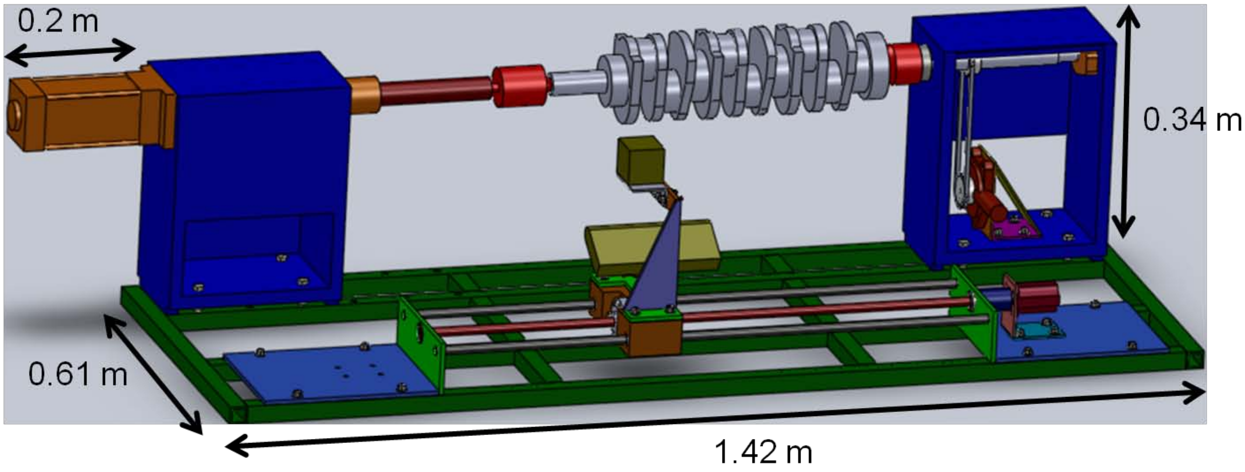


Figure 25: The final design of the prototype

8.2 The Camera Slide Setup

To meet all of our customer requirements we set up the camera on a slider that moves right to left due to a rotating acme screw and nut system. Figures 26, 27 and 281 on the following pages, shows how the camera and light source are attached to the slider mechanism. The camera is on a sliding and rotating plate, made of welded aluminum, and the light source is on a pivoting platform, made of welded aluminum. Both of these support systems are there to make sure the camera angle and light source angle stays fixed and focused on the crankshaft surfaces. The camera support bracket is made of aluminum plate that has been welded into a sturdy support for the camera. The camera support bracket is attached to the top of the main slider unit. The main slider unit will be made from aluminum block and machined to accept the nut and flange that mate to the acme screw along with the two slider bushings that support the camera translation. The sliding camera supports and the acme screw are mounted into aluminum plates that are attached to the base on either end of the sliders. The two sliders are made from steel rods and press fit into the aluminum plates on both ends. The acme screw is attached to a stepper motor using a rigid collar. The stepper motor will be able to communicate the position of the camera to a computer based on the number of steps the motor has moved. Once the computer tells the motor to turn a set number of steps the camera will be positioned correctly to take the image and will wait to be told by the computer to take the image until the optical encoder on the driven shaft says the crankshaft is in the correct position. Several things from our new setup have changed from our alpha design. The camera now takes the image from the side of the rotating crankshaft as opposed to above it. This keeps the center of gravity of the design down making the system more stable and easier to integrate into a final design. Also our camera motor is now in direct line with the rotating shaft which helps in packaging and it reduces components. Also to note in the final design, our camera and light source now have adjustability built in.

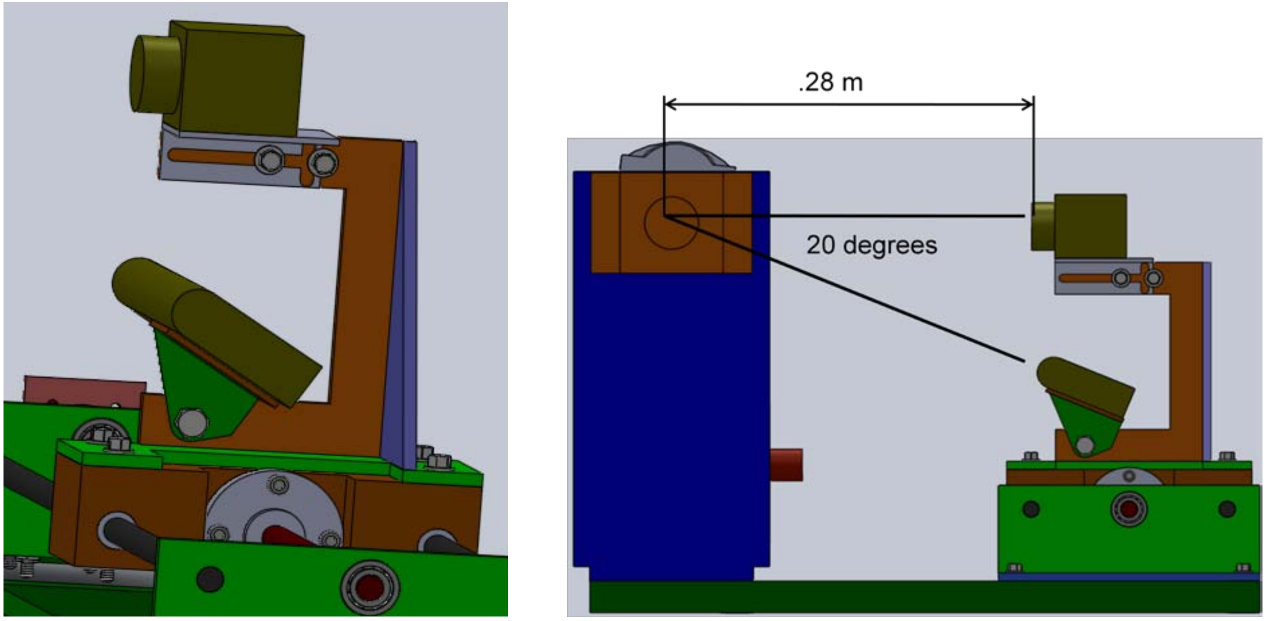


Figure 26: Setup of the camera, light source, and slider mechanisms

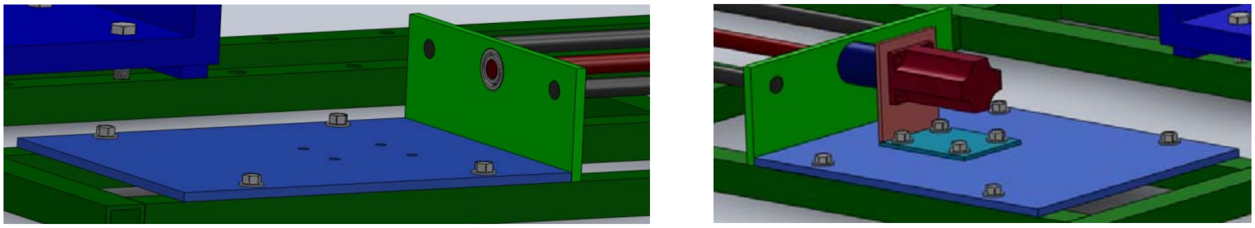


Figure 27: The camera slider end support without a motor (LEFT) and with the motor (RIGHT)

8.3 The Crankshaft Rotation Setup

As mentioned above we will use a conical support structure to support and rotate the crankshaft. We will be using donated materials from QPAC to support our conical shafts. Shown in Figure 28 below, the driven support shaft, made of precision ground steel, will be supported on both ends by roller ball bearings. On the end of the shaft with the cone there is a thrust bearing which allows the shaft to rotate freely when a crankshaft has been loaded onto the cone. When a crankshaft is loaded onto the cone there will be around 90 psi of pressure pressing the cone against the wall of the bearing support so the thrust bearing will remove the metal on metal friction that would otherwise slow the system down. On the far end of the shaft is a locking collar that will prevent the shaft from sliding out of the support bearing. Also on the precision ground shaft is a 23 tooth sprocket that is connected to another 23 tooth sprocket that is on the motor output shaft. These sprockets are connected using an ANSI 25 chain. This chain and sprocket system is how the crankshaft will be rotated into position for the camera to take the correct images. The motor is connected to the crankshaft support system by using an aluminum bracket that has been bolted to the bottom of the support structure. The last item that is connected to the shaft is the optical encoder. The optical encoder will be sending signals telling the computer what position the crankshaft has been rotated to. Using this rotating shaft design it is beneficial to use an optical encoder rather that the sonar sensor which we had chosen previously since the sonar sensor is easier to integrate and will be more accurate once programmed correctly. Also to note with the large end supports for the crankshaft the whole mechanism is much bigger and heavier than our previous design.

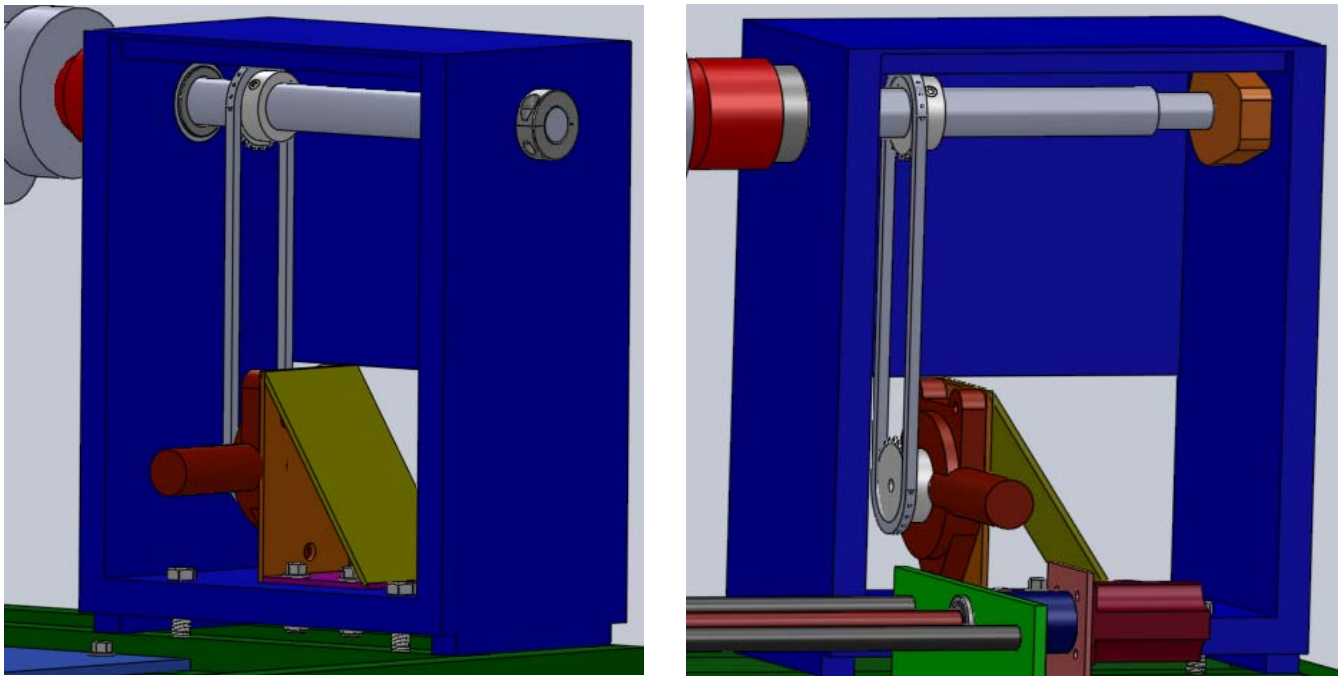


Figure 28: The driven end of the rotating crankshaft setup

On the free spinning end of the rotating crankshaft setup is a similar conical shaft that allows the crankshaft to rotate but this shaft is also connected to a pneumatic cylinder. The pneumatic cylinder will be what is used to clamp the crankshaft in place during the rotation process. The pneumatic cylinder can provide up to 175 psi of clamping force but we will only be using 90 psi.

The pneumatic cylinder can extend out three inches (shown in Figure 16 below) which allows for several different crankshaft lengths. Since we discovered that there are crankshafts that are different in length by more than three inches we also designed in three sets of hard adjustment holes. These holes, shown in Figure 30 below, will allow the setup to move the free rotating end inward or outward to allow for any length crankshaft to be inspected.

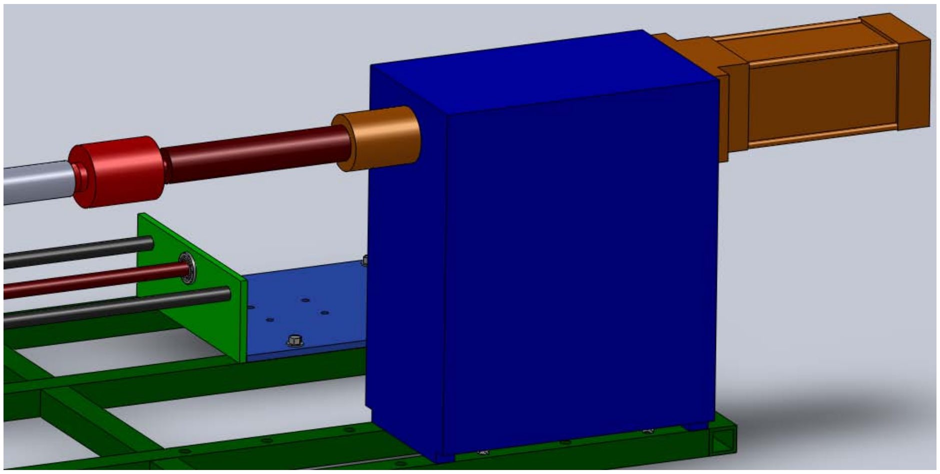


Figure 29: Pneumatic cylinder extended out six inches

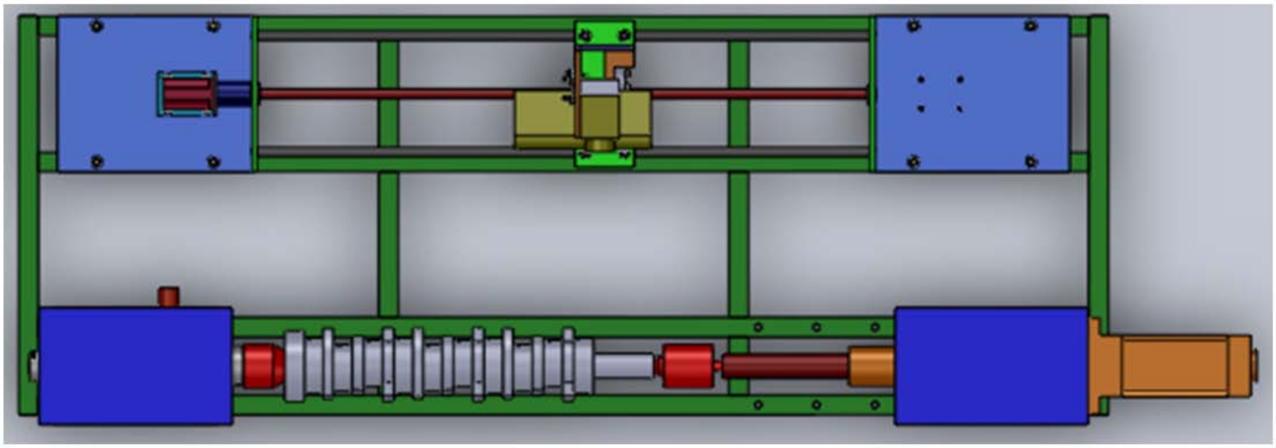


Figure 30: Overhead view to show three inch adjustment holes

8.4 The Prototype

Our final prototype will be mounted on a cart, shown in Figure 31 page 32, to help achieve the customer requirement that our prototype can be moved by only two people. Also shown in the figure is the emergency stop button. This button will be used if the system needs to be immediately stopped for any reason. Mounted to the bottom of the cart is the air tank that we will use to provide air to the pneumatic cylinder during demonstrations. There are c-clamps to make sure our project stays on the top of the cart in case something or someone bumps into it. Finally there are wheel chalks around two of the wheels to keep the cart from moving once the cart is in place for any demonstrations.

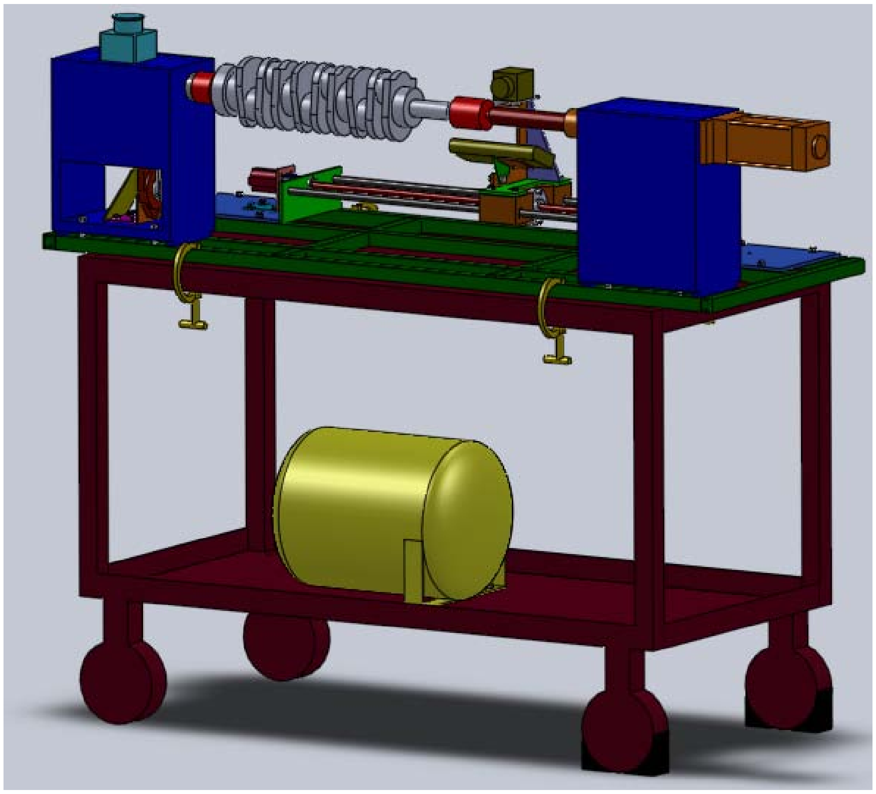


Figure 31: Our prototype on top of the cart

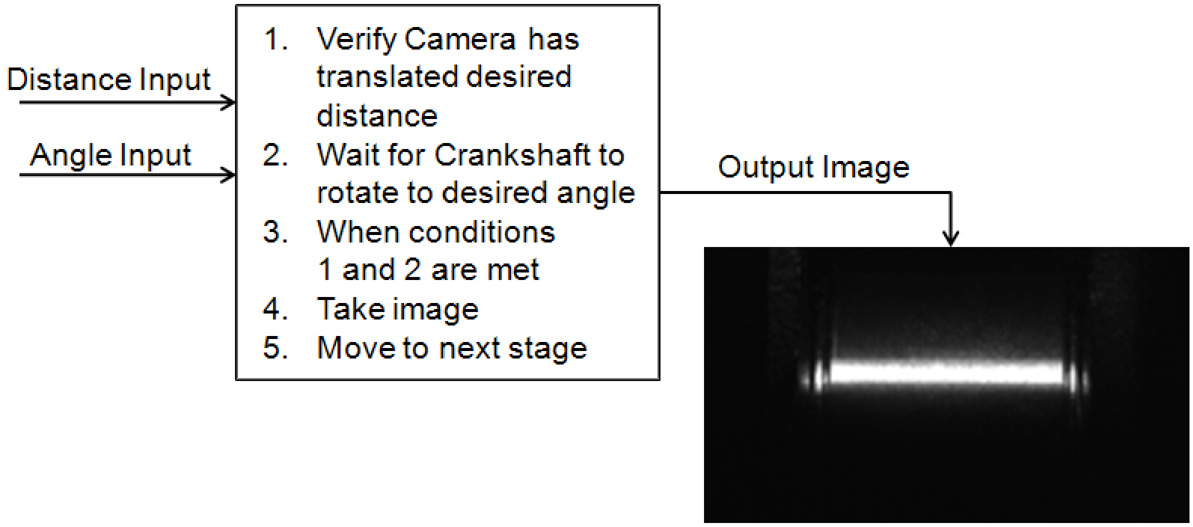
8.5 Programming and Integration

The last integral component of our Final Design is the programming and control component. We have already mentioned that we will use LabVIEW as the main compiler to analyze and control our mechanism. In this section we would like to provide the logical steps our code will take to ensure each a picture of each crankshaft pin and journal surface is taken. We would also like to provide a circuit diagram to support how we will integrate all of the electrical and mechanical components.

8.5.1 LabVIEW

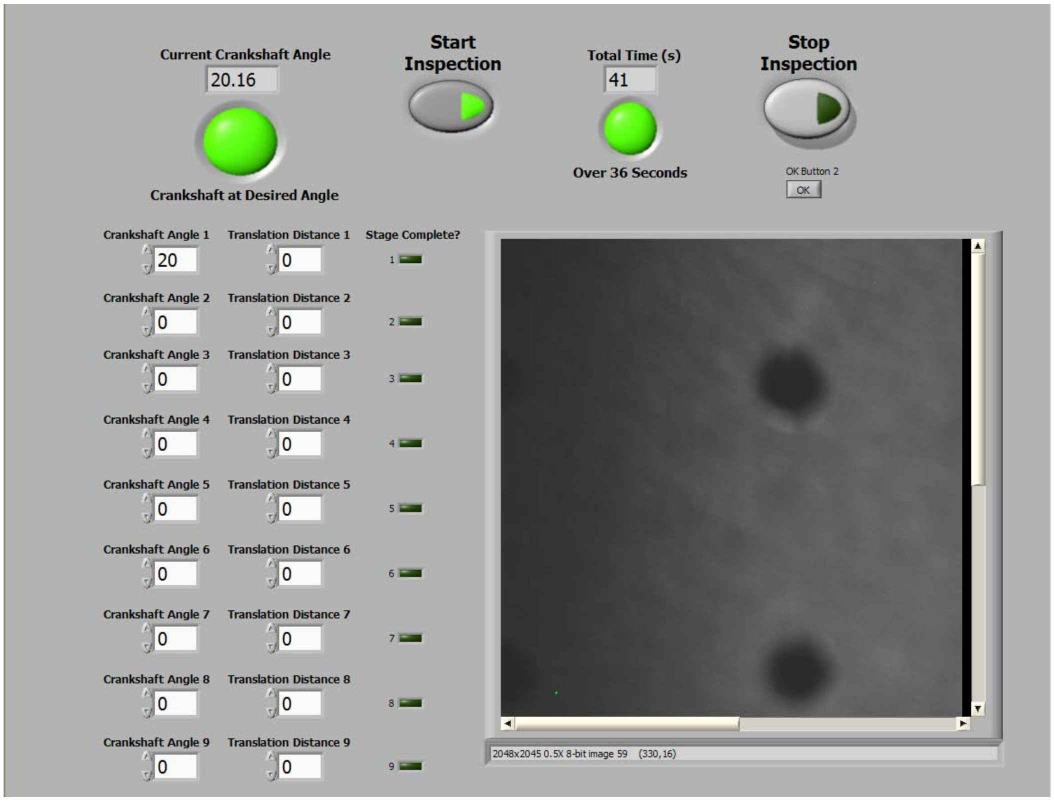
Within LabVIEW there will be a variety of complex algorithms to obtain a functional program. After we ensure control of each component with LabVIEW we can begin using those inputs and producing viable outputs. Once this is accomplished we will use the encoder to continuously measure relative angular position of the crankshaft after a start button is pressed. This start button will be pressed by the user once the crank is placed in the home position, which we will assume for now to be when the first crankshaft pin is vertically downward. Next, we will make sure the camera is triggered to take a picture when the crankshaft is in the correct position as well as camera and light source. After a picture is taken we will translate the camera and light source and allow for the next picture to be taken. A diagram displaying these user inputs and final output as well as pseudo-code can be seen in Figure 32 on p. 33. Once the conditions are met a cyclic procedure occurs until all surfaces have been photographed. Finally, the entire mechanism will be re-set where the camera and light source return to the starting position and the DC motor shuts off. We have begun establishing some pieces of the code as you can see in Figure 34 and

Figure 35 on pages 33 and 34. Of course these are preliminary examples of our final code and user interface.



```
1. Verify Camera has translated desired distance
2. Wait for Crankshaft to rotate to desired angle
3. When conditions 1 and 2 are met
4. Take image
5. Move to next stage
```

Figure 32: Psuedo-Code



Current Crankshaft Angle: 20.16

Total Time (s): 41

Crankshaft Angle	Translation Distance
Crankshaft Angle 1: 20	Translation Distance 1: 0
Crankshaft Angle 2: 0	Translation Distance 2: 0
Crankshaft Angle 3: 0	Translation Distance 3: 0
Crankshaft Angle 4: 0	Translation Distance 4: 0
Crankshaft Angle 5: 0	Translation Distance 5: 0
Crankshaft Angle 6: 0	Translation Distance 6: 0
Crankshaft Angle 7: 0	Translation Distance 7: 0
Crankshaft Angle 8: 0	Translation Distance 8: 0
Crankshaft Angle 9: 0	Translation Distance 9: 0

2048x2045 0.5X 8-bit image 59 (330,16)

Figure 33: Example of LabVIEW User Interface

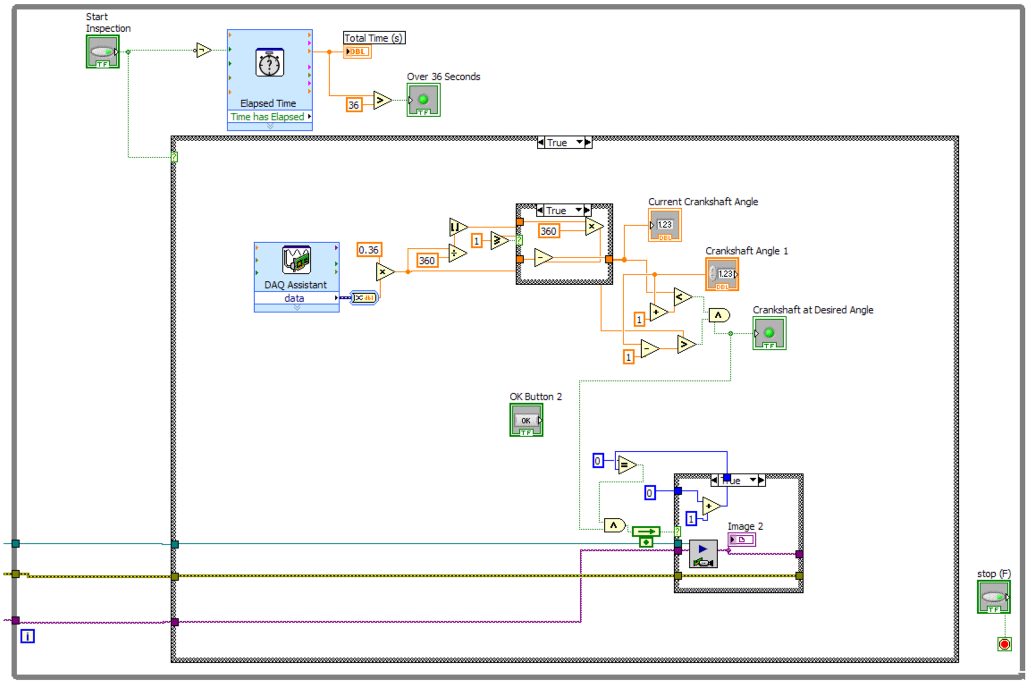


Figure 34: Example of LabVIEW Block Diagram

8.5.2 Mechatronics

Integration of both our mechanical inspection machine and electronic components will be very important. Before integration we must have both programming and the assembly functioning. Once this is complete we can integrate the two sections together using the circuit diagram provided in Figure 35 on p. 35. Within the electrical components we need to first ensure that the computer reads the encoder properly and that it communicates with the stepper motor driver and camera effectively. Once these tasks are accomplished we can integrate the components with the program and if needed make further adjustments.

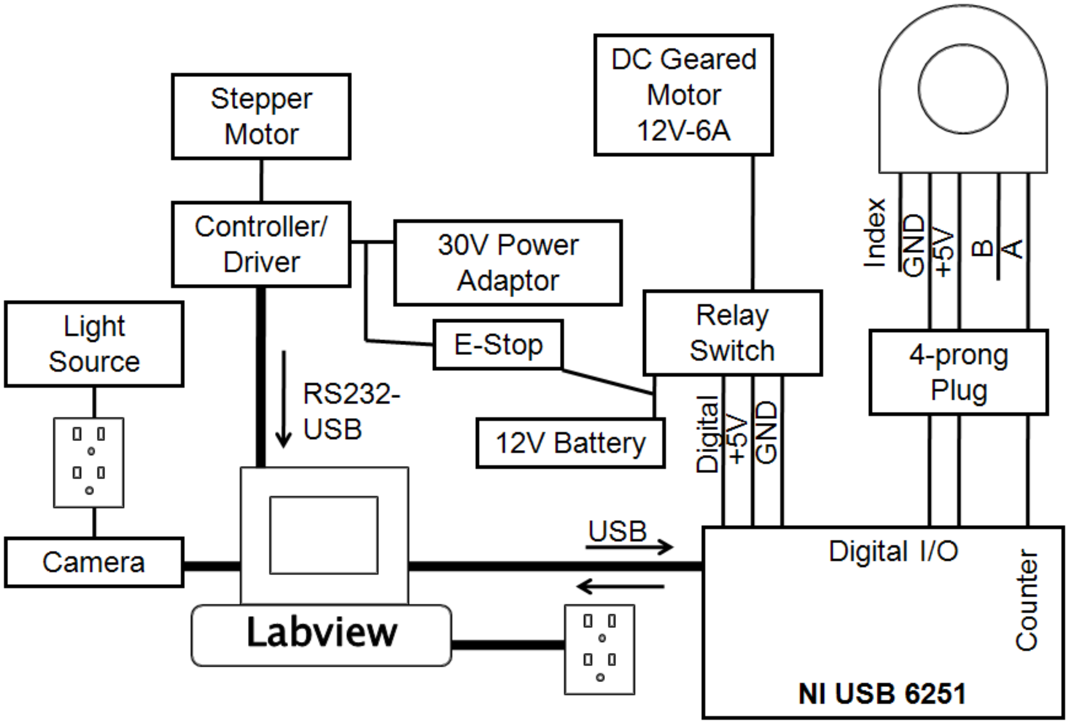


Figure 35: Circuit Diagram

9. PROTOTYPE DESCRIPTION

Since our project only allows us to build a prototype there are a few things that would need to be changed before installing the prototype in an assembly line. For our prototype we use an air tank to supply air to the pneumatic cylinder but this would need to be converted to use the air provided to the assembly line. For our prototype we will physically be actuating the lever that controls the air valve but once put into an assembly line the air valve should be controlled by a computer and actuated once a robot inserts a crankshaft. For our prototype we will be using a donated motor that has more than enough torque required for this application and we recommend using a smaller motor that is specifically designed for this system. For our prototype we are using a 12 volt battery to power our motor but this should be changed to a 12 volt power supply. For our demonstration purposes a 12 volt battery will be more than sufficient however a 12 volt power supply is the right way to power such a motor for an extended period of time. Before our prototype is run we must install the crankshaft the same way every time since we do not have any automatic homing programmed into our mechanism. Again for the sake of testing our prototype this is ok but when installed into an assembly line there should be some type of automatic homing to ensure the crankshaft is inserted into the system the same every time. Finally, our prototype is mounted to a cart so it can be easily moved by two people but once installed into an assembly line it should be hard mounted onto a permanent table.

10. FABRICATION PLAN

The first thing fabricated is the base of our design. Once the tubes are cut and welded, fabrication of the parts for the camera support began. First we water jetted the plates that were then welded together to build the camera support, light support, and the motor supports. Once all of the brackets were made we began to adapt the pieces that we bought to work with our project.

After adapting our sprockets and chains along with assembling the camera support brackets we assembled all of the camera sliders and made sure that all of the camera components functioned properly. Following the completion of the camera system we then fabricated the driven shaft and its components. Following the components completion we finished the manufacturing of the crankshaft support system. With all of the fabrication of the systems completed we then attached the computer components so we could control our motors accordingly. For many more details on the exact plan of our fabrication process please refer to Appendix C.

11. VALIDATION RESULTS

Upon completion of our prototype fabrication, several critical tests had to be conducted in order to verify that all the engineering specifications have been met. Many of these tests were incorporated directly into our LabVIEW user interface. This section describes the specifications that we tested for in order of decreasing priority and how these tests were conducted.

11.1 Total inspection time to be less than 36 seconds

The technical requirement with the highest priority for our project is keeping the total test duration under 36 seconds. Fortunately, the validation process for this requirement is very straightforward and can be checked during any test run with a stopwatch. When the test operator clicks the start button to run the inspection, a stopwatch can easily start timing the total test duration. After a picture is taken of the last crankshaft inspection surface, the camera and light source returns to its zero position, and the crankshaft spins down to a stop, the timer will stop and the total inspection time will be observed. After several test runs, we determined that the inspection takes 34.5 seconds from start to finish. Thus, we have verified that this total inspection time is less than the 36 second limit, and have validated the most important requirement for our project.

11.2 Camera centered with pins/journals within 10 mm

In order for us to validate that the camera is centered with the pin and journal surfaces when each picture is taken, we demonstrated that we can control the translational distance of the camera and light course as it moves along the length of the crankshaft. The camera and light source translation is driven by the number of pulses sent to the Excitron stepper motor, and due to the geometry of our mechanism 4000 steps will correlate to one inch of translation for the camera and light source. Thus, we conducted a test that directly measures with a ruler how far the camera and light source actually translated and compared it to how far we told it to translate. We expected this to be accurate to 0.01 mm due to the resolution of the stepper motor. This test demonstrated that we can control the position of the camera, thus showing that each picture will be taken well within 10mm of the surface center.

11.3 Picture of each journal taken from same distance ± 1mm

Due to the geometry of both our final design and the crankshafts we tested, the distance from the camera to each journal were constant throughout our tests. Journals are always positioned on the central axis of the crankshaft, and the screw and slider beams that the camera will translate on are parallel to this central axis. Thus, no testing was required to validate that we have consistent distance with our pictures.

11.4 Picture of each pin taken from same distance ± 1mm

In order for us to validate that the distance from the pin to the camera is consistent when each picture is taken, we had to demonstrate that we can successfully indicate the rotational position of the crankshaft using the optical encoder. The validation process for this requirement was implemented directly into our LabVIEW user interface. The distance from the pin that is to be inspected next to the camera depends on the rotational angle of the crankshaft; this rotational angle will be dynamically displayed on the screen as well as the desired angle to indicate when the pin is in the right position. When the angle read from the optical encoder matches the desired angle inputted by the operator, we signal the camera to take a picture. The operator was be able to visually verify that the reflected light from the pin was positioned well within the window of the picture taken.

11.5 Angle between the camera and light source fixed

The camera and light source support includes adaptable features that allow the angle between these devices to adjust based on the type of crankshaft being tested. These adjustable features of the support once tightened and secured in place will remain fixed throughout the duration of the tests. The only thing we needed to verify for this requirement is that any vibrations that occur from the dynamics of the system don't cause the adjustable plates to loosen and cause the angle to change slightly. A very straightforward test was conducted to validate this requirement; we measured the angle directly before and after an inspection using a protractor and confirm that the angle did not change.

11.6 Picture tracking

Validation of this requirement was implemented directly into our LabVIEW user interface. We had specific output areas in proper order for the pictures to display once taken, so no actual experimentation or testing was needed.

11.7 Weight of crankshaft to stay between 100 and 300 N

We spoke with QPAC Micropolishing, the company who provided us with the head and tail stock pieces used to secure and rotate the crankshafts, and they confirmed the structural integrity of these donated parts being able to support crankshafts between 100 and 300N. Validation of this requirement, however, involved a demonstration of the versatility of our mechanism. We loaded and ran several inspections for the crankshafts used in our demonstrations, and have shown that the entire tail stock can be maneuvered along the machine to fit different sized crankshafts of varying weight. Thus, no actual experimentation or testing was needed.

11.8 Other Requirements

There are three other requirements that needed to be visually verified during our inspection: Ensuring no contact with the journals and pins, no more than two people are required to maneuver the mechanism, and avoiding the oil holes when taking pictures. Throughout our demonstrations given at company meetings and the Design Expo, we were able to validate these requirements by wheeling the mechanism around with the cart, keeping off of the journals and pins when loading the crankshaft into the mechanism, and looking at the images after the test to ensure that no oil holes were photographed.

12. DISCUSSION

Having completed the assignment, we believe that we have met all of the criteria and specifications provided; that being said there is certainly room for improvement. Though we have met all of our goals, some of these goals could have been approached better and improved. Before looking at these aspects, however, it is important to note the prototypes strengths.

Due to large safety factors, the prototype is extremely robust. The cart used to move the prototype around can hold a maximum of 1200 pounds, a weight that is more than enough for any type of crankshaft that may be inspected. Each end stock used to support the crankshaft is made up of ½” to ¾” thick steel plates. Even the motor mounts themselves were designed using 1/8” aluminum plate. The square tube lattice that the entire mechanism sits upon is made up of 1” steel-square tube with 1/8” thick wall, and then assembled by welding seam to seam. We spared little effort to make this machine as robust as possible; this machine will surely last as long as it is needed.

In hindsight, it is clear that there is room for improvement. Though robust, a few aspects could be stronger. First and foremost, the “driven cone,” used to hold the crankshaft as well as spin it, is constructed out of aluminum. This was done for ease of manufacturing. However, if given more time and budget, a steel or stainless steel cone should be utilized. It is evident by observation that the aluminum cone cannot stand up to the pressures that it must withstand to hold the crankshaft in place. Another point of improvement involves the camera/light source translation system. As one can see, the slider rods have no means for adjustment. Thus, should these bars become out of parallel, due to bending or warp, there would be no way to readjust them. Cams or eccentrics should be added in order to account for this adjustment. Another area to improve, and probably the most important area, is the translation system itself. When the camera/light source reaches more toward the center of the slider rods, an evident vibration can be observed. We believe this vibration to be mainly due to the fact that the camera screw is bent; however, using larger slider rods with linear ball bearings would also greatly improve this flaw. Using a screw that is more appropriately designed for this type of system would also be preferred that this may provide a much more robust system as a whole. Another thing that should be improved is the reconfigurable rolling tailstock or stand. This stand is able to unbolt and move its position. However, as it currently is designed, the mechanism base must first be unbolted from the cart to allow access to the nuts on the underside of the stand. Welding nuts to the mechanism stand at each position could greatly improve this design. This way the user would simply need to unbolt the stand and adjust it without having to do any other laborious task. Another adjustment that should be implemented is the ability to adjust the crankshaft supports to allow for alignment of the two support cones. Right now we are using a shim on the air piston shaft which gives us the alignment we need but this is not a permanent solution. One way this could be accomplished is by making the bolt holes in the stands larger to allow for those slight alignment adjustments. Lastly, as far as the machine itself is concerned and in a more of an aesthetic context, it would be an improvement to hide the attachment points of the mechanism stand to the base. Bolting the bottom of the square tubes to the cart and then plugging the holes with plastic covers could do this. This would greatly increase the professional look of the design in general.

Concerning programming, there is one thing that would have been great had we had time to improve it. The stepper motor used to translate the camera/light source does not send back a "true" command when it is done stepping. Because of this, we have had to program the machine through timing. Given a new stepper motor with this feedback feature, the speed of the mechanism could be greatly increased, thus reducing the total inspection time.

All in all, the final prototype is a working, professional machine. It meets each criteria and performs continuously and consistently. Given another semester, we are sure that this machine could be perfected beyond any need.

13. RECOMMENDATIONS

First and foremost, everything mentioned as weaknesses in the design in the previous Discussion section should be treated as recommendations. This includes changing the driven cone to steel, strengthening the slider rods and adding linear bearings, adding parallel adjustment for the slider rods, replacing the camera screw with a more suitable successor, adding weld nuts to the reconfigurable stand, hiding the mechanism stand attachment points, and replacing the stepper motor with one that has feedback.

We also recommend a new way to lock the cart-wheels; perhaps by replacing the wheels with locking casters. A more serious recommendation is to invest in a new computer dedicated to this machine. A computer dedicated to this sole function will allow for much greater performance and much faster processing. The program will run faster, thus the inspection will run faster. This point cannot be stressed enough as the current configuration will crash the computer if more than a few programs are opened and the mouse is moving. It should be noted that these recommendations are simply suggestions. The machine works as it currently stands and will continue working given the proper maintenance. A short summary of maintenance procedures are described below; for a more detailed summary please refer to the user manual in Appendix E:

Before running a test after a long hiatus:

- Wipe the slider rods with a clean towel to remove any settled dust or debris.
- Spray the slider rods and screw with a lubricant, such as WD-40.
- Allow the computer to fully boot before opening any programs.
- Once the program is opened, attempt to run an inspection.
    - This inspection is expected to fail
- Close the program, and open it again.
- Run the inspection.

14. CONCLUSION

Many of today's engines require extremely smooth crankshaft main and pin finishes due to increasingly tighter bearing clearances and the use of thinner viscosity motor oils. If the polishing of the crankshaft mains and pins are not adequate, microscopic surface peaks can cause premature bearing failure. A new method has been developed to inspect surface finish using a blue light source and a camera. Our team was tasked to take this new method and build an automated machine to prove its capabilities. With this new method, it is proven that a crankshaft can be inspected accurately for a polished or non-polished analysis in under 36 seconds. It is also proven that this new inspection method is a more efficient method since it is able to inspect each crankshaft off the manufacturing line as opposed to the current method of inspecting only one in every 50.

The most important specification is that the entire inspection process must take less than 36 seconds. Second, each surface must be positioned with respect to the camera within a tolerance of millimeters. Lastly, due to the speed at which the crankshaft will rotate, a crankshaft weight constraint of 100 to 300 N was established.

Following vigorous analysis of our concepts, we developed a Final Design. This design rotates the crankshaft, translates the camera beside it, and uses a rotary encoder to detect the mechanisms position. The horizontal position of the crankshaft allows the user to easily install and uninstall the crankshaft with respect to the manufacturing line. With this configuration, the design's footprint, weight, and cost are minimized due to the use of smaller motors and fewer components. One major advantage to this design is the feasibility of manufacturing and assembly. Lastly, with the degrees of freedom split between the rotation of the crankshaft and the translation of the camera, the programming of the mechanism becomes much simpler.

Upon completion of our prototype fabrication, several critical tests were conducted in order to verify that all the engineering specifications were met. Many of these tests were incorporated directly into our LabVIEW user interface. Between measuring critical parameters regarding distances and angles and visually verifying the quality of the output images, we determined that we satisfied each of the customer requirements for the machine.

15. ACKNOWLEDGMENTS

We would like to thank and acknowledge a number of sponsors and contributors to this project:

- Dr. Hagay Bamberger (ERC/RMS)
- Dr. Yoram Koren (ERC/RMS)
- En Hong (ERC/RMS)
- Steve Erskine (ERC/RMS)
- Julie DeFilippo (ERC/RMS)
- Bob Coury (Undergraduate Shop)
- Verne Bunch (Excitron)
- Ken Barton (QPAC)
- Loren (QPAC)
- Steve Simon (Balance Tech)
- Mandar Gokhale (Department of Mech. Engr.)
- Tom Bress (Department of Mech. Engr.)
- John Baker (Department of Mech. Engr.)
- Brian Barnes (Department of Mech. Engr.)
- Student Team Project Center (Wilson Center)
- Smart Materials and Structures Design Lab

16. INFORMATION SOURCES AND REFERENCE LIST

Information was gathered through a range of sources to obtain a working knowledge of the project at hand. Some of these sources include interviews, patents, and academic literature. This section presents the current industrial benchmarks as well as engineering information gathered.

16.1 Current Industrial Benchmarks

Our sponsor indicated that the current process for inspecting crankshaft surface finishes involves checking one crankshaft out of every 50 made and analyzing the finish [2]. This analysis can be done using various Ra testers. One type of these testers is an automated crankshaft Ra tester, specifically, a patented ADCOLE 1000 as seen in Figure 36 [3]. This automated crankshaft roughness tester is designed to measure a number of surface parameters using a stylus, or a sharp needle. It is described as a “fast system” that has “unprecedented accuracy” [4]. This product is very similar to our ideal inspection mechanism; however, it is different in the regards that it uses a stylus rather than a light source and camera. The cost of this device is a minimum of $165,000.00 USD according to a 2002 thomasnet.com press release.

Figure 36: ADCOLE 1000 [4]

A second inspection mechanism we have investigated is a manual crankshaft Ra tester. Numerous testers are commercially available and are very similar in their functionality, however, these are hand-held. Due to the fact that there are so many of these testers only one will be discussed for benchmarking. The Mahr Pocket Surf, as seen in Figure 37 (pg. 39), is a patented manual Ra tester, as opposed to an automatic tester like the ADCOLE 1000 [5]. This device is said “to provide years of accurate, reliable surface finish gauging.” The cost of this device is generally quoted at around $2,000 USD [6]. This device uses a stylus as well and can report information quickly and accurately. Our mechanism uses a light source which is a non-contact means of inspection. Currently the only non-contact means of inspection involves a laser with a very small detection range (approximately less than 1 cm) [2].

Figure 37: Mahr Pocket Surf [6]

16.2 Engineering Information

As previously mentioned, these benchmarked machines measure the Ra, or the average of peaks and valleys on the surface. The higher the value of a surface's Ra, the worse its finish [6]. The current inspection process is very time consuming and could lead to the previous 50 crankshafts having defects. Decreasing the value of Ra is very important due to tighter bearing clearances on the journals and pins as well as thinner oils (5W-30) now being used [9]. To maintain a crankshaft's strength and durability, the journal and pin surfaces must be well finished to withstand maximum loading capacity and maintain sufficient lubricating oil [10, 11]. However, decreasing the Ra too much could result in poor oil distribution. For this reason, a good Ra value is generally considered to be about 2 [8].

16.3 Company Interviews

To help us gain valuable industry knowledge about the crankshaft polishing process we visited two companies, BalanceTech and QPAC.

On October 1st we went to BalanceTech Inc., a company that engineers and manufactures a complete line of industrial precision measurement & testing equipment out in Whitmore Lake, MI, [7]. Specifically, we were interested in how they balance crankshafts. This visit gave us several design ideas about how to support and spin the crankshaft. Other useful insight discovered was on what kind of motors we could use to rotate a crankshaft. Along with actually seeing a crankshaft supported we were able to see different ratation speeds to get a feel for how fast one could safely spin a crankshaft. It was observed that 80 RPM was well within the ability of the crankshaft to spin, a speed that we should not come anywhere close to. BalanceTech helped to answer several questions about their specific crankshaft support structure that one couldn't get answered through other means of research. It was an invaluable experience to see a hands-on demonstration of a rotating crankshaft. It was also observed that the crankshaft was easily and quickly rotated by simply resting on rolling bearings. Thus, the weight of the crankshaft alone was enough to stabilize the system.

Following our BalanceTech visit we went out and spoke with QPAC, a micro-polishing company in Lansing, MI. QPAC is a company that provides the machines to most automotive manufactures for polishing the pins and journals, which is the process that is completed right before our inspection would take place [8]. While at QPAC we saw how crankshafts are polished and talked with them to understand how the crankshafts leave the polishing station and proceed down the assembly line. Other valuable insight came from understanding their support structure for rotating crankshafts and how it differed from BalanceTech. Overall QPAC was very helpful for our project and correlated well with supporting our Alpha Design.

Lastly, we have interviewed one expert in the static and dynamic analysis field and have gained valuable insight into how to go about this project's static analysis. Given the types of bearings, gears, and shafts that we may require, as well as an input and output torque, we expect to support our static analysis using RomaxDesigner, an analysis tool used in industry [12]. This information will be helpful to influence and support possible design solutions.

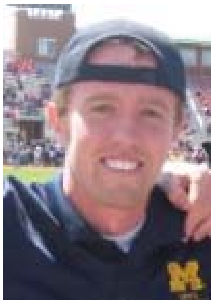
17. TEAM BIOS

Our team consists of four 5th year Mechanical Engineering students each with different backgrounds, thus each member brings a unique set of characteristics and perspectives to the team. With each member heading up their areas of expertise, four different approaches will be analyzed to create the best working prototype. Please meet our team:

17.1 Ian Lind

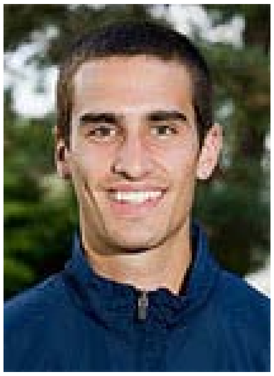
Ian Lind was born in Ann Arbor and raised in Hamburg Michigan while attending Pinckney schools. He is enrolled in his 5th year at the University of Michigan and is working on getting his B. S. E. in Mechanical Engineering. When he is not studying he is working with the University of Michigan Baja Team to design and build a competitive Baja racecar. His mechanical engineering interest comes from wanting to know how everything works and wanting to be able to fix anything that is broken. After graduation he plans on getting a job to begin earning money and start a family. He has played hockey for 17 years and soccer for 15. As a freshman in college he played hockey for the University of Michigan Club Hockey Team.

17.2 Mike Luginbill



Mike Luginbill was born and raised in Troy, Michigan where he graduated from Troy High School in 2005. Currently, he is enrolled in the Sequential Graduate and Undergraduate Studies program where he hopes to graduate in April 2010 with a B.S.E and M.S.E in Mechanical Engineering. Building houses for Habitat for Humanity when he was younger sparked his interest in mechanical engineering. Mike was a four year varsity letter winner for the Men's Track and Field team as well as a member of the 2008 Big Ten Outdoor Championship team. After graduation, he hopes to acquire a full-time job somewhere in the United States with particular interest in Mechatronics. In his spare time, Mike enjoys hanging out with friends, biking, and participating in his church.

17.3 Tony Nalli



Tony Nalli was born and raised in Ann Arbor, Michigan and graduated from Dexter High School in 2005. He is enrolled in his 5th year at the University of Michigan and is currently pursuing his B.S.E in Mechanical Engineering with a Minor in Mathematics. Aside from academics, Tony is also a member of the Men's Varsity Track and Field and Cross Country teams. His interest in Mechanical Engineering stems from a desire to explore a broad field that is full of opportunities. After graduation, Tony plans to apply to and attend graduate school where he will study either Mechanical Engineering or Engineering Management. In his spare time, Tony enjoys movies, music, and spending time with friends.

17.4 Joe Shaktman

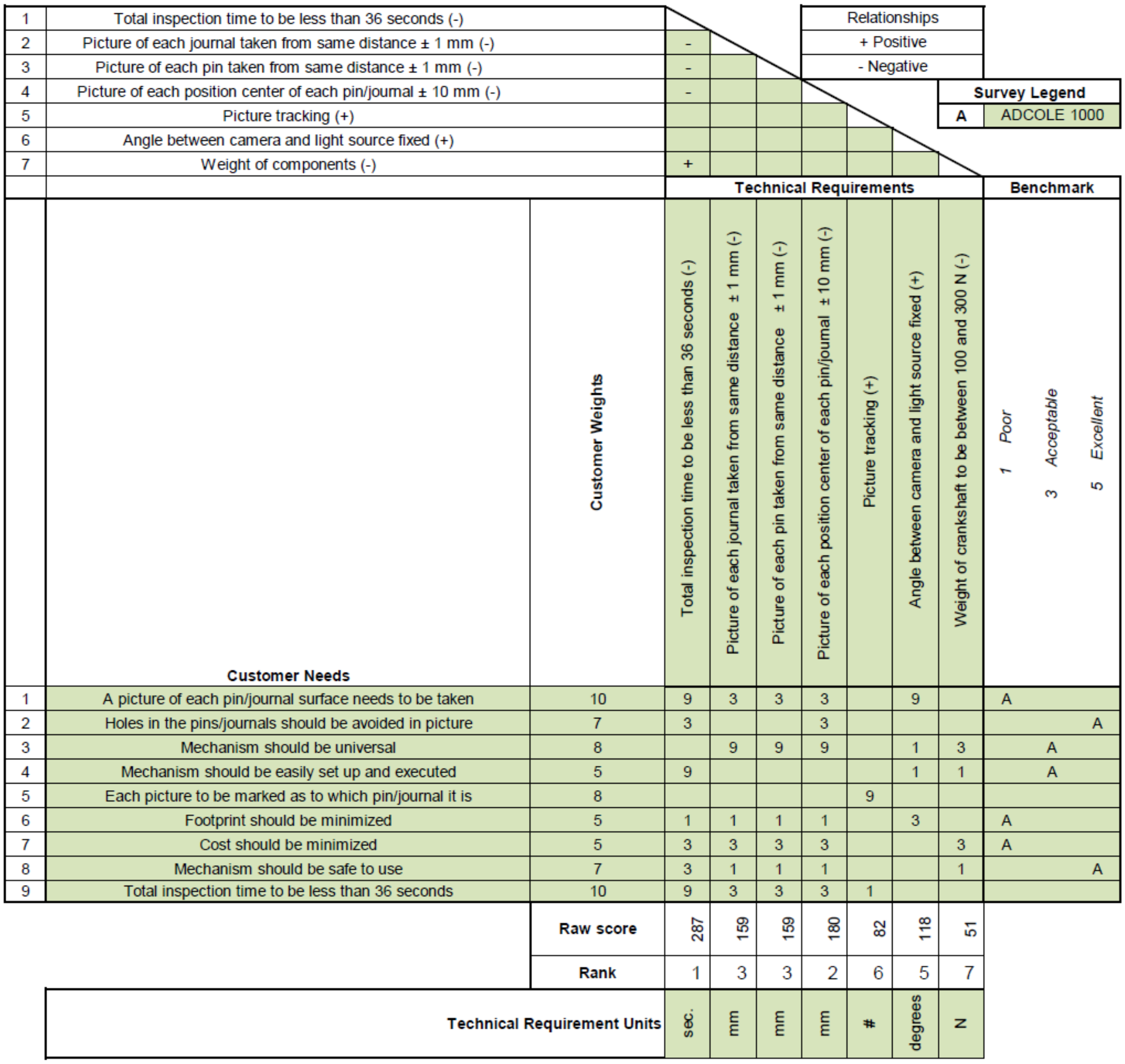
Joe Shaktman was born and raised in South Hamilton, Massachusetts, about 20 minutes north of Boston. He is currently enrolled in his fifth year at the University of Michigan working toward his B.S.E. in Mechanical Engineering; a degree he has aspired toward since he began working on cars in his younger years. Joe is also the Vice President of the Michigan Sign Club, a group dedicated to teaching Sign Language and spreading knowledge of the Deaf Culture. After graduation, Joe plans on joining the work force in New England, with the possibility of attending graduate classes after a few years. In his spare time, Joe enjoys working on his Jeep, sailing, and fishing.

18. REFERENCES

1. Image on cover page: See [11]
2. (Bamberger, H., personal communication, September 15-22, 2009)
3. Hutter, K., Wagner, J. (1987). U.S. Patent No. 4,651,438. Washington, D.C.: U.S. Patent and Trademark Office.
4. ADCOLE Corp. (2009). Visited: September 19th, 2009. <www.adcole.com>.
5. Parsons, F. G., Miller, M. H., Cote, E. F. (1988). U.S. Patent No. 4,776,212. Washington, D.C.: U.S. Patent and Trademark Office.
6. Mahr GmbH. Visited: September 19th, 2009. <http://www.mahr.com/index.php?NodeID=2410>.
7. Balance Technology (2009). Visited: October 21st, 2009. <http://www.balancetechnology.com/>.
8. QPAC Micropolishing (2007). Visited: September 19th, 2009. <http://www.micropolishing.com/home/>.
9. Rockcliff Machine Inc. (2008). Visited: September 19th, 2009. <http://www.rockcliffmachine.com/index.htm>.
10. Verimation Technology, Inc. (2002). "NDT inspection unit for axle shaft/crankshaft." Visited: September 19th, 2009. <http://www.directindustry.com/prod/verimation-technology/ndt-inspection-unit-for-axle-shaft-crankshaft-34509-215091.html>.

11. Promar Precision Engine Rebuilders, Inc. (2004). Visited: September 19th, 2009. <http://www.promarengine.com/>.
12. (Sheridan, K., personal communication, September 23, 2009)
13. Fraden, J. Handbook of Modern Sensors (2004). Springer Science and Business Media. New York, NY.
14. SparkFun Electronics (2008). Visited: October 12th, 2009. <http://www.sparkfun.com>.
15. National Instruments (2008). Visited: October 15th, 2009. <http://www.ni.com>.
16. Adapted from Otto, K., 2005. Design4X Inc., <www.robuststrategy.com>.
17. DIY-Photography (2009). Visited: November 11th, 2009. <http://www.diyphotography.net/shutter-speed>
18. Norton, Robert L. Machine Design –An Integrated Approach (1996). Prentice Hall. 18.4.
19. McMaster-Carr (2009). Visited: November 16th, 2009. <www.mcmaster.com.>
20. Excitron (2009). Visited: November 17th, 2009. <ww.excitron.com>

APPENDIX A – QFD [16]



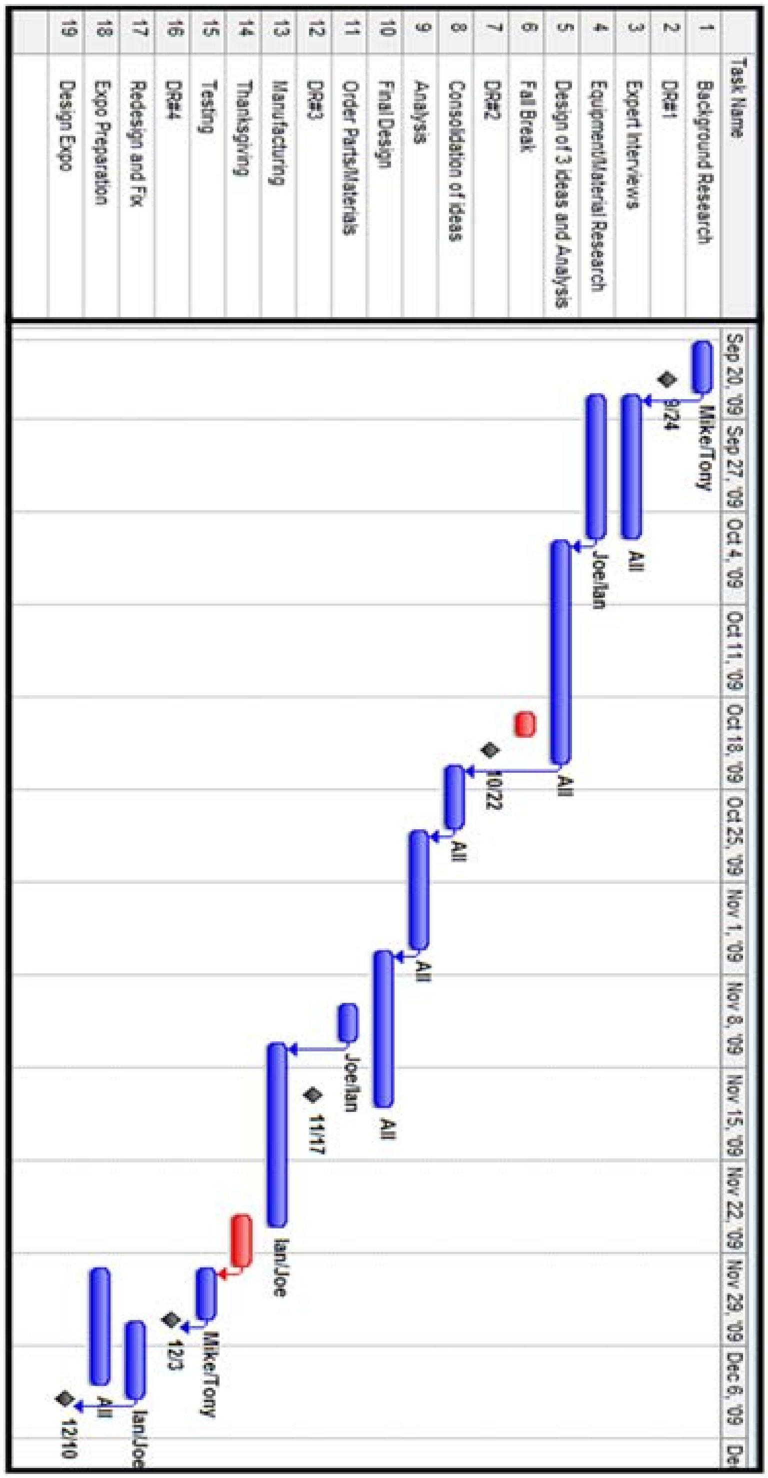
	Correlations	1	2	3	4	5	6
1	Total inspection time to be less than 36 seconds (-)						
2	Picture of each journal taken from same distance ± 1 mm (-)	-					
3	Picture of each pin taken from same distance ± 1 mm (-)	-					
4	Picture of each position center of each pin/journal ± 10 mm (-)	-					
5	Picture tracking (+)						
6	Angle between camera and light source fixed (+)						
7	Weight of components (-)	+					

Relationships
+ Positive
- Negative

Survey Legend	
A	ADCOLE 1000

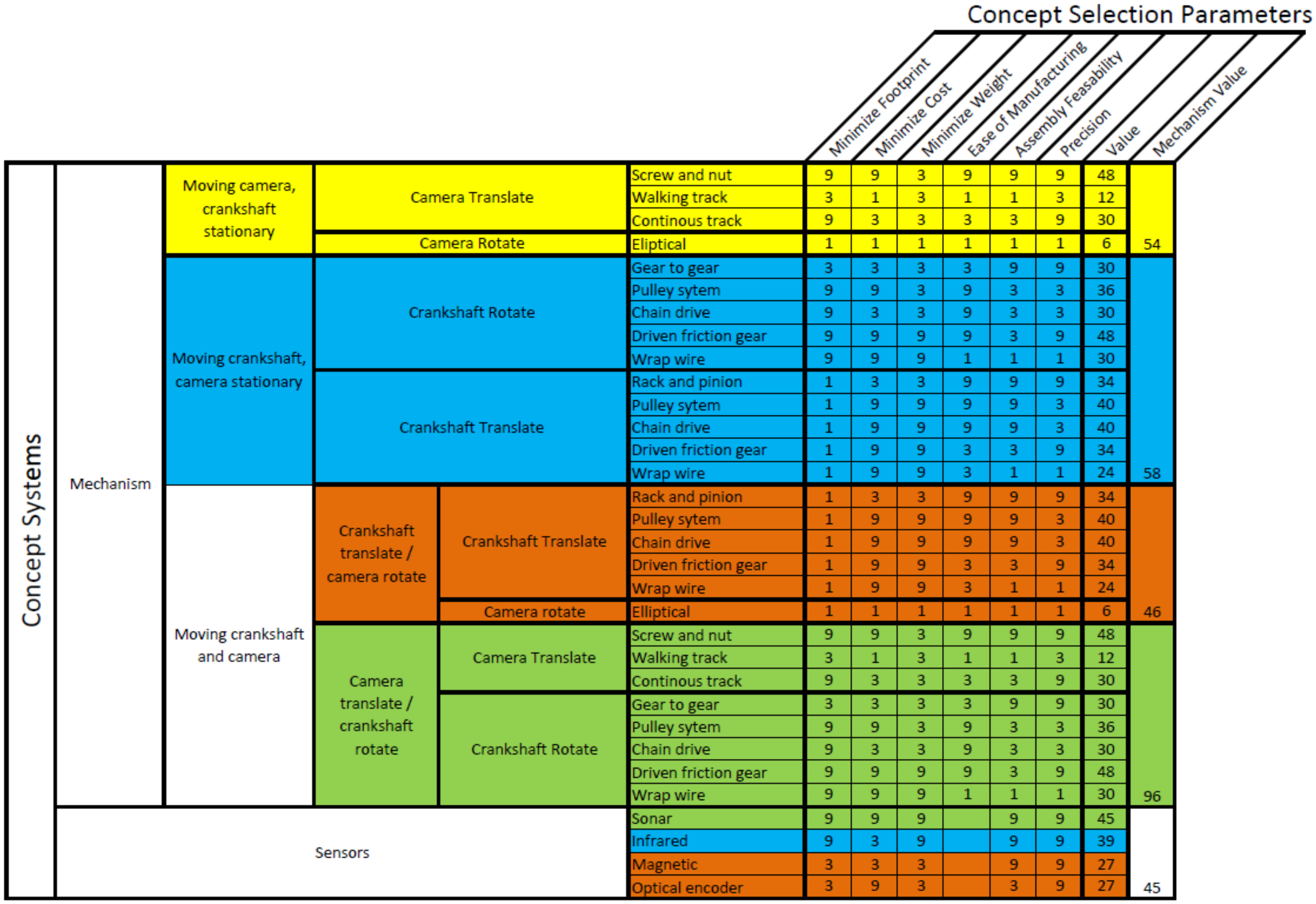
	Customer Needs	Customer Weights	Total inspection time to be less than 36 seconds (-)	Picture of each journal taken from same distance ± 1 mm (-)	Picture of each pin taken from same distance ± 1 mm (-)	Picture of each position center of each pin/journal ± 10 mm (-)	Picture tracking (+)	Angle between camera and light source fixed (+)	Weight of crankshaft to be between 100 and 300 N (-)	Benchmark: *1 Poor*	*3 Acceptable*	*5 Excellent*
1	A picture of each pin/journal surface needs to be taken	10	9	3	3	3		9		A		
2	Holes in the pins/journals should be avoided in picture	7	3			3						A
3	Mechanism should be universal	8		9	9	9		1	3		A	
4	Mechanism should be easily set up and executed	5	9					1	1		A	
5	Each picture to be marked as to which pin/journal it is	8					9					
6	Footprint should be minimized	5	1	1	1	1		3		A		
7	Cost should be minimized	5	3	3	3	3			3	A		
8	Mechanism should be safe to use	7	3	1	1	1			1			A
9	Total inspection time to be less than 36 seconds	10	9	3	3	3	1					
		Raw score	287	159	159	180	82	118	51			
		Rank	1	3	3	2	6	5	7			
	Technical Requirement Units		sec.	mm	mm	mm	#	degrees	N			

Gantt Chart



	Task Name
1	Background Research
2	DR#1
3	Expert Interviews
4	Equipment/Material Research
5	Design of 3 ideas and Analysis
6	Fall Break
7	DR#2
8	Consolidation of ideas
9	Analysis
10	Final Design
11	Order Parts/Materials
12	DR#3
13	Manufacturing
14	Thanksgiving
15	Testing
16	DR#4
17	Redesign and Fix
18	Expo Preparation
19	Design Expo

Design Matrix



Concept Systems					Minimize Footprint	Minimize Cost	Minimize Weight	Ease of Manufacturing	Assembly Feasability	Precision	Value	Mechanism Value
Mechanism	Moving camera, crankshaft stationary	Camera Translate		Screw and nut	9	9	3	9	9	9	48	54
				Walking track	3	1	3	1	1	3	12	
				Continous track	9	3	3	3	3	9	30	
		Camera Rotate		Eliptical	1	1	1	1	1	1	6	
	Moving crankshaft, camera stationary	Crankshaft Rotate		Gear to gear	3	3	3	3	9	9	30	58
				Pulley sytem	9	9	3	9	3	3	36	
				Chain drive	9	3	3	9	3	3	30	
				Driven friction gear	9	9	9	9	3	9	48	
				Wrap wire	9	9	9	1	1	1	30	
		Crankshaft Translate		Rack and pinion	1	3	3	9	9	9	34	
				Pulley sytem	1	9	9	9	9	3	40	
				Chain drive	1	9	9	9	9	3	40	
				Driven friction gear	1	9	9	3	3	9	34	
				Wrap wire	1	9	9	3	1	1	24	
	Moving crankshaft and camera	Crankshaft translate / camera rotate	Crankshaft Translate	Rack and pinion	1	3	3	9	9	9	34	46
				Pulley sytem	1	9	9	9	9	3	40	
				Chain drive	1	9	9	9	9	3	40	
				Driven friction gear	1	9	9	3	3	9	34	
				Wrap wire	1	9	9	3	1	1	24	
			Camera rotate	Elliptical	1	1	1	1	1	1	6	
		Camera translate / crankshaft rotate	Camera Translate	Screw and nut	9	9	3	9	9	9	48	96
				Walking track	3	1	3	1	1	3	12	
				Continous track	9	3	3	3	3	9	30	
			Crankshaft Rotate	Gear to gear	3	3	3	3	9	9	30	
				Pulley sytem	9	9	3	9	3	3	36	
				Chain drive	9	3	3	9	3	3	30	
				Driven friction gear	9	9	9	9	3	9	48	
				Wrap wire	9	9	9	1	1	1	30	
Sensors				Sonar	9	9	9		9	9	45	45
				Infrared	9	3	9		9	9	39	
				Magnetic	3	3	3		9	9	27	
				Optical encoder	3	9	3		3	9	27	

🟩	Best Solution
🟦	Second Best Solution
🟨	Second Worst Solution
🟧	Worst Solution

1	Poor Coorelation
3	Good Coorelation
9	Excellent Coorelation

APPENDIX B – Engineering Calculations

Derivation 1:

$$D_{Max} = \frac{Wl^3}{48EI} = \frac{5lbs(32in)^3}{48(27557kpsi)(\pi(.25)^4/4)} = 0.04inches = 1mm$$

Derivation 2:

$$I = m(R_1{}^2 + R_2{}^2)/2 = 30kg \cdot (.0762^2 + .0254^2)/2 = 0.097kg \cdot m^2 = 331in^2 \cdot lbs$$

Derivation 3:

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{30rpm \times \frac{\pi}{30}}{2\sec} = \frac{\pi rad/s}{2\sec} = 1.57rad/s^2$$

$$T = I \times \alpha = (0.097kgm^2 \cdot 1.57rad/s^2) = 0.152Nm = 1.35inlbs$$

Derivation 4:

$$M_{rad} = P \cdot f \cdot (D/2) = 150N \cdot (0.004) \cdot (0.0254m/2) = 0.0076Nm = 0.067inlbs$$

$$M_{thr} = P \cdot f \cdot (D_o + D_i)/4 = 444N \cdot (0.4) \cdot (0.0254m + 0.05m) = 3.35Nm = 29.7inlbs$$

$$T_{NET} = I \times \alpha + 3 \cdot M_r + M_{thr} = 1.35inlbs + 3(0.067inlbs) + 29.7inlbs = 31.3inlbs$$

Derivation 5:

$$Load = 4.5kg = 10lbs$$

$$\frac{\Delta x}{\Delta t} \cdot n \cdot spr = sps \rightarrow \frac{1.5in}{0.5s} \cdot 10rev/in \cdot \frac{200steps}{1rev} = 6000sps$$

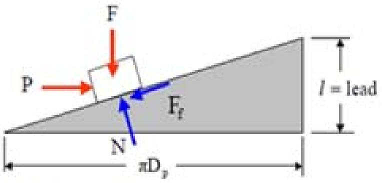
$$6000sps \cdot \frac{60s}{\min} \cdot \frac{1rev}{200steps} = 1800rpm$$

$$I_{shaft} = mR^2/2 = 1.361kg \cdot (.0064^2)/2 = 2.79 \cdot (10^{-5})kg \cdot m^2$$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{1800rpm \times \frac{\pi}{30}}{0.2\sec} = \frac{188.5rad/s}{0.2\sec} = 942.5rad/s^2$$

$$T_{shaft} = I \times \alpha = (2.79 \cdot (10^{-5})kg \cdot m^2 \cdot 942.5rad/s^2) = 0.0263Nm = 0.233inlbs$$

Derivation 6 [18]:



P ≡ Force needed to move load

T ≡ Torque needed to move load up

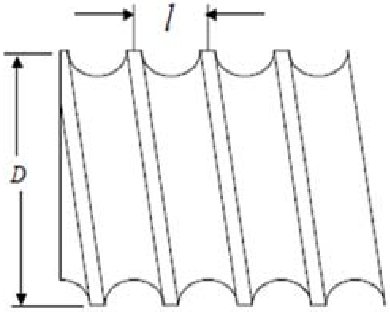
F ≡ Load to be moved

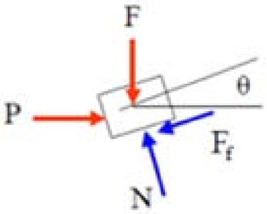
D_p ≡ Pitch diameter

μ ≡ Coefficient of friction

N ≡ Normal Force

F_f ≡ Friction Force





$$\tan\theta = \frac{l}{\pi D_p}$$

$$\sum F_h = P - F_f\cos\theta - N\sin\theta = 0$$
$$\sum F_v = -F - F_f\sin\theta + N\cos\theta = 0$$
$$F_f = \mu N$$

$$P - \mu N\cos\theta - N\sin\theta = 0$$
$$-F - \mu N\sin\theta + N\cos\theta = 0$$

$$N = \frac{F}{\cos\theta\left(1 - \mu l/\pi D_p\right)}$$

$$P = F\left(\frac{l + \mu\pi D_p}{\pi D_p - \mu l}\right)$$

$$\boxed{T = \frac{FD_p}{2}\left(\frac{l + \mu\pi D_p}{\pi D_p - \mu l}\right)}$$

$$T_{srew} = 4.4kg \cdot \frac{0.0127}{2}\left(\frac{0.1 + (0.25 \cdot \pi \cdot 0.0127}{\pi \cdot 0.0127 - 0.25 \cdot 0.10}\right) = 0.206Nm = 1.83inlbs$$

$$T_{total} = T_{shaft} + T_{screw} = 0.233inlbs + 1.83inlbs = 2.06inlbs$$

Derivation 7:

$$30rpm \cdot \frac{2\pi}{1rev} \cdot \frac{1\min}{60s} \cdot 1000cpr \cdot \frac{1rev}{2\pi} = 500Hz$$

Derivation 8:

$$F = p\pi({d_1}^2 - {d_2}^2)/4$$

$$F = 175psi \cdot \pi((1in)^2 - (0.5in)^2)/4 = 103.1lbf = 458N$$

Derivation 9:

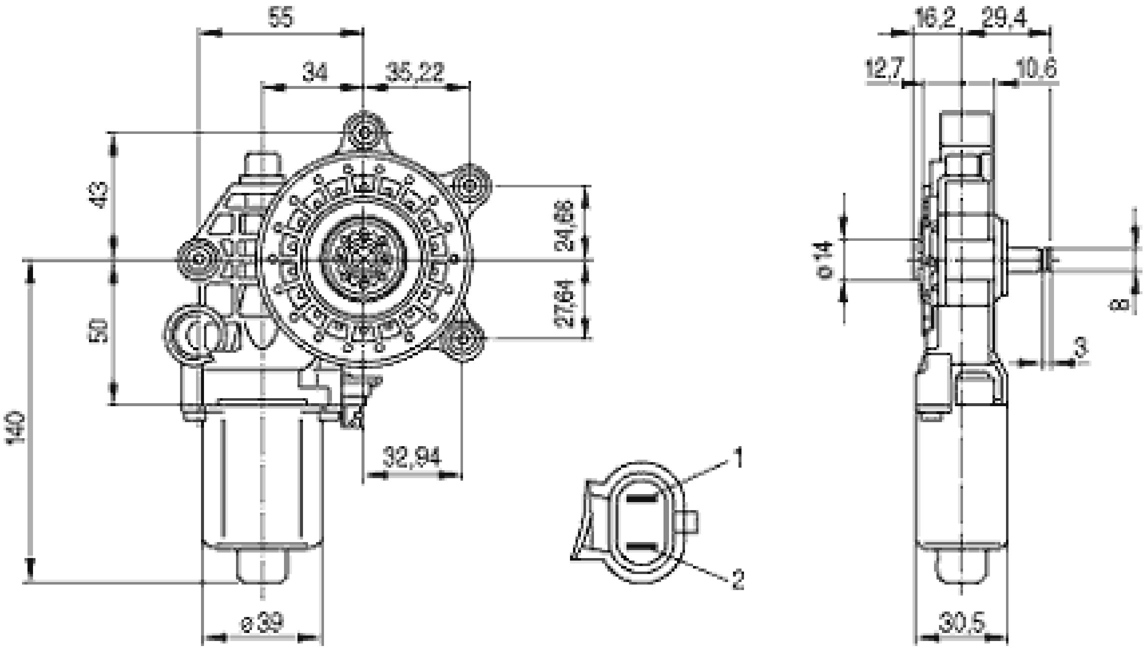
$$p = 4F/(\pi({d_1}^2 + {d_2}^2))$$

$$p = 4(33.72lbf)/(\pi((1in)^2 - (0.5in)^2)) = 57.2psi$$

Selected Motor Characteristics

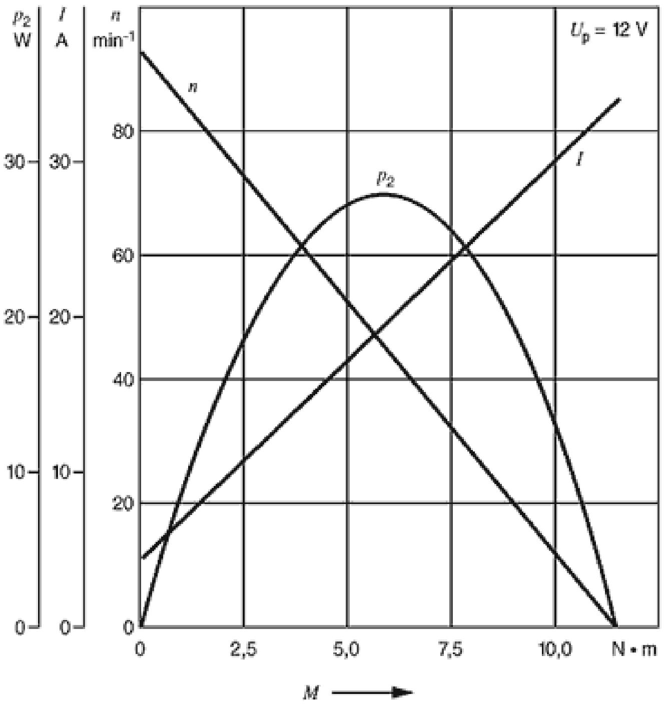
Bosch 12V FPG DC Gearmotor

Engineering Drawing:

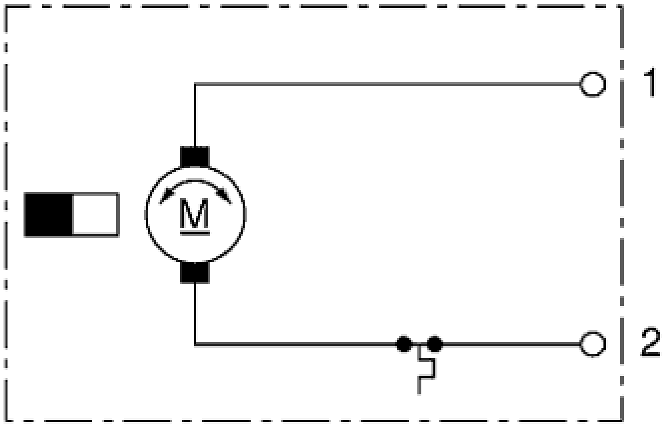


*All dimensions in mm

Characteristic Curve:

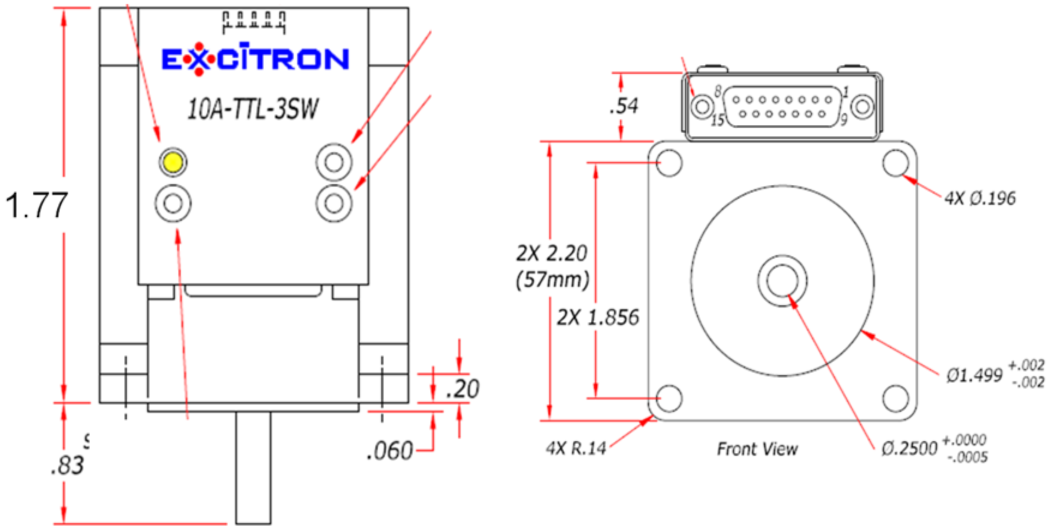


Connection Diagram:



Excitron SM 45-60 Stepper Motor

Engineering Drawing:



*All dimensions in inches

APPENDIX C – Safety Report

ME 450 Safety Reporting: Fall 2009

Project #: 16 **Date:** 11/15/09

Report Version #: 1.1

Project Title: Automated Fixture for Crankshaft Inspection

Team Member Names: Ian Lind, Mike Luginbill, Tony Nalli, Joe Shaktman

Team Member Uniquenames: ianlind, lugimich, tnalli, shaktman

Attach your Safety Report to this cover page and instructions found on Pages 2 and 3.

The Safety Report is to be completed by your team and must be approved by your section instructor (or approved substitute) prior to any hands-on experimentation, manufacturing or testing of your prototype.

The safety hazards inherent in your experimental plans, component selection, manufacturing methods, assembly techniques, and testing must be expressed and evaluated before any hands-on work with safety consequences will be allowed to proceed.

The purpose of this safety report is to assure that you have thought through your hands-on work before it begins, and that you have shared your plans with your Section Instructor. You may submit more than one version. This will likely be necessary as your project evolves.

APPROVAL:

Name: ____________________________

Signature: ____________________________

Date: ____________________________

Safety Reporting Directions: Please address the following points and questions.

1. **Executive Summary**. Answer the following questions: What activities or designs are covered by this report? What hazards have you identified and eliminated? What analysis have you performed and why do you conclude that the activities/designs are low risk? Be sure you consider all aspects of your project: experimental data collection, component design, system design, manufacturing, assembly, and testing.

2. **Experimentation Plans Prior to Design Completion**. For your experimentation, list what data you will be collecting and why. Are any experiments that might have safety risks unnecessary? Why/Why not?

3. **Purchased Component and Material Inventory**. Provide an inventory of all materials (solid materials such as aluminum/wood/etc.) and purchased components you will be using. Why are these materials and components necessary?

    a. Complete an FMEA for any purchased components that have safety risks. Provide the FMEA table as an appendix to this Safety Report and summarize the results in your own words for the main report body.

4. **CAD Drawings and DesignSafe Summary for Designed Parts**. Provide CAD drawings for components you have designed and will manufacture.

    a. Conduct a risk assessment using Designsafe software (available on CAEN) for each designed component and for the full assembly of components constituting your design. Provide the Designsafe output as an appendix to this safety report and summarize the results in your own words for the main report body.

5. **Manufacturing**. Provide a list of all fabrication or manufacturing activities you will perform. Where will these activities take place? Why are these processes necessary?

    a. CAD drawings for parts to be manufactured are required (per #4 above).

    b. For machining or forming processes, list special setup requirements and the operational conditions that will be employed (e.g., speeds, feeds, etc.).

6. **Assembly**. How and where will your components be assembled? On what basis do you conclude that the assembly will not fail before use, during use, or after use?

7. **Design Testing and Validation**. How and where will your final design be tested? Which design specifications are being validated through the testing? Do you plan to test aspects of your design as you manufacture your prototype, or are you going to be validating a finished prototype after most/all manufacturing has been completed?

    a. What would you consider to be your first major test of the design?

   b. Have you arranged with your Section Instructor to have a cognizant individual present at your first major test? Who will this be? When do you expect this first test to take place?

8. **Additional Appendices**:

   a. For every chemical (powder, liquid, gas – distinguished from a “material” defined in step 2 above as a solid) you propose for use in testing or design, you must supply a complete MSDS as an appendix.

   b. If relevant safety documentation is provided with a purchased component, include it as an appendix.

9. **Submission**. After addressing points 1-8 above, please do the following:

   a. Submit this report to your Section Instructor for signature. Please check with your Section Instructor to learn if a hard copy or an electronic copy is preferred for signature. Regardless, please create an electronic copy for filing and email to Bob Coury and Dan Johnson (below).

   b. After the report is signed, email a copy to Bob Coury (hornet@umich.edu) and our course GSI Dan Johnson (danijohn@umich.edu)

      i. Both Bob and Dan are expected to raise additional safety concerns that will be shared with the students and the Section Instructor. They have the authority to stop any activity they deem unsafe, regardless of whether a safety report has been signed. If this happens, the safety report will be revised and re-signed by the Section Instructor, then emailed with revisions to Bob Coury and Dan Johnson.

1. **Executive Summary**.

Initial Experimentation Elements

No experimental work needs to be done prior to the design.

Design Elements

The design task that our team has undertaken this semester has several elements to consider. Our mechanism as a whole will have large moving parts that can pose as a safety concern if not properly designed. The most important safety feature that we will implement in our design is an emergency switch that will cut the power to our mechanism in the event of a rare emergency. For our camera/light source design we selected a motor that will provide over 8 times the torque required from our calculations. For our crankshaft rotation design we have selected a motor that will provide approximately 5 times the torque required to turn the crankshaft at 30 rpm. To power our pneumatic cylinder we have selected a pressure tank that can hold over 2 times the maximum pressure needed to secure the crankshaft into the mechanism. Due to these safety factors, we are confident that we have minimized the risks involved in our automated crankshaft inspection mechanism.

Manufacturing Elements

For the components of our design that we will manufacture ourselves, we will need to utilize our previous knowledge from machine shop training to safely machine our parts. We will use CNC milling, drilling, press fitting, cutting via water jet and welding to produce and join the various components that will be needed for our project. Most of our team members have advanced machining knowledge and experience through work and university clubs, but we will still request supervision if concerned about specific machine shop procedures and will always follow proper machine shop safety protocol. We will be cautious of the fast moving equipment, sharp edges, and flying debris that come along with our own processes, as well as any surrounding groups' processes.

Assembly Elements

Most of the assembly of our prototype will be very low-risk processes, as many of the components will be assembled with fasteners or screwed together directly. There are, however, welding operations required for our base structure and several mounting brackets. These operations can pose a high-risk situation if not handled correctly. Wearing the proper gear, shoes, and eye protection, along with expert supervision will be necessary safety precautions during this welding process.

Testing Elements

We are confident that we have designed our mechanism to support the static and dynamic demands of rotating a crankshaft. Testing our mechanism after everything has been designed, manufactured, and assembled should be a low-risk safety concern so long as we are familiar and comfortable with powering and controlling our motors prior to testing it with the crankshaft and camera/light source in place.

2. **Collected Data**

We will have several components of our mechanism interfaced to the computer using LabVIEW software. We will be collecting data from an optical encoder to determine the position of the crankshaft during its rotation, from the camera/light source stepper motor driver to determine the translational distance across the crankshaft, and lastly from the camera itself when it takes a picture of each surface to be inspected. All three of these inputs to LabVIEW are necessary to properly position the camera/light source in front of the crankshaft as well as obtain a picture of each inspection surface. The means to collect this data does not pose a safety concern to our team.

In order to collect this data, however, the tests themselves will involve large moving parts and a pressurized tank thus posing some safety risks to our team. There is a risk of rupture/explosion of the pressurized tank, as well as obvious risks of getting too close to the moving parts of our mechanism. These tests are necessary though, as our customer requirements cannot be met with a different procedure. We believe that we have minimized the sources of danger in our project as well as built in safety features and factors which allow safe operating conditions and quick stopping of our test in the event of an emergency.

3. Prototype Material and Purchased Component Inventory

Our final working prototype will contain a combination of manufactured and purchased components. The figures below describe the final complete prototype. Each part/material in the following inventories is marked to show its position in our final prototype. We have been fortunate to have some of our components donated by QPAC, a crankshaft micro-polishing company based in Lansing MI, and these components (along with other components that were given to us by our sponsor) are described below. It should be noted that not all of the parts are shown for figure clarity.

a. *Raw Materials Inventory*

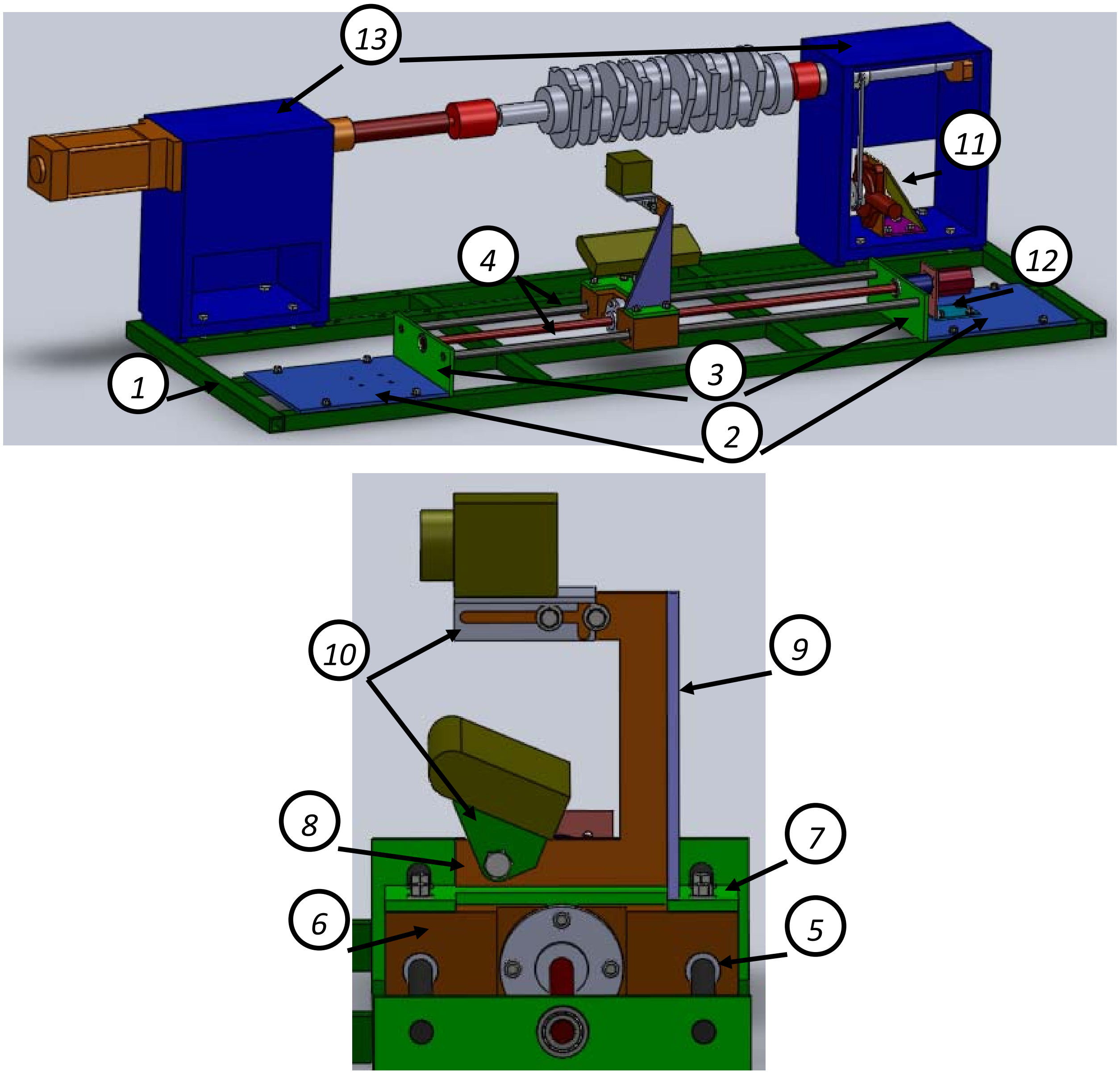


Figure 1: Top: Complete Isometric View showing components using raw materials. Bottom: Camera/Light Assembly showing components using raw materials.

The following is the raw material inventory for manufactured components. The numbers refer to Figure 1, pg. 6.

1. Mechanism Base
   - Material: Low-Carbon Steel Square Tube
   - Stock Shape & Dimensions: Square - 1"X1", .120" Wall Thickness, 6' Length (x5) (4 pieces 54" long, 2 pieces 20.5" long, 2 pieces 3" long, 2 pieces at 7.5" long, 2 pieces at 6" long)
   - Source: www.mcmaster.com

   Description:
   The mechanism base is built of square steel tubing welded together at butt joints. Holes will then be drilled to bolt down the mechanism itself. This base will be clamped to a movable cart for ease of transportation.

2. Camera Rod Support Base
   - Material: Multipurpose Aluminum (Alloy 6061)
   - Stock Shape & Dimensions: Plate - 1/4" Thick, 8" Width, 1' Length (x2)
   - Source: www.mcmaster.com

   Description:
   The Camera Rod Support Bases provide a means to bolt down the entire camera translation system. These will be welded to #3, the Camera Rod Support Ends. Holes will be put in both to bolt to the Mechanism Base, and on one to attach the Stepper Motor Stand.

3. Camera Rod Support Ends
   - Material: Multipurpose Aluminum (Alloy 6061)
   - Stock Shape & Dimensions: Plate - 1/4" Thick, 8" Width, 1' Length (x1)
   - Source: www.mcmaster.com

   Description:
   The Camera Rod Support Ends will support the slider rods (#4) as well as the bearing that will support the screw. Holes will be put in the component to accept the rods and the screws. It will then be welded to the Camera Rod Support Base.

4. Slider Rods
   - Material: Unhardened Precision Steel Drive Shaft
   - Stock Shape & Dimensions: Cylinder - 1/2" OD, 72" Length
   - Source: www.mcmaster.com

   Description:
   The Slider Rods will support the Camera/Light Structure, allowing it to easily translate across them. The two rods will be cut from the 72" length of shaft.

5. Slider Bushings
    - Material: Alloy 932 (SAE 660) Bronze Sleeve Bearing
    - Stock Shape & Dimensions: Cylinder - 1/2" Shaft Diameter, 3/4" OD, 3" Length
    - Source: www.mcmaster.com

    Description:
    The Slider Bushings act as a bearing to allow the Camera/Light Structure to easily translate back and forth on the Slider Rods.

6. Camera Base
    - Material: Aluminum (Alloy 6061)
    - Stock Shape & Dimensions: Square - 3" Thick, 8" X 8"
    - Source: McMaster-Carr

    Description:
    The Camera Base is the foundation for the entire camera/light structure. This slides along the Slider Rods and is a means to attach the camera and light stand.

7. Camera Stand Base
    - Material: Multipurpose Oversize Aluminum (Alloy 6061)
    - Stock Shape & Dimensions: Plate - 1/4" Thick, 8" X 8"
    - Source: www.mcmaster.com

    Description:
    The Camera Stand Base is the bottom plate of the Camera Stand. This is welded to the Camera Stand Attachment Plate, and the Camera Stand Rigidity Plate. It is then bolted to the Camera Base.

8. Camera Stand Attachment Plate
    - Material: Multipurpose Aluminum (Alloy 6061)
    - Stock Shape & Dimensions: Plate - 1/4" Thick, 6" Width, 1' Length
    - Source: www.mcmaster.com

    Description:
    The Camera Stand Attachment Plate is welded to the Camera Stand Base and the Camera Stand Rigidity Plate. This is where the Camera and Light brackets attach to.

9. Camera Stand Rigidity Plate
    - Material: Multipurpose Aluminum (Alloy 6061)
    - Stock Shape & Dimensions: Plate - 1/4" Thick, 6" Width, 1' Length
    - Source: www.mcmaster.com

Description:
The Camera Stand Rigidity Plate is welded to the Camera Stand Base and Attachment Plates. This plate gives the entire Camera Stand its rigidity as it is translated across the Slider Rods.

10. Camera/Light Mounting Brackets
    - Material: Corrosion Resistant Aluminum (Alloy 5052)
    - Stock Shape & Dimensions: Plate - 1/8" Thick, 3" Width, 1' Length
    - Source: www.mcmaster.com

    Description:
    The Camera/Light Mounting Brackets provide a means to attach the camera and light to the Camera Stand Attachment Plate. These also provide a means of adjustment to the positions of the camera and light.

11. Crankshaft Motor Stand
    - Material: Corrosion Resistant Aluminum (Alloy 5052)
    - Stock Shape & Dimensions: Plate - 1/8" Thick, 3" Width, 1' Length
    - Source: www.mcmaster.com

    Description:
    The Crankshaft Motor Stand provides a means of attaching the Crankshaft Motor to the Driven Stand.

12. Stepper Motor Stand
    - Material: Corrosion Resistant Aluminum (Alloy 5052)
    - Stock Shape & Dimensions: Plate - 1/8" Thick, 2-1/2" Width, 1' Length
    - Source: www.mcmaster.com

    Description:
    The Stepper Motor Stand provides a means of attaching the Stepper Motor to the Camera Rod Support Base.

13. Driven and Rolling Crankshaft Stands
    - Material: Mostly Steel
    - Stock Shape & Dimensions: Box – 12”x10”x6” with .5” to .75” wall thickness
    - Source: Donated by QPAC

    Description:
    The Driven and Rolling Crankshaft Stands bolt to the Mechanism Base and provide the means of supporting the crankshaft and rotating it. These are made of .5” to .75” thick steel plates welded together.

b. Purchased Components Inventory

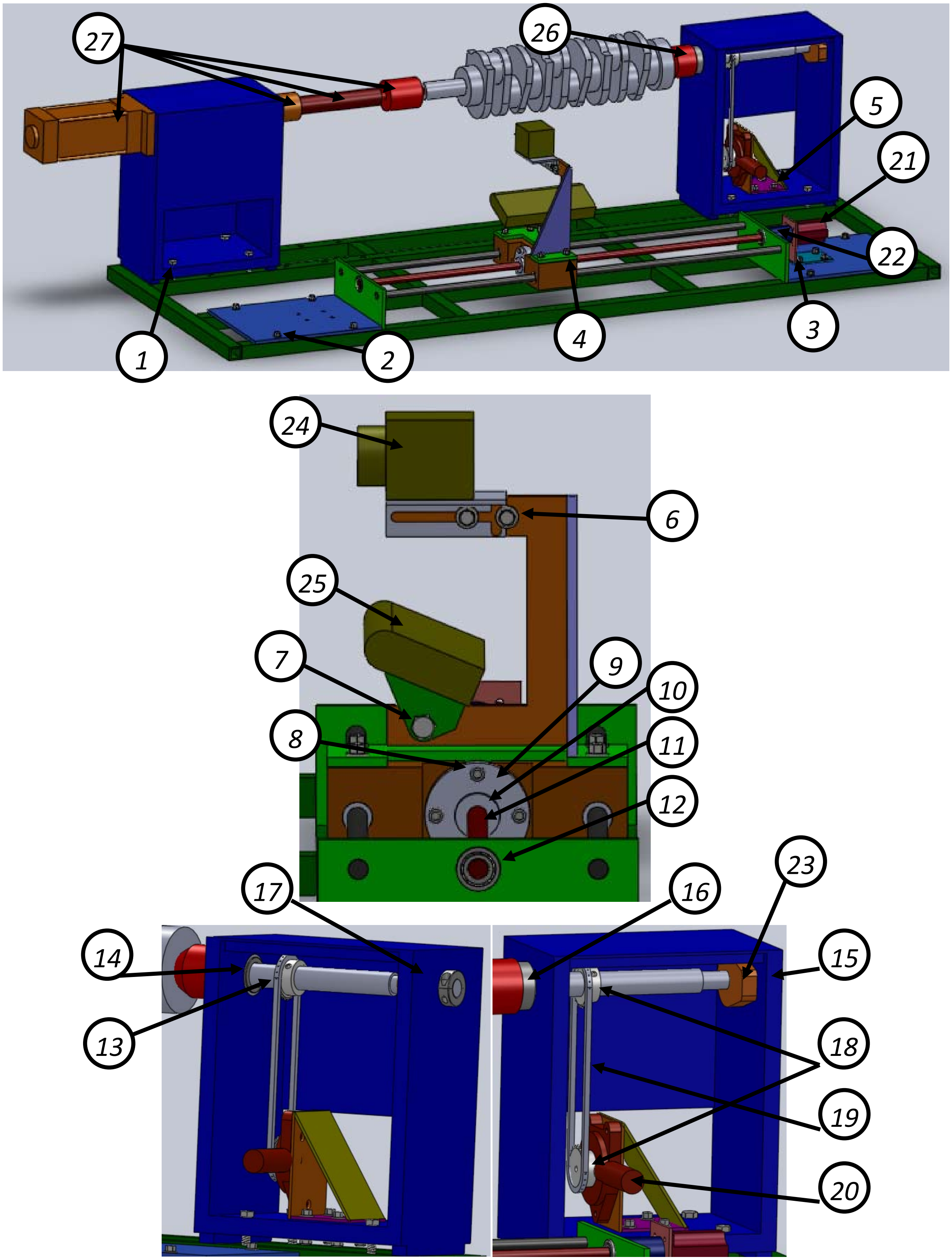


Figure 2: Top: Complete Isometric View showing purchased components. Middle: Camera/Light Assembly showing purchased components. Bottom: Driven Stand showing purchased components.

The following is a description of the purchased component inventory. The numbers refer to Figure 2, on pg 10.

1. Driven and Rolling Stand Bolts and Nuts
    - Quantity: 8 Bolts and 8 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 91247A221, Nut: 90630A155

    Description:
    These bolts are 3/8” diameter, 1.75” length used to bolt the Driven and Rolling Stands to the Mechanism Base. They are mated with locking nuts with the same thread dimension.

2. Rod End Support Base Bolts and Nuts
    - Quantity: 8 Bolts and 8 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 92979A122, Nut: 95615A120

    Description:
    These are ¼” diameter, 1” length bolts used to bolt down the Rod End Support Base to the Mechanism Base. They are mated with locking nuts with the same thread dimension.

3. Stepper Motor Stand Bolts and Nuts
    - Quantity: 4 Bolts and 4 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 92979A122, Nut: 95615A120

    Description:
    These are ¼” diameter, 1” length bolts used to bolt down the Stepper Motor Stand to the Rod End Support Base. They are mated with locking nuts with the same thread dimension.

4. Camera Stand Base Plate Bolts
    - Quantity: 4
    - Vendor: www.mcmaster.com
    - Catalog Listing: 92979A122

    Description:

These are ¼” diameter, 1” length bolts used to bolt down the Camera Stand Base Plate to the Camera Base. They are threaded into the Camera Base itself.

5. Crankshaft Motor Mount Bolts and Nuts
    - Quantity: 4 Bolts and 4 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 92979A122, Nut: 95615A120

Description:
These are ¼” diameter, 1” length bolts used to bolt down the Crankshaft Motor Mount to the Driven Stand. They are mated to lock nuts with the same thread dimensions.

6. Camera Mounting Bracket Bolts and Nuts
    - Quantity: 2 Bolts and 2 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 92979A122, Nut: 95615A120

    Description:
    These are ¼” diameter, 1” length bolts used to bolt the Camera Mounting Bracket to the Camera Stand Attachment Plate. They are mated with locking nuts with the same thread dimension.

7. Light Mounting Bracket Bolt and Nut
    - Quantity: 1 Bolt and 1 Nut
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 92865A215, Nut: 90630A155

    Description:
    This bolt is 3/8” diameter, 1.75” length used to bolt the Light Mounting Bracket to the Camera Stand Attachment Plate. It is mated to a locking nut with the same thread dimension.

8. Flange Attachment Bolts and Nuts
    - Quantity: 4 Bolts and 4 Nuts
    - Vendor: www.mcmaster.com
    - Catalog Listing: Bolt: 90128A554, Nut: 95615A120

    Description:
    These bolts are ¼ inch diameter bolts, 3 inches in length that attach the screw flange to the Camera base. They are mated to locking nuts with the same thread dimensions.

9. Screw Flange
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 95082A642

    Description:
    This Flange provides a foundation for the Screw Nut to attach to. It is bolted to the Camera Base.

10. Screw Nut

- Quantity: 1
- Vendor: www.mcmaster.com
- Catalog Listing: 95072A209

Description:
This nut screws into the Screw Flange. It transmits the torque from the Camera screw into a translational movement.

11. Camera Screw
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 98980A008

    Description:
    This screw is turned by the Stepper Motor. It turns in place and pushes or pulls the Screw Nut, which in turn translates the entire Camera/Light Unit across the Slider Rods.

12. Screw Bearing
    - Quantity: 2
    - Vendor: www.mcmaster.com
    - Catalog Listing: 6383K34

    Description:
    These bearings are roller bearings that allow the Camera Screw to turn in place.

13. Driven Shaft
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 8641T6

    Description:
    This is a dual diameter shaft. It is 1” diameter for 9 inches and ¾” diameter for 3 inches. This allows us to mate a 1” ID sprocket as well as a ¾” ID Optical Encoder.

14. 1” ID Driven Shaft Bearing
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 7929K43

    Description:
    This is a roller bearing that allows the Driven Shaft to rotate in place.

15. ¾” ID Driven Shaft Bearing (not shown)

- Quantity: 1
- Vendor: www.mcmaster.com
- Catalog Listing: 5905K26

Description:
This is a roller bearing that allows the Driven Shaft to rotate in place.

16. Driven Shaft Thrust Bearing
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 60715K15

    Description:
    This Thrust Bearing allows the Cone to press up against the Driven Stand without creating a lot of friction. This will allow the crankshaft to rotate much easier.

17. Locking Collar
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 9961K22

    Description:
    This Collar locks the driven shaft into the Driven Stand. It will keep the entire shaft assembly from slipping out when a crankshaft is not installed.

18. Crankshaft Sprockets
    - Quantity: 2
    - Vendor: www.mcmaster.com
    - Catalog Listing: Motor Sprocket: 2737T151, Shaft Sprocket: 2737T157

    Description:
    These sprockets transfer the Crankshaft Motor’s torque to the Driven Shaft. The Motor Sprocket has a 1” ID, and the Shaft Sprocket has a ¼” ID. Both have an OD of 1.97”.

19. Chain
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 6261K283

    Description:
    This chain connects the two Sprocket gears together in order to transfer the torque from the motor to the driven shaft.

20. Crankshaft Motor

- Quantity: 1
- Vendor: Donated from Smart Materials and Structures Design Lab
- Catalog Listing: None. Window Regulator motor from a CTS Cadallac

Description:
This motor creates the torque and speed needed to rotate the crankshaft. It is powered by a 12V power source.

21. Stepper Motor
    - Quantity: 1
    - Vendor: www.excitron.com
    - Catalog Listing: SM60-45

    Description:
    This stepper motor turns the Camera Screw with translates the entire camera/light mechanism. It is controlled by an accompanying controller through LabView.

22. Connecting Collar
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 3084K31

    Description:
    This collar connects the Stepper Motor to the Camera Screw. It has two bore sizes to adjust for the fact that the Camera Screw diameter and the motor output shaft diameter are different.

23. Optical Encoder
    - Quantity: 1
    - Vendor: www.usdigital.com
    - Catalog Listing: E6-1000-750-I-S-H-D-B

    Description:
    This optical encoder records the angle at which the crankshaft is at in order to take pictures of each surface at the correct time. It's disk is mounted to the 3/4" side of the Driven Shaft and it's case and reader are mounted to the side of the Driven Stand.

24. Camera
    - Quantity: 1
    - Vendor: Provided by the Customer
    - Catalog Listing: Pulnix TM-4200CL, P/N 21014583

    Description:

This camera integrates with a computer through a serial port. It is able to take pictures in a matter of milliseconds and can easily be integrated into LabView. This is what will be used to take each picture of each surface. This will be mounted to the Camera Mount Bracket.

25. Light Source
    - Quantity: 1
    - Vendor: Provided by the Customer
    - Catalog Listing: None

    Description:
    This is a blue LED light source that shines on each surface to give the camera a reflection to photograph. It is mounted to the Light Mount Bracket.

26. Driven Cone
    - Quantity: 1
    - Vendor: Donated by QPAC
    - Catalog Listing: None

    Description:
    This cone was donated by QPAC. It will be mounted to the 1” side of the Driven Shaft through means of a pin. This cone will press into the crankshaft and will be the surface which rotates it.

27. Miscellaneous Stand Pieces
    - Vendor: Donated By QPAC

    Description:
    These pieces are permanently attached to the Rolling Stand. The entire Rolling Stand assembly was donated by QPAC. It consists of the stand itself, a spinning cone, a pneumatic piston and cylinder, and a slide bearing. The stand itself, shown as the blue feature, provides the foundation for the rest of the components. The spinning cone is the bright red feature. This presses into the crankshaft and allows it to rotate. The pneumatic piston is the dark red feature. This is where the spinning cone mounts to. This piston in conjunction with the pneumatic cylinder, the box shaped feature shown in orange, applies a pressure of approximately 90 psi to clamp the crankshaft between the two cones. The cylindrical orange feature is a slide bearing and this allows the pneumatic piston to easily slide back and forth. Not shown in Figure 2 is the pneumatic air valve. This will connect to the air tank and will allow control to open or close the pneumatic piston.

28. Air Tank (Not Shown)
    - Quantity: 1
    - Vendor: Not yet known
    - Catalog Listing: Not yet known

    Description:
    This air tank will be pressurized with 90 psi (rated for 125 psi). It will be used to power the pneumatic piston in order to clamp the crankshaft between the two cones.

29. Air Tank Connections (Not Shown)
    - Quantity: Several
    - Vendor: Home Depot
    - Catalog Listing: Several

    Description:
    These connections include adaptors and air hose in order to connect the air tank to the pneumatic piston.

30. Cart (Not Shown)
    - Quantity: 1
    - Vendor: Donated by The Duderstadt
    - Catalog Listing: None

    Description:
    This cart is a 4 foot long, 2 foot wide steel roll-around cart. It can support 1200 pounds and will be used to transport and support the entire mechanism.

31. 12-Volt Utility Battery (Not Shown)
    - Quantity: 1
    - Vendor: Home Depot
    - Catalog Listing: 12-V Utility

    Description:
    This battery will be used to power the 12-Volt Crankshaft Motor. A Computerized Relay Switch will be used to complete and circuit.

32. Computerized Relay Switch (Not Shown)
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 7266K41

    Description:

This is a Spade-Terminal Relay, 10 Amps, 5-Pin, 12 VDC Input Voltage. It is used to open and close the circuit between the 12-V Utility Battery and the Crankshaft Motor. It will be controlled through a computer.

33. Emergency Stop Switch (Not Shown)
    - Quantity: 1
    - Vendor: www.mcmaster.com
    - Catalog Listing: 6785K27

    Description:
    This is a resettable emergency stop switch. This will be mounted within the operators reach in case of an emergency. It will turn off all power to the mechanism, stopping all motion almost instantly.

34. Wiring (Not Shown)
    - Quantity: Several
    - Vendor: Home Depot
    - Catalog Listing: None

    Description:
    These will include various gauge wires to connect all of the electrical components. This will also include various connections, including battery connections and quick disconnects for ease of transportation.

35. Data Acquisition Unit (Not Shown)
    - Quantity: 1
    - Vendor: Provided by Sponsor
    - Catalog Listing: NI-USB-6251 BNC

    Description:
    This will allow ease of communication between the computer (LabView) and the optical encoder, stepper motor, and the computerized relay switch.

36. Computer (Not Shown)
    - Quantity: 1
    - Vendor: Provided by Sponsor
    - Catalog Listing: None

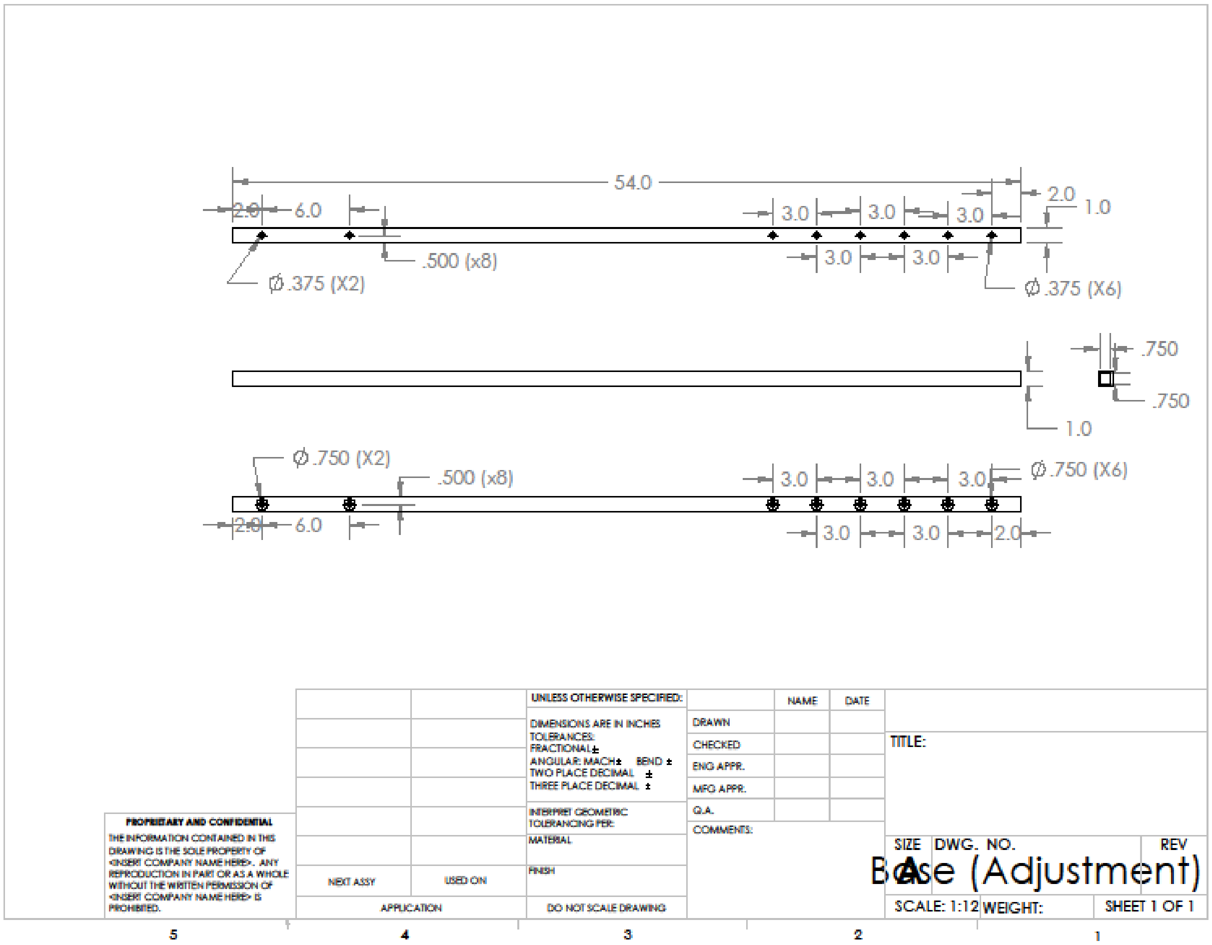
    Description:
    This computer will be used as the main interface between the mechanism and the user. It will be used to set up the machine for a certain crankshaft, to run the inspection, and to analyze the results. All programming will be done using LabView.

c. *FMEA Analysis Results of Purchased Components*

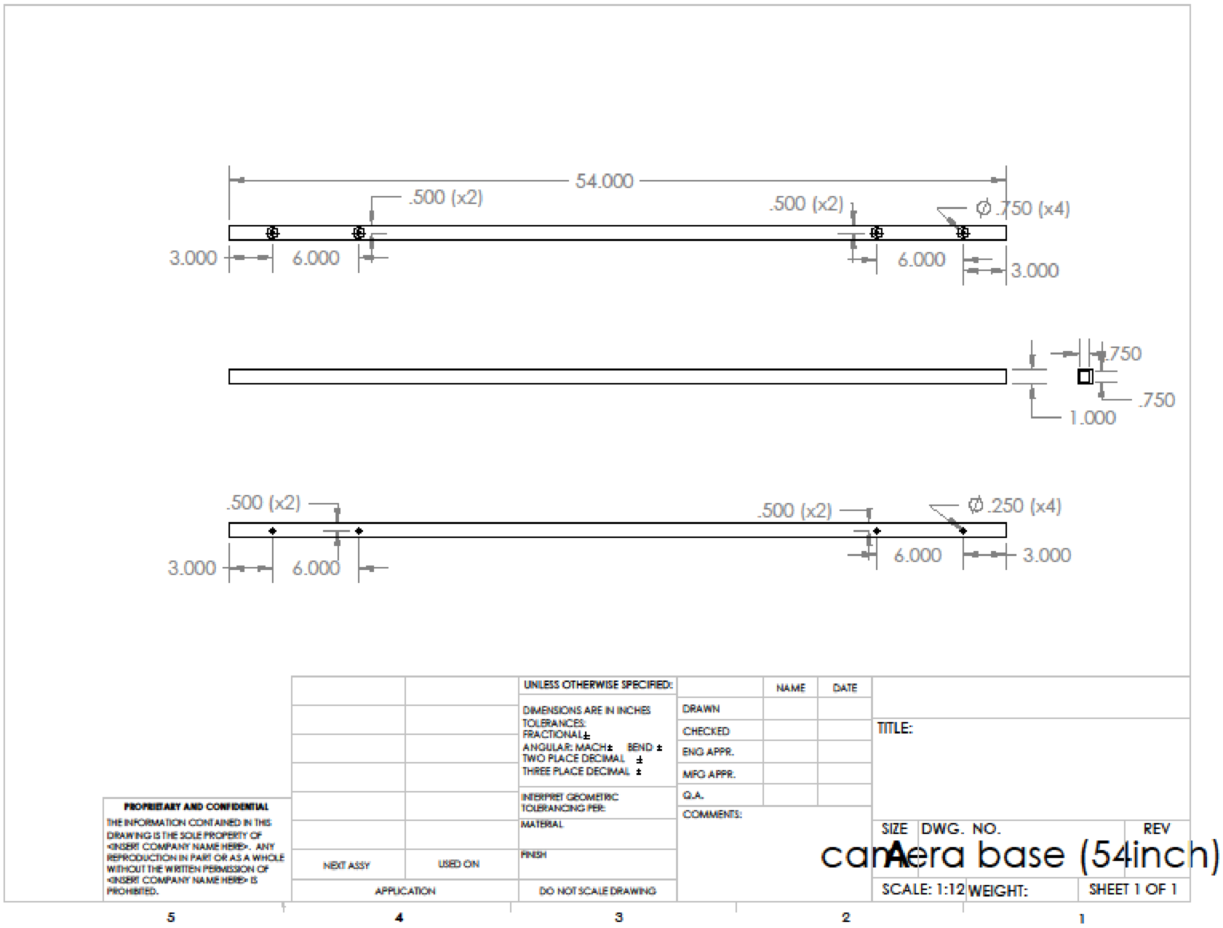
FMEA Analysis was done on the components that were deemed to be the most likely to fail. For our mechanism only one sub-system was deemed most likely to fail; this being the pressurized system including the air tank, its connections, and the pneumatic piston. A complete failure of any of these parts would be catastrophic due to the high pressures being used; however a much less severe gas leak is more likely. These leaks could occur around the pneumatic piston seals, any connections, or any cracks in the walls of the air tank. These leaks, if undetected, could cause the pneumatic piston to lose its clamping pressure over time. Once enough pressure is lost, the crankshaft being supported may become dislodged and fall, creating a hazard. This hazard can be easily avoided by checking each connection prior to any mechanism test. Pressure can be increased slowly while the operator listens for leaks and makes adjustments as needed before pressures become dangerous. It should also be noted that any failure of the air tank itself will be extremely rare as it is rated for a psi of 125, but we will only be putting in 90 psi. It can also be ensured that the system will see a maximum of 90 psi due to the fact that the supply air that will be used (air in GG Brown) is at a maximum of 90 psi.

4. CAD Drawings of Designed Parts

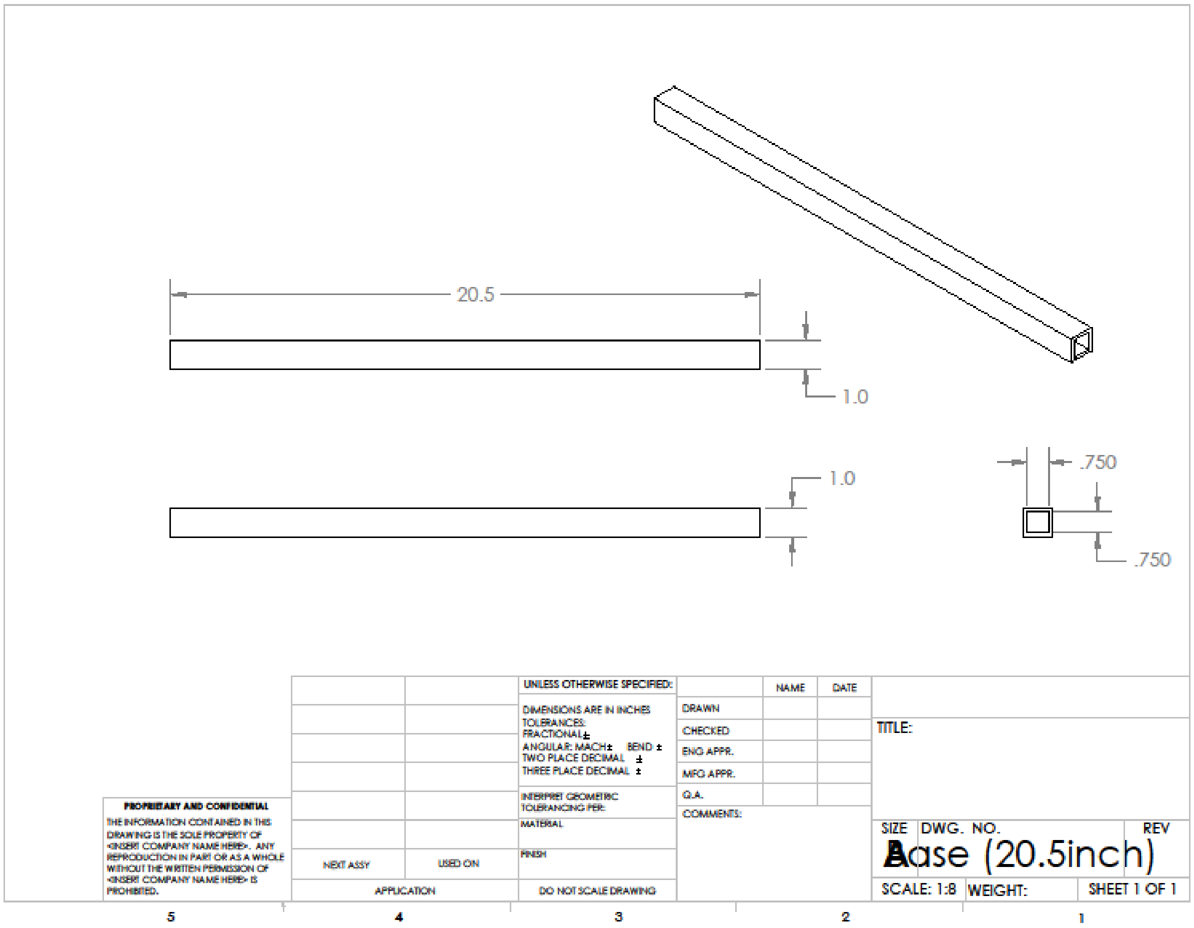
a. 54” Length Square Tube with Holes to mount Driven and Rolling Stands (x2)



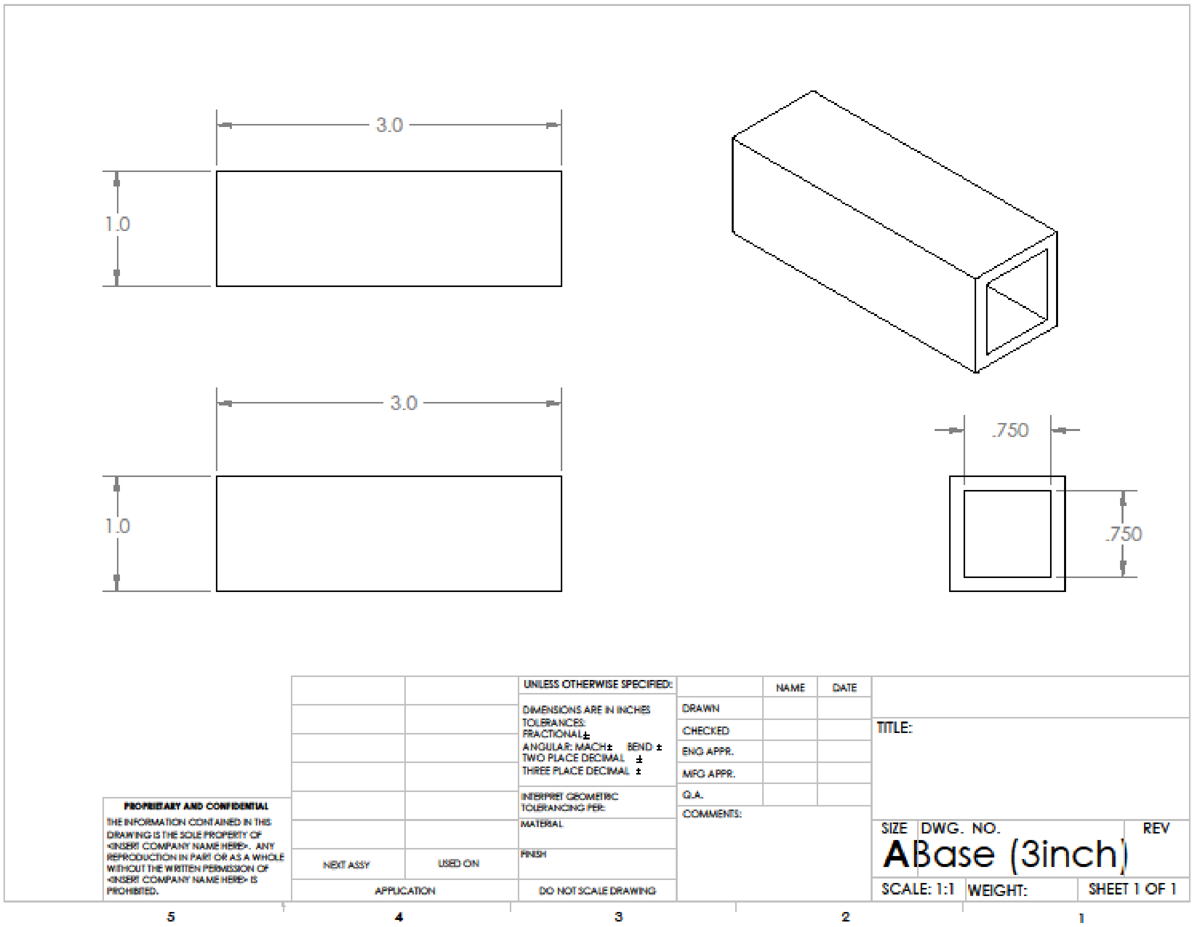
b. 54" Length Square Tube with Holes to mount Camera Rod End Support Base (x2)



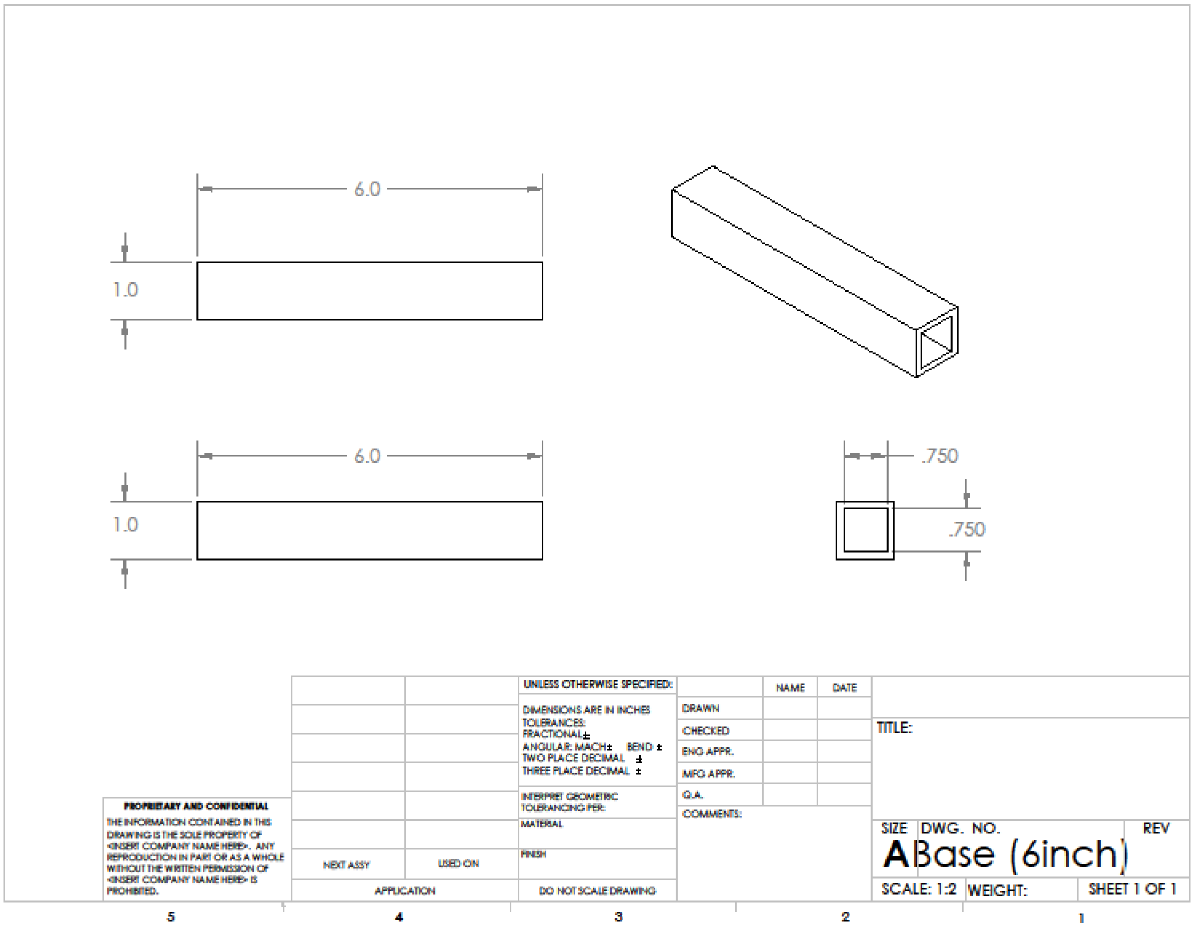
c. 20.5” Length Square Tubes for Mechanism Base (x2)



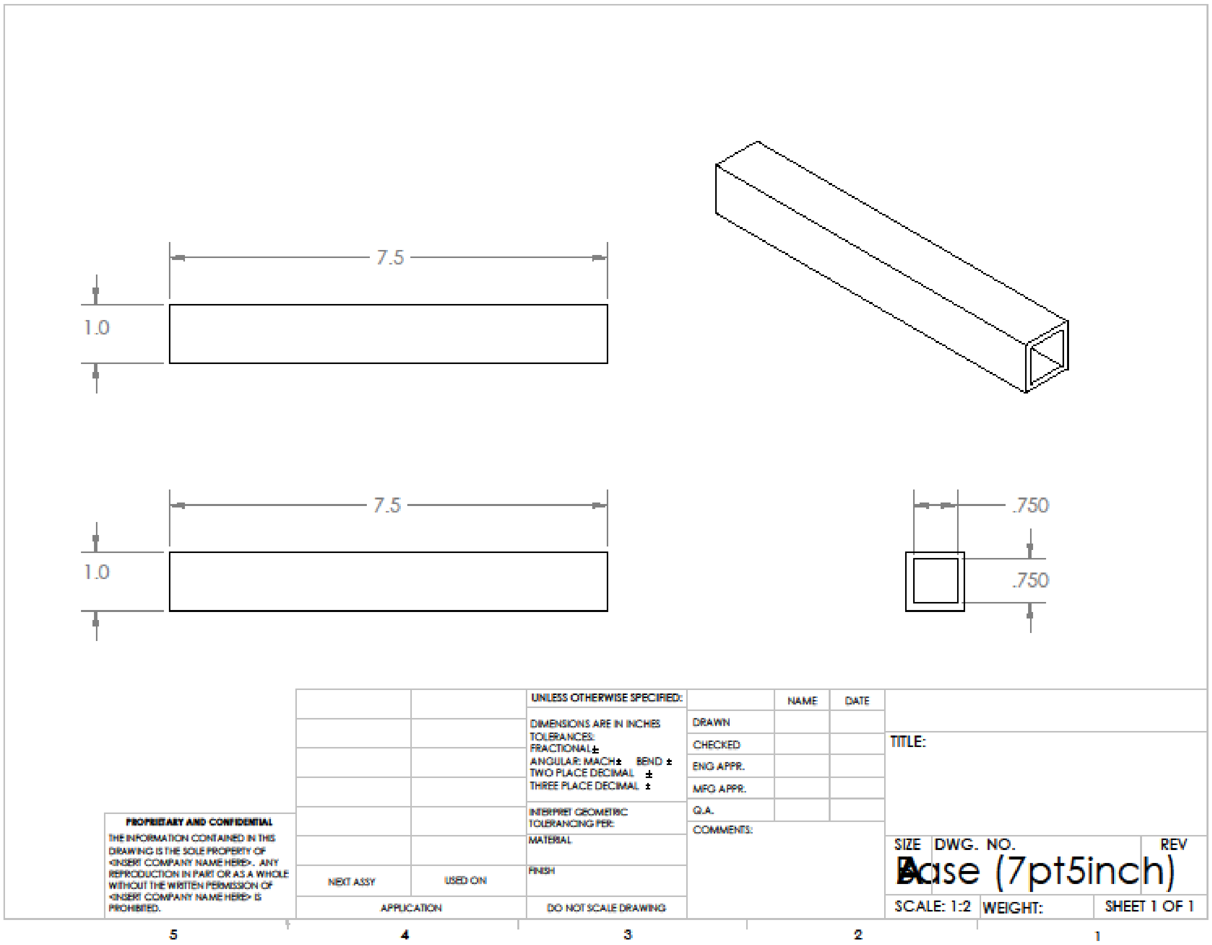
d. 3” Length Square Tubes for Mechanism Base (x2)



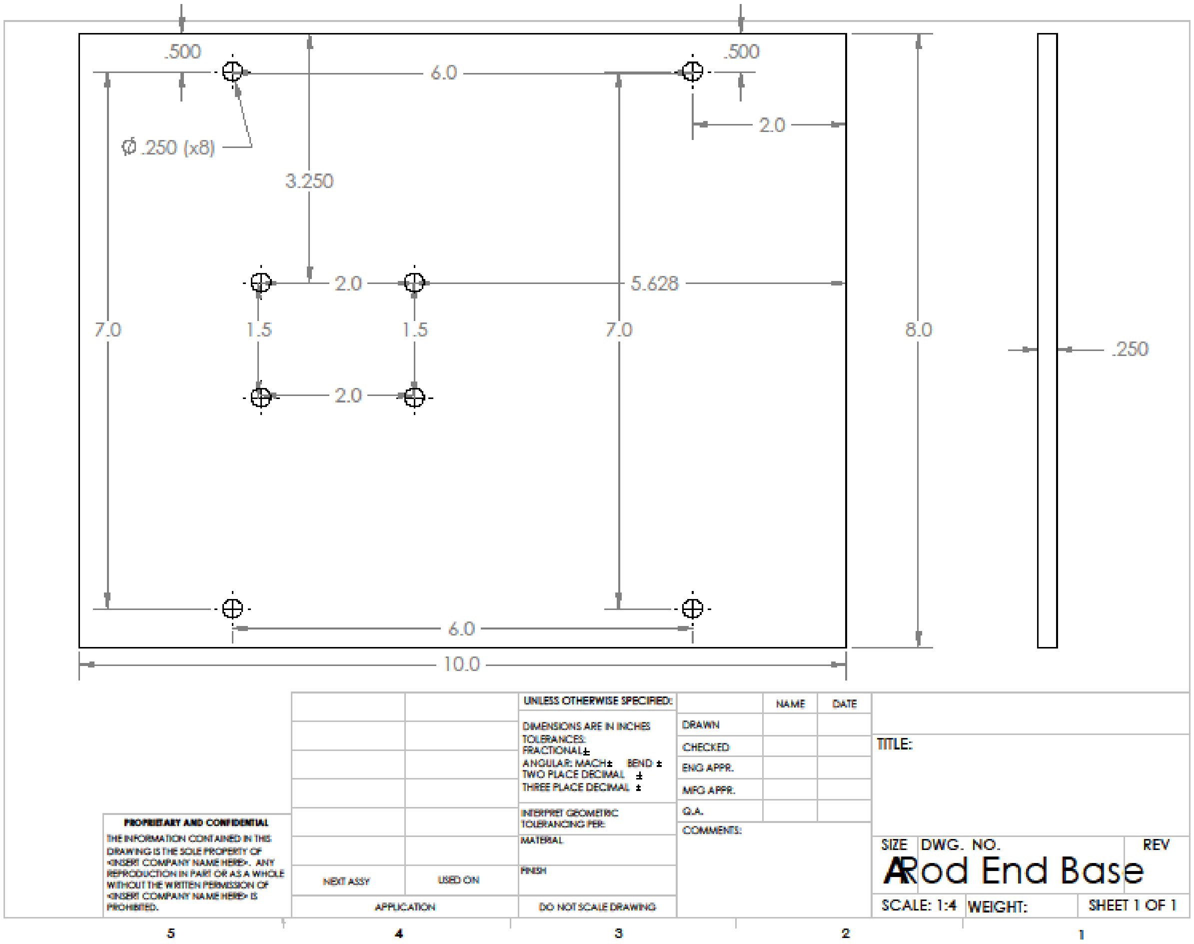
e. 6” Length Square Tubes for Mechanism Base (x2)



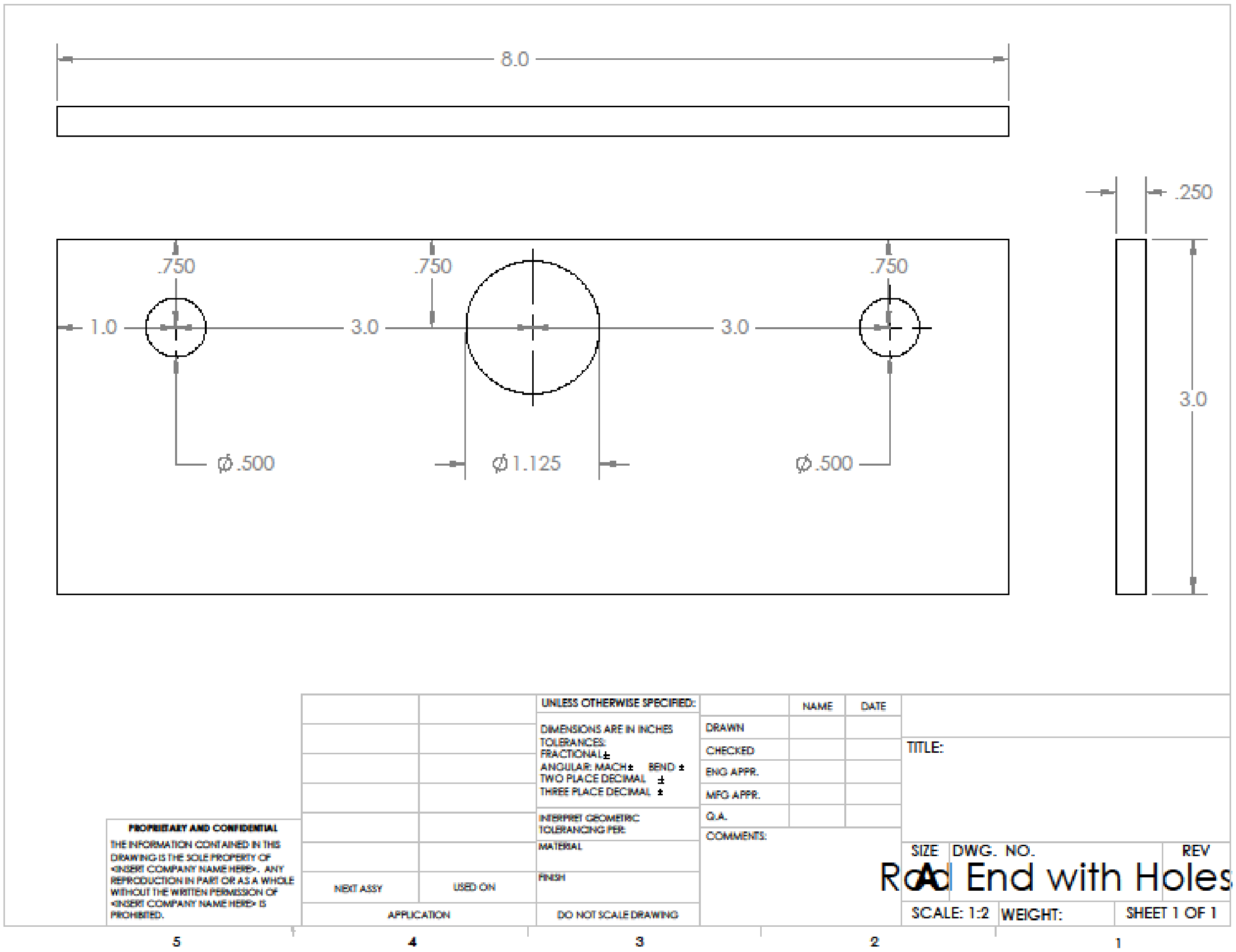
f. 7.5” Length Square Tubes for Mechanism Base (x2)



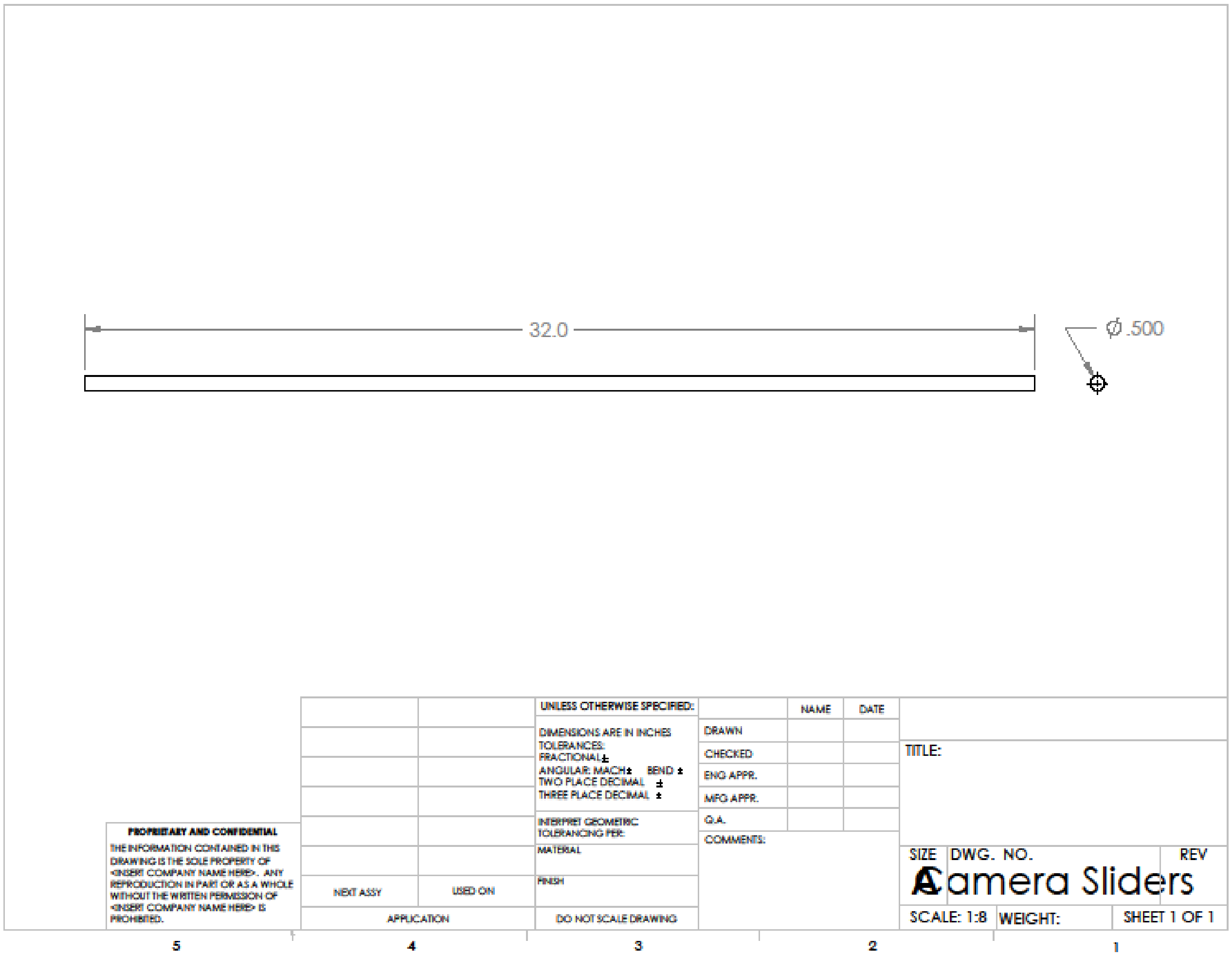
g. *Camera Rod End Support Base (x2)*



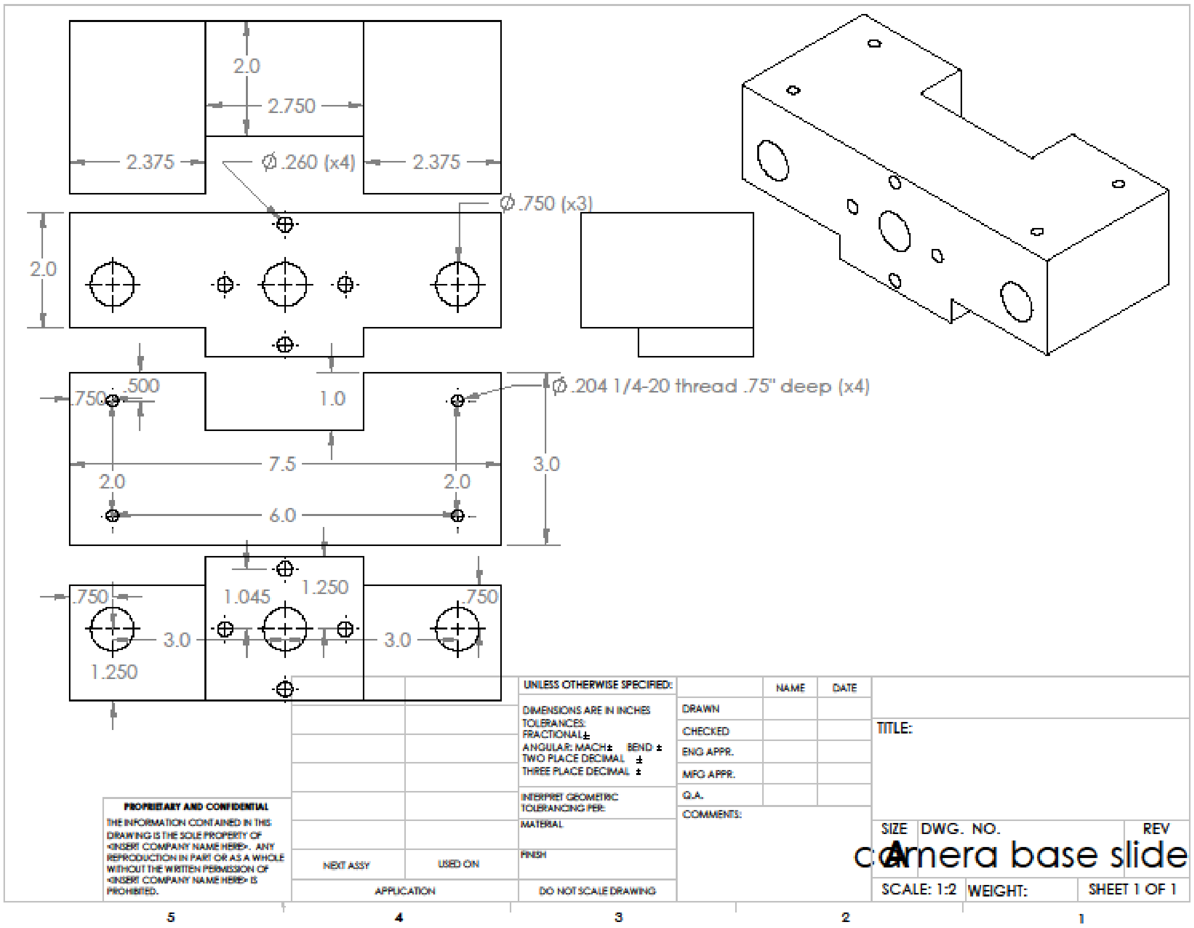
h. Camera Rod End Supports (x2)



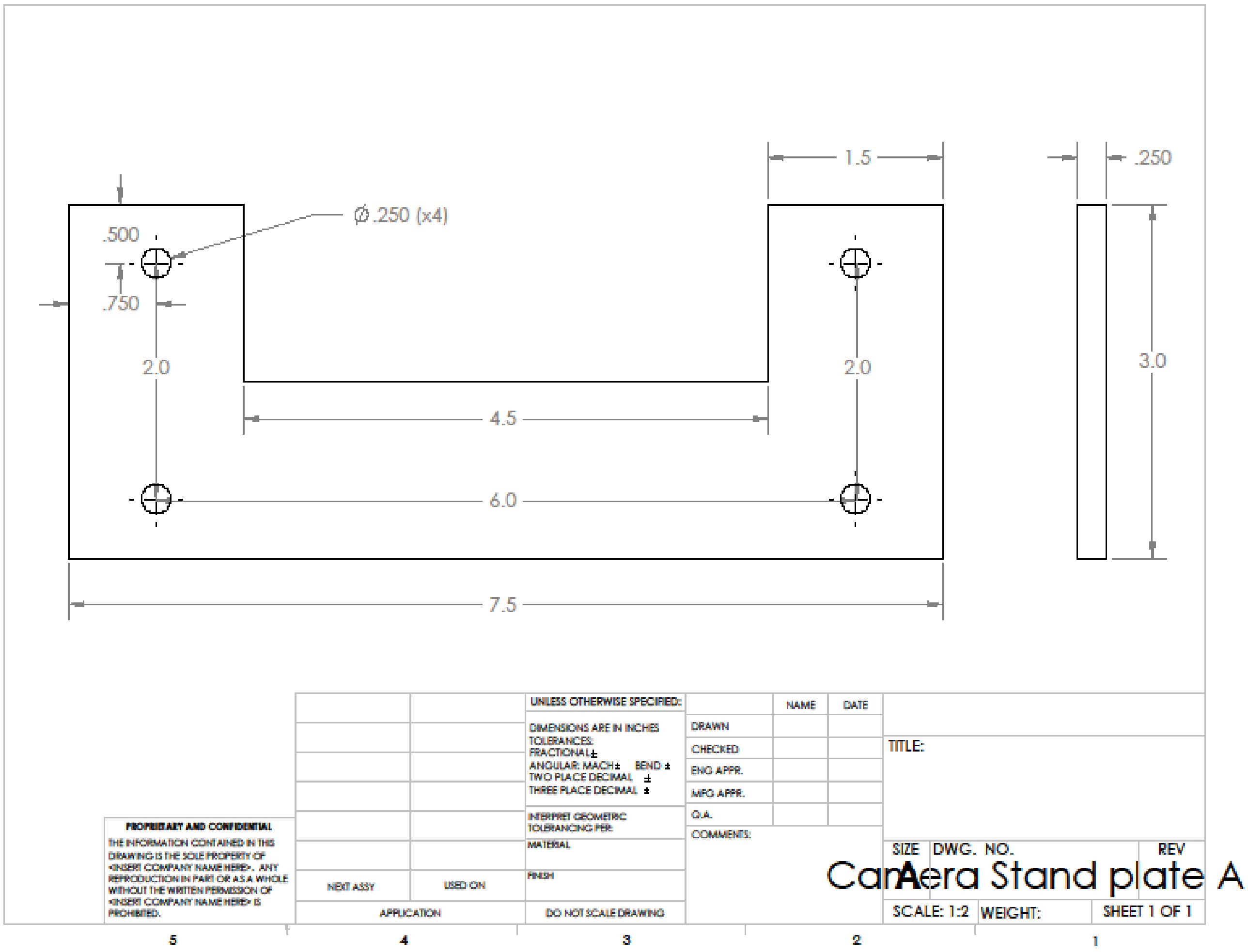
i. Slider Rods (x2)



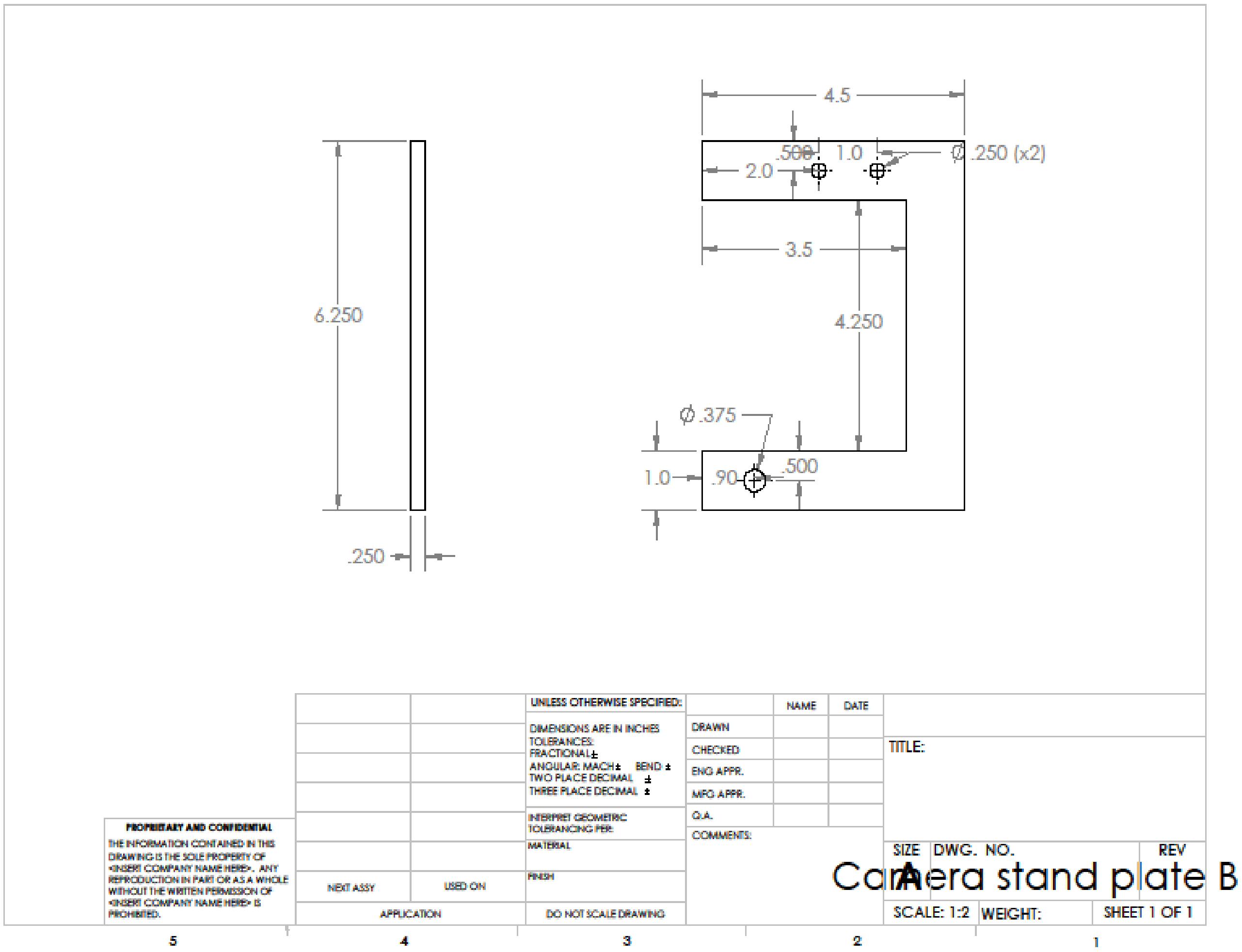
j. *Camera Base*



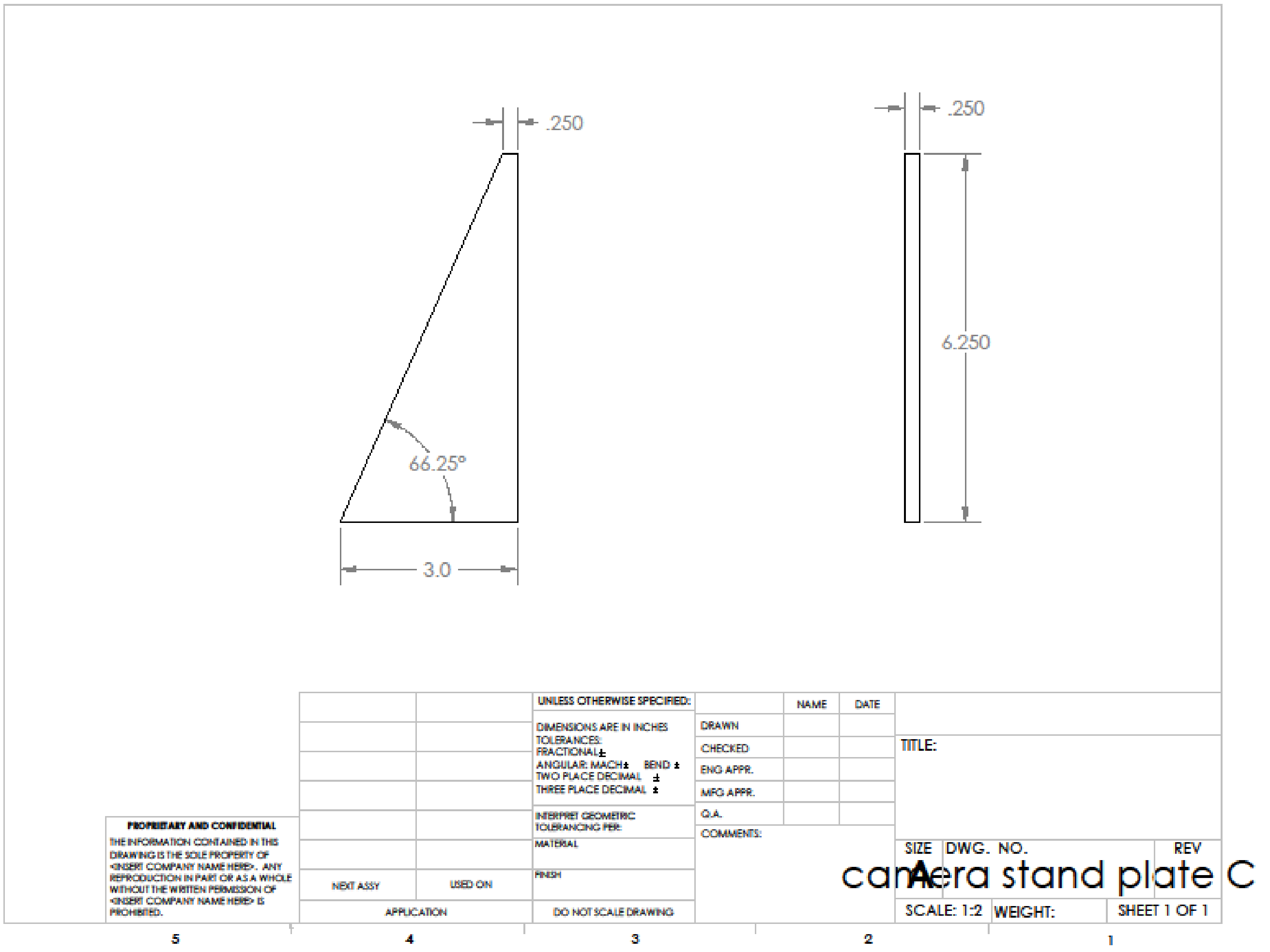
k. Camera Stand Base Plate



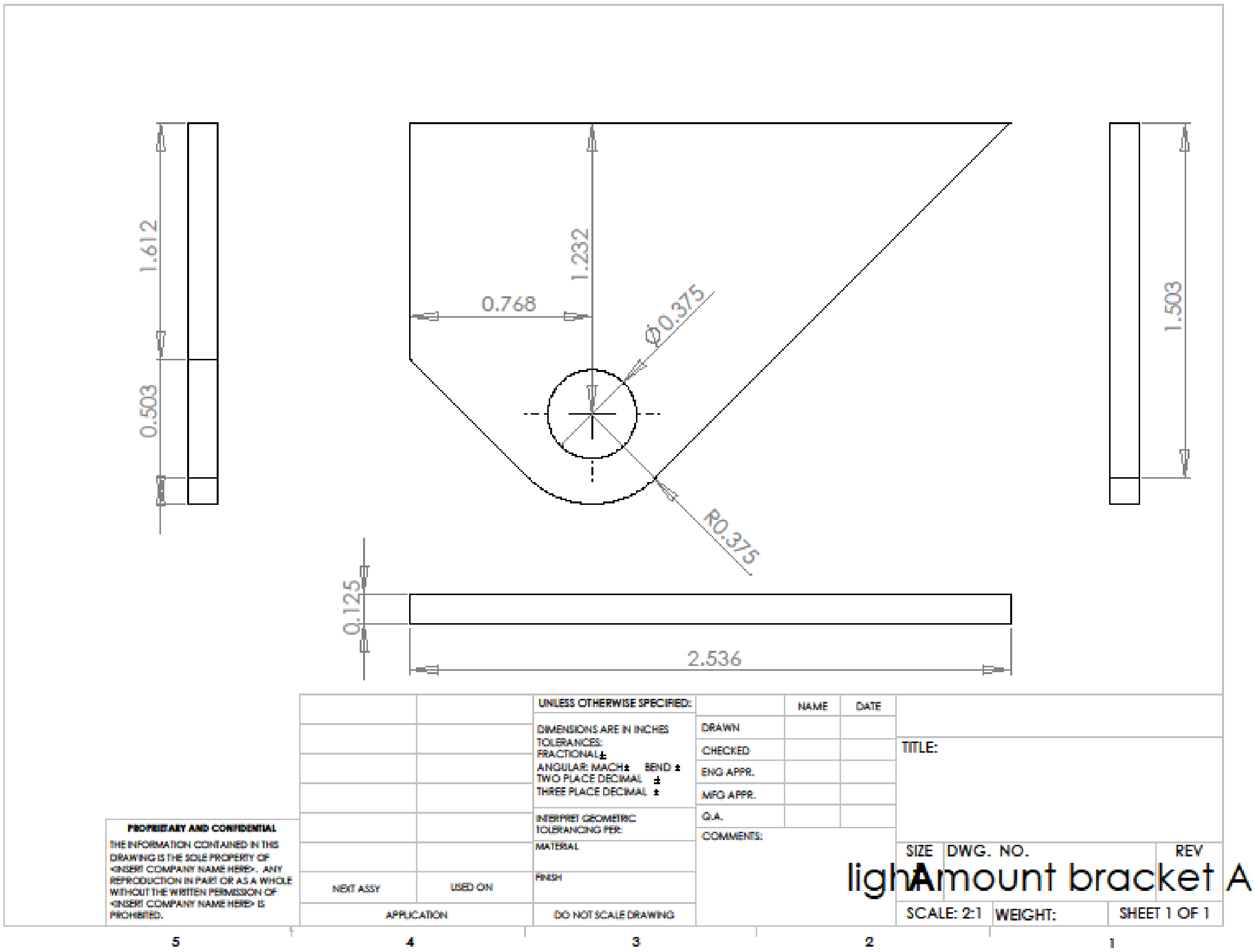
l. Camera Stand Attachment Plate



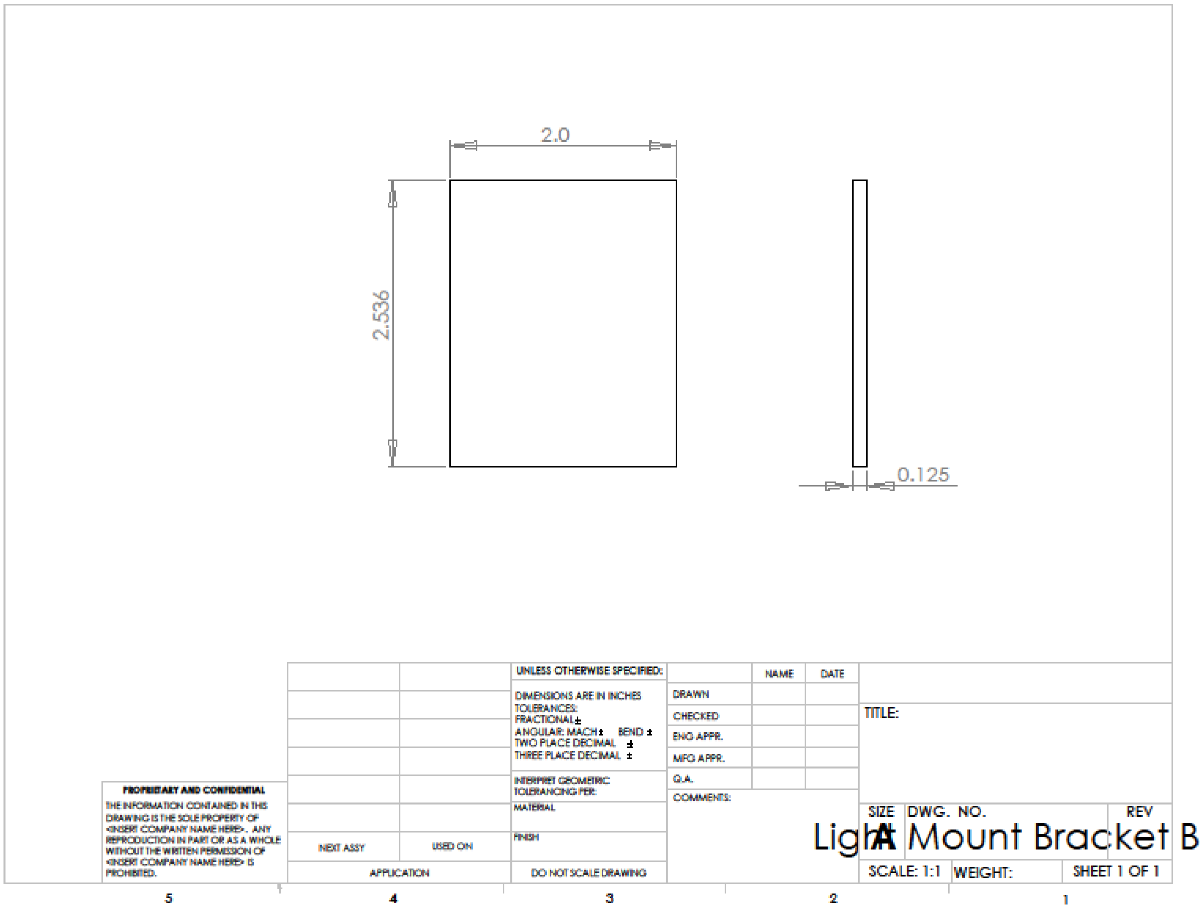
m. *Camera Stand Rigidity Plate*



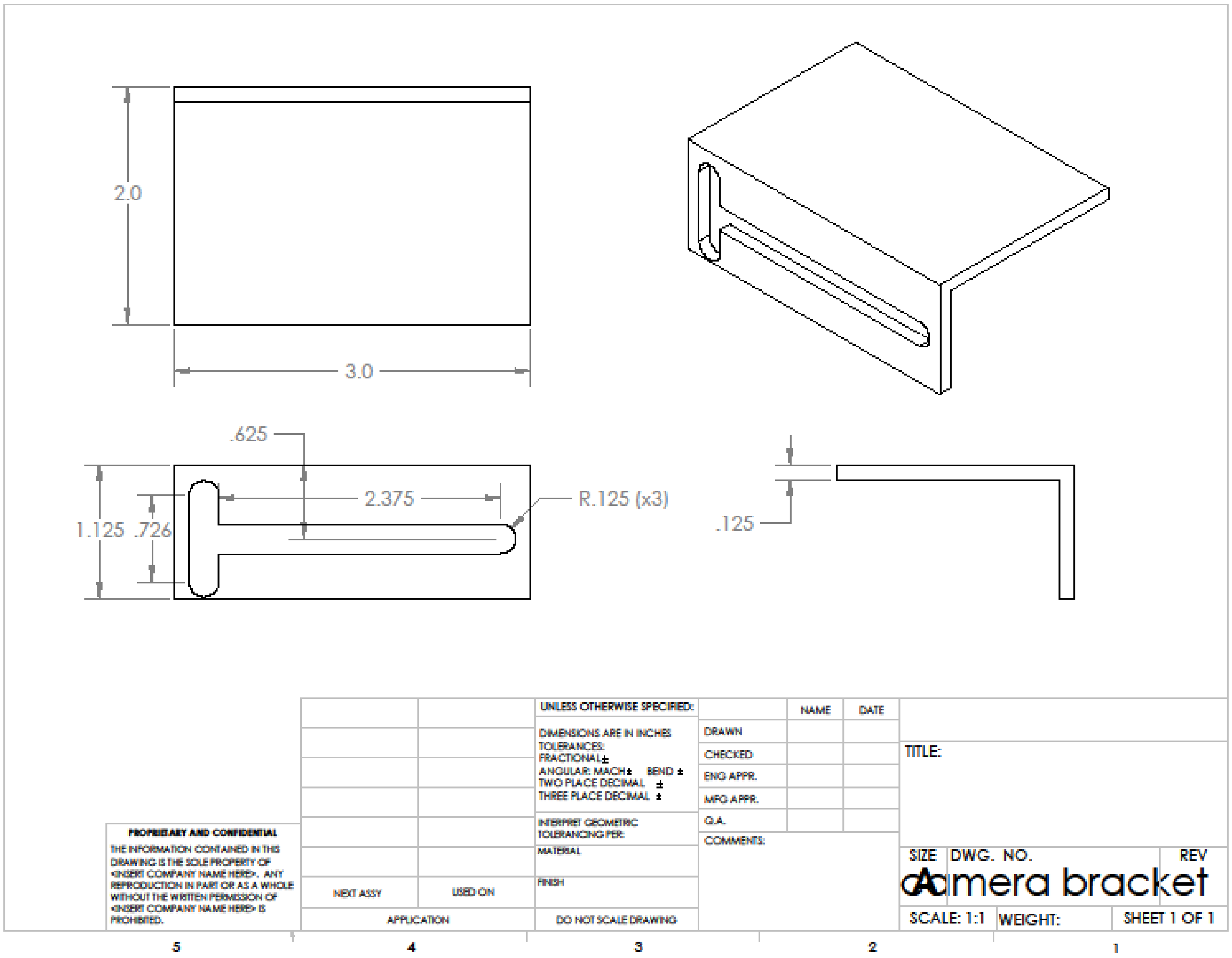
n. Light Source Mount Bracket Bolt Side



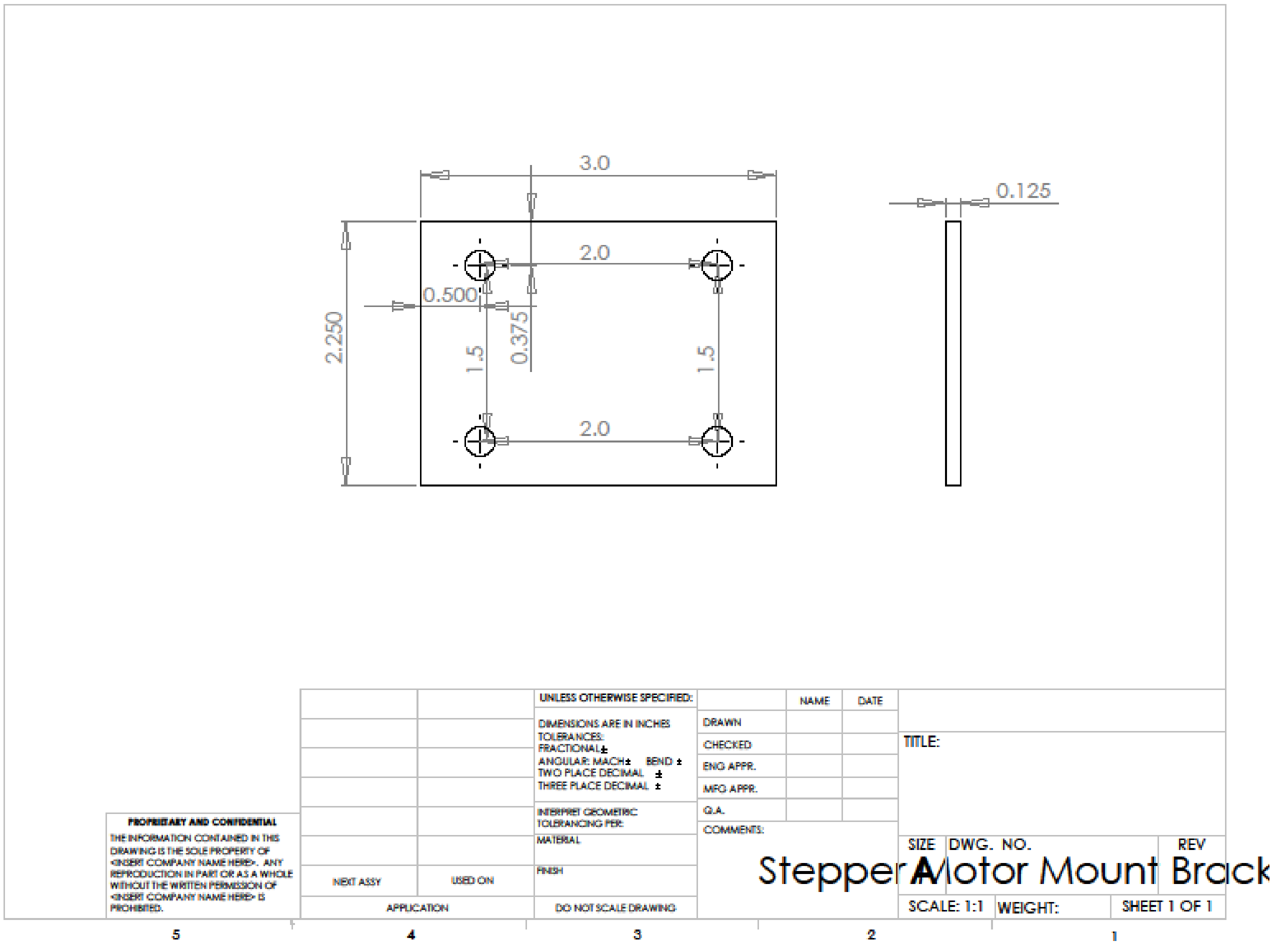
o. Light Source Mount Bracket Light Side



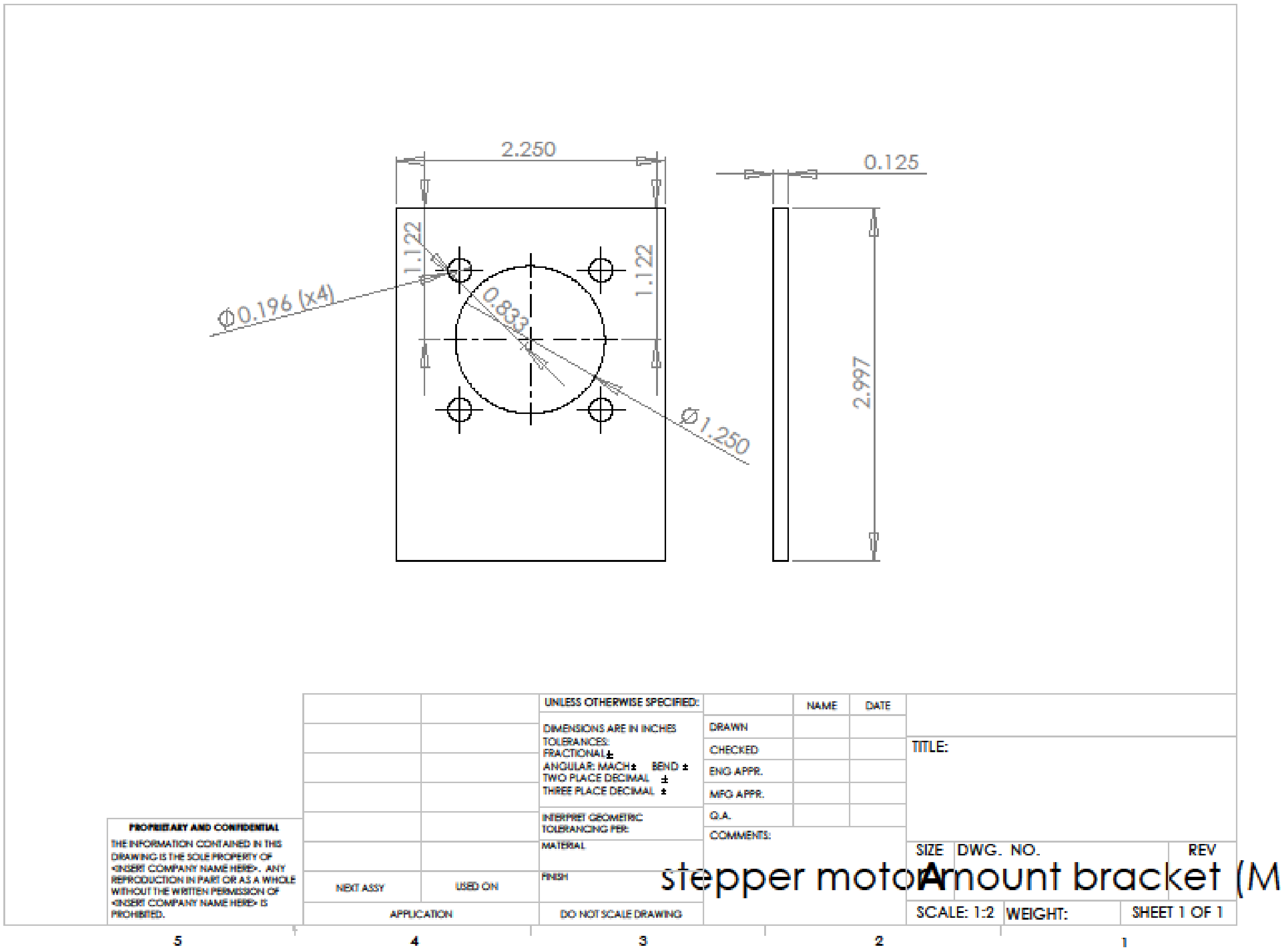
p. Camera Mount Bracket (Already made-Provided by Sponsor with Camera)



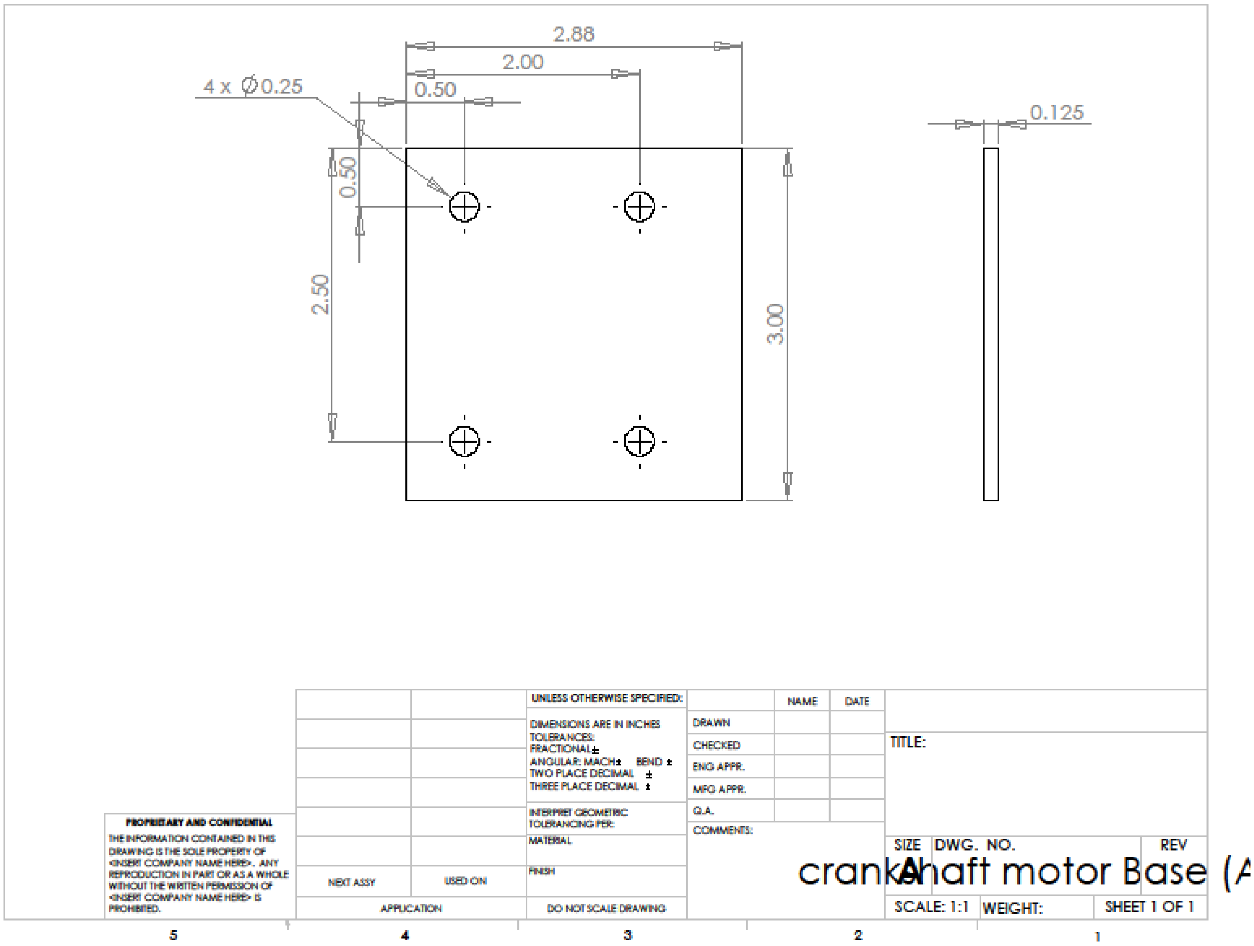
q. *Stepper Motor Mount Bracket Base*



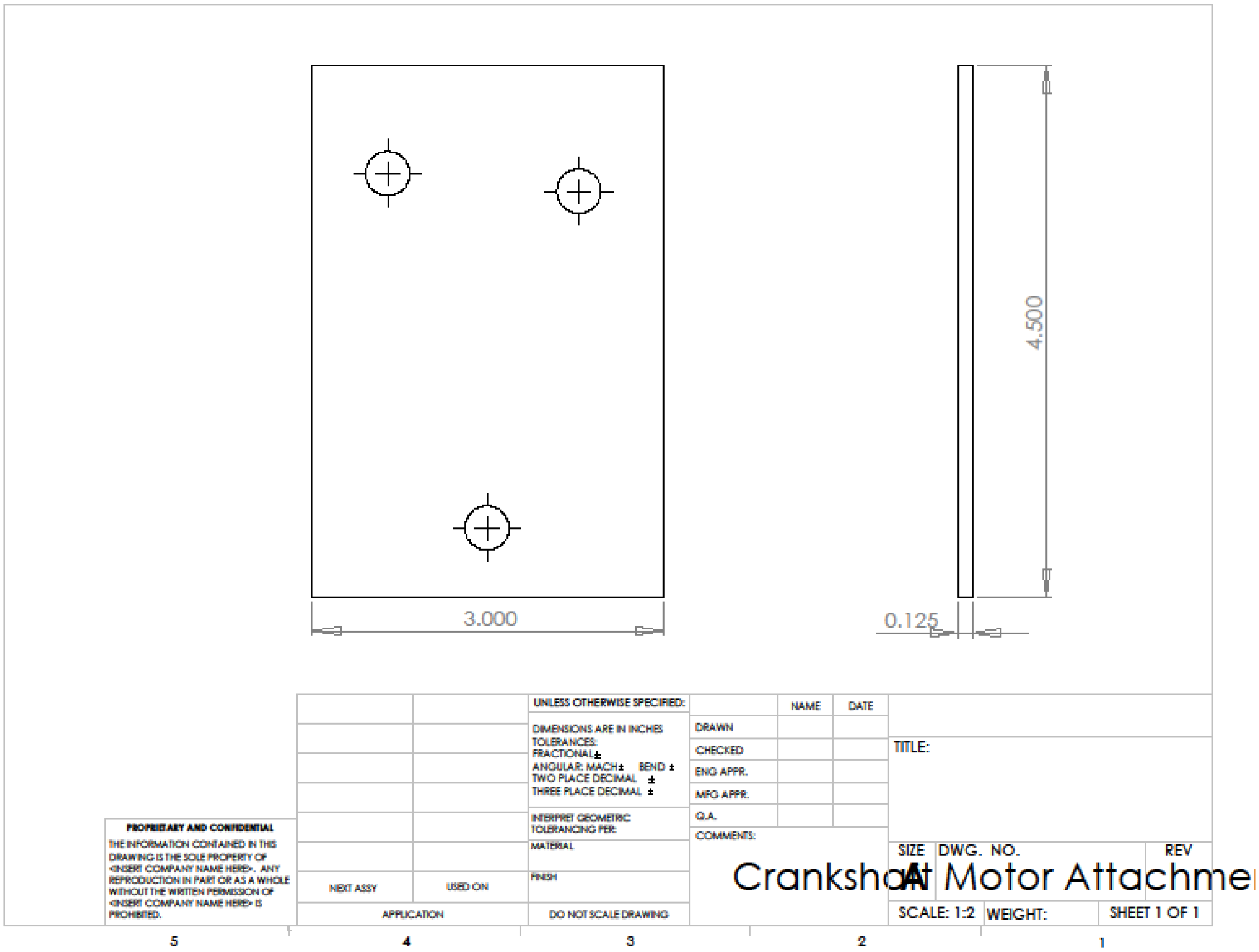
r. *Stepper Motor Mount Bracket Motor Side*



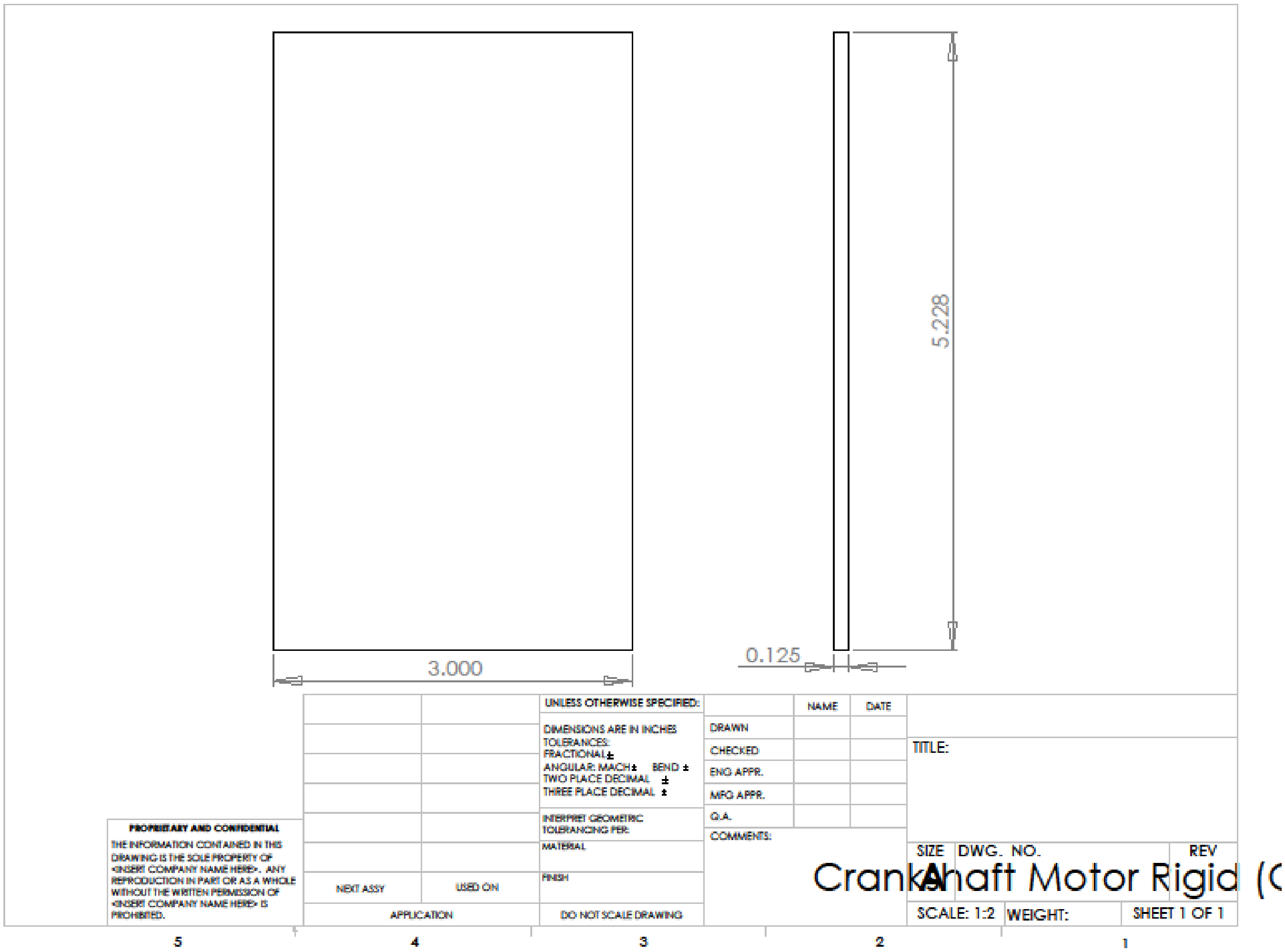
s. *Crankshaft Motor Mount Bracket (Base)*



t. *Crankshaft Motor Mount Bracket Motor Side (Holes will be located by putting the motor against the plate and then marking and drilling them by hand)*



u. Crankshaft Motor Mount Bracket Rigidity Plate



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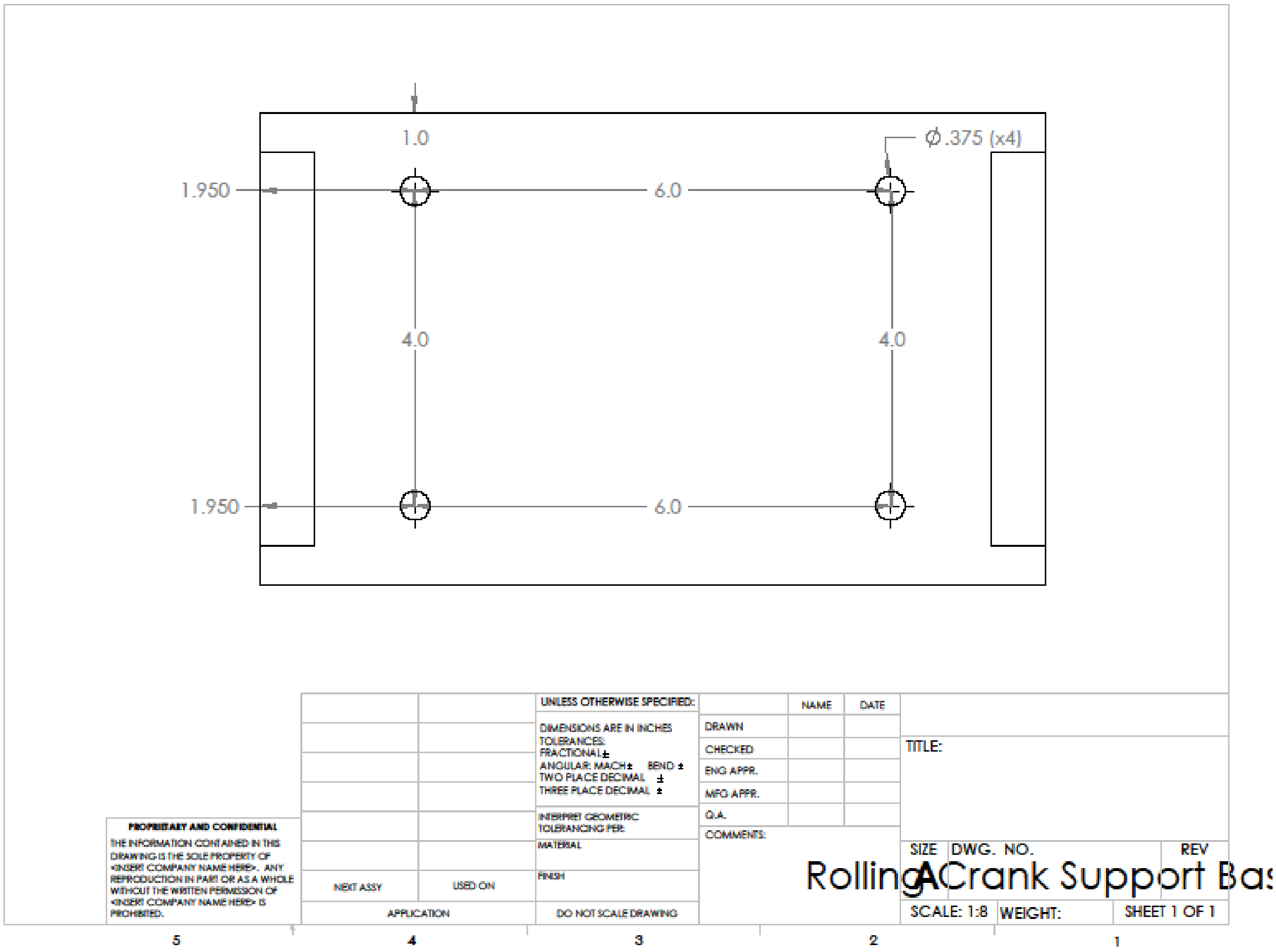
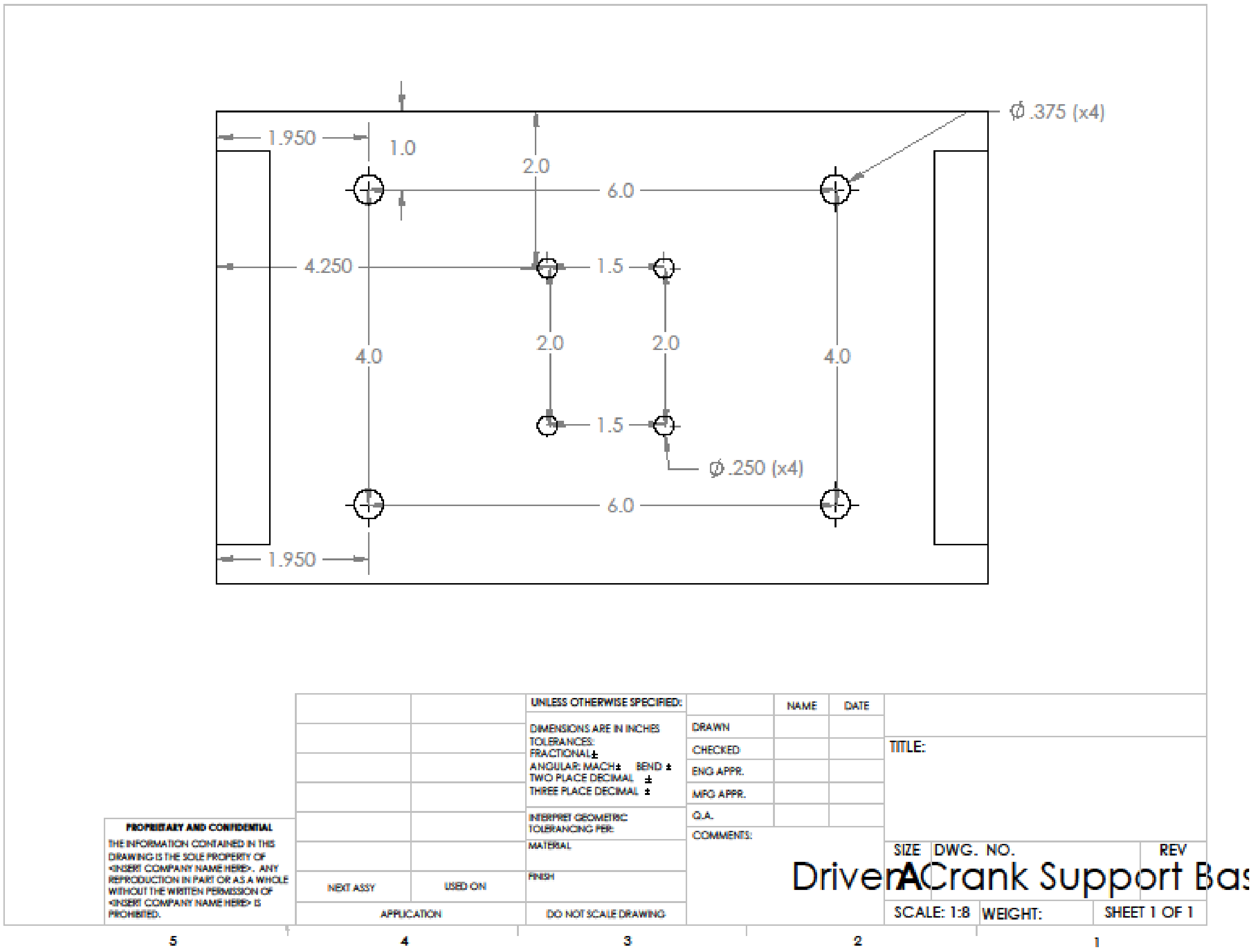
v. *Rolling Stand Mount Hole Locations*



w. Driven Stand Mount Hole Locations



4.1 Designsafe Results for Manufactured Components

Designsafe was used to assess the risks and hazards inherent in the components we designed (Appendix B). These parts are the Stepper Motor Mount Bracket, the Crankshaft Motor Mount Bracket, the Camera Rod Ends, the Camera Base, and the Camera Stand. The Light Mount Bracket was not analyzed due to its obvious lack of safety hazards since it is not holding very much weight and any loss of its integrity will not cause any kind of hazardous failure. The base itself was also analyzed separately as it was much more appropriately analyzed as part of the entire assembly. Failure modes of the analyzed components were mostly due to the ways that they were attached. Because these parts are not seeing very much weight, this was not considered. However, these parts do see a lot of vibrations and cyclic motions from the movement of the mechanism. These movements, over time, could cause cracks in the welds, or looseness of the components themselves. If not attended to, these instabilities could cause catastrophic failure depending on the time of failure. With periodic inspections of welds and bolt tightness, any failures of these components can be easily avoided.

Designsafe was also used to assess the risks of the completed prototype (Appendix C). In the full system, hazards associated with potential instability of the apparatus and inertia concerns of the crankshaft exist. Instability can be addressed by using clamps to secure the mechanism base to the cart. Injury to the operator can be prevented by keeping the rotational speed of the crankshaft at a minimum of 30 rpm. This speed will be controlled simply because the motor will be connected to a 12 Volt Battery and at 12 Volts, the motor turns at 30 rpm. A kill switch will also be integrated into the design to kill power to both motors in case the user gets too close. These hazards seem relatively minor, but they are present and were taken into account.

5. **Manufacturing Processes**

All of the parts described above will be manufactured through a combination of Water Jetting, Milling, and Cutting and Drilling.

Pieces to be manufactured using the Water Jet:

- Camera Rod End Support Base (x2)
- Camera Rod End Supports (x2)
- Camera Stand Base Plate
- Camera Stand Attachment Plate
- Camera Stand Rigidity Plate
- Light Source Mount Bracket Bolt Side
- Light Source Mount Bracket Light Side
- Stepper Motor Mount Bracket Base
- Stepper Motor Mount Bracket Motor Side
- Crankshaft Motor Mount Bracket (Base)

- Crankshaft Motor Mount Bracket Motor Side
- Crankshaft Motor Mount Bracket Rigidity Plate

Pieces to be manufactured using Milling:

- Camera Base

Pieces to be manufactures using Cutting and Drilling:

- 54” Length Square Tube with Holes to mount Driven and Rolling Stands (x2)
- 54” Length Square Tube with Holes to mount Camera Rod End Support Base (x2)
- 20.5” Length Square Tubes for Mechanism Base (x2)
- 3” Length Square Tubes for Mechanism Base (x2)
- 6” Length Square Tubes for Mechanism Base (x2)
- 7.5” Length Square Tubes for Mechanism Base (x2)
- Slider Rods (x2)
- Rolling Stand Mount Hole Locations
- Driven Stand Mount Hole Locations

5.1 Water Jet

The Water Jet is a very useful tool that is able to easily cut out two dimensional parts using a water/sand solution at high pressure. The machine is easily programmed with a simple .dfx drawing. The water jet is extremely accurate, precise, and fast. There is one drawback to the machine and that is that it creates a taper in its cut. This taper is only about 0.005 inches across a half-inch thick piece of material, but could pose a problem. Fortunately, for most of the parts being made with this machine, this taper will not pose an issue as the tolerances do not need to be that tight. However, for the Camera Rod End Supports, there are three press-fit holes that need to be very precise. Because the material we are using is aluminum, the holes will be cut .005 inches undersized, and any expansion of the hole will be done using a rough abrasive. This process should ensure an accurate and precise press-fit.

5.2 Milling

The Camera Base will be manufactured completely using a Manual and CNC Mill. The basic shape of the Base will be done using a Manual Mill as these dimensions are much more easily and quickly created by hand. Milling will be done using a ½ inch 4-flute endmill at a speed of 1200 rpm with a feed of approximately 70 inches per minute. The holes in the Base are much more difficult to create by hand and thus will be done with a CNC Mill. Using the same endmill at the same speed and feed seen in the Manual Mill operation, these holes can be quickly and easily programmed and created. To finish off the Camera Base, four blind holes will have to be tapped using a ¼-20 tap. A manual mill will be used along with a tap guide to ensure a good and straight tap.

5.3 Cutting and Drilling

The last part of manufacturing deals with Cutting and Drilling. The pieces for the base and the slider rods will be cut using a cut-off saw. After the base is welded together (to be explained in the next section), holes will be drilled using a manual mill with a drill attachment. The Rolling and Driven Stand Mount Holes will also be drilled using a manual miss with a drill attachment. Holes will be drilled with a 1/4" drill at a speed of 750 rpm and a feed rate of 15 inches per minute, a 3/8" drill at speed of 520 rpm and a feed rate of 10 inches per minute, and a 3/4" drill at a speed of 250 rpm and a feed rate of 5 inches per minute.

6. **Assembly**

All assembly can be split up into three methods; welding, press-fitting, and fastening. The assembly, excluding welding, will take place in the Engineering Research Center for Reconfigurable Manufacturing Systems. All welding will take place in the Wilson Center. The basis that is being used to prove that the assembly will not fail before, during or after use is based on static analysis with the materials being used and the weights and forces the materials will be exposed to. This analysis shows that each component can withstand the maximum forces with a safety factor or more than three. Lastly, the CAD model proves that each component, manufactured and purchased, will fit together without interference.

6.1 Welded Components

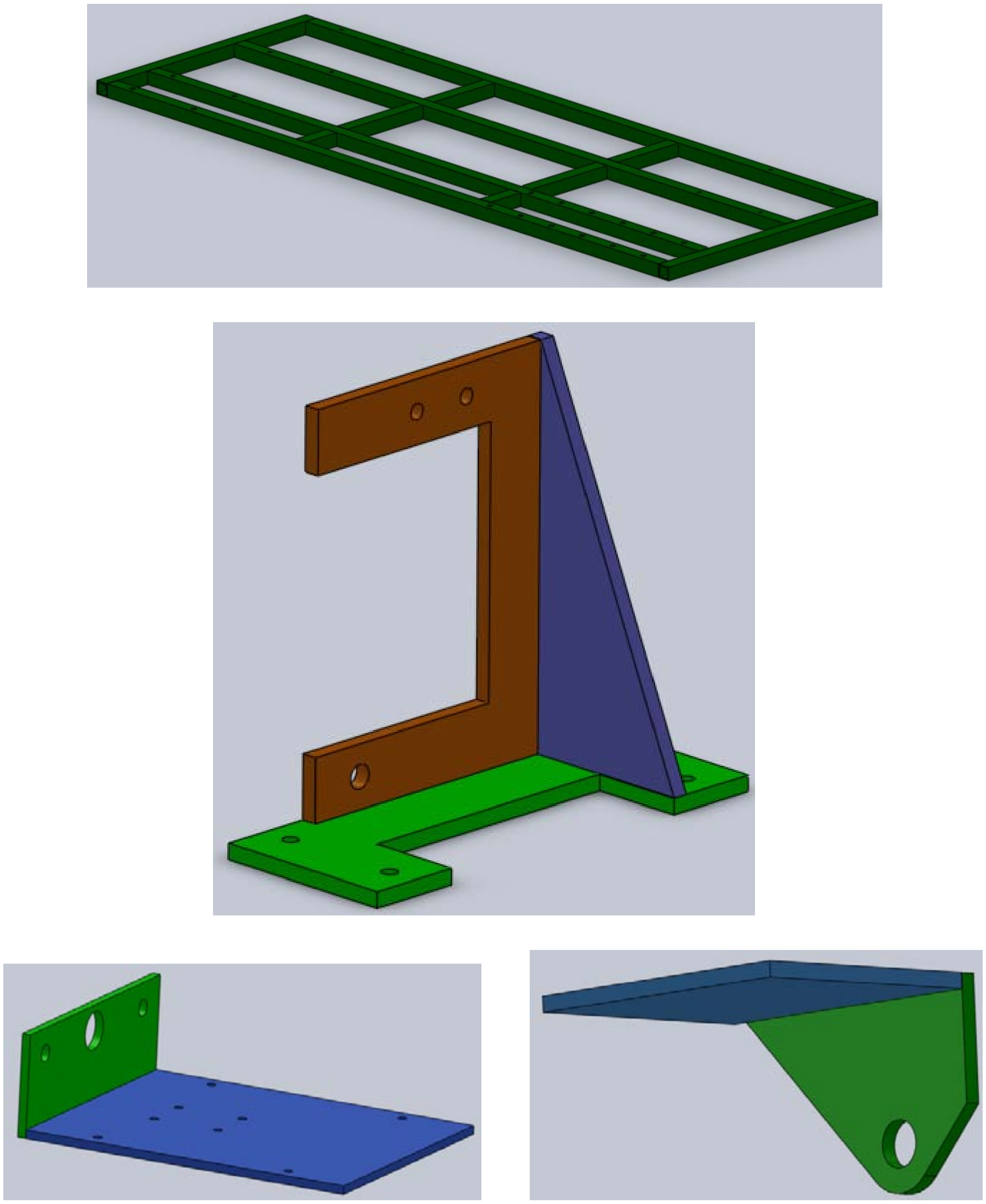


Figure 3: Top: Mechanism Base, Middle: Camera Stand, Bottom Left: Camera Rod End Support and Base, Bottom Right: Light Mounting Bracket.

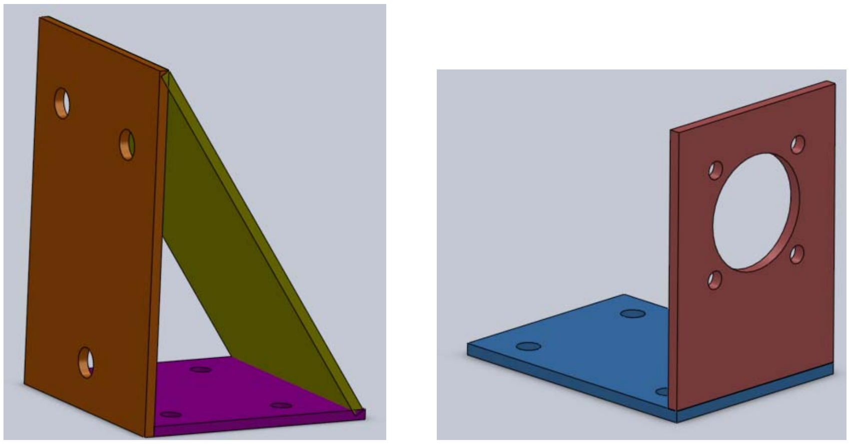


Figure 4: Left: Crankshaft Motor Mount Bracket, Right: Stepper Motor Mount Bracket.

The base, seen in Figure 3 (pg. 46), is made up of the pieces described in drawings (a) through (f) in section 4 above. The pieces are welded together to create a 56” x 20.5” square, as shown in Figure 5 below.

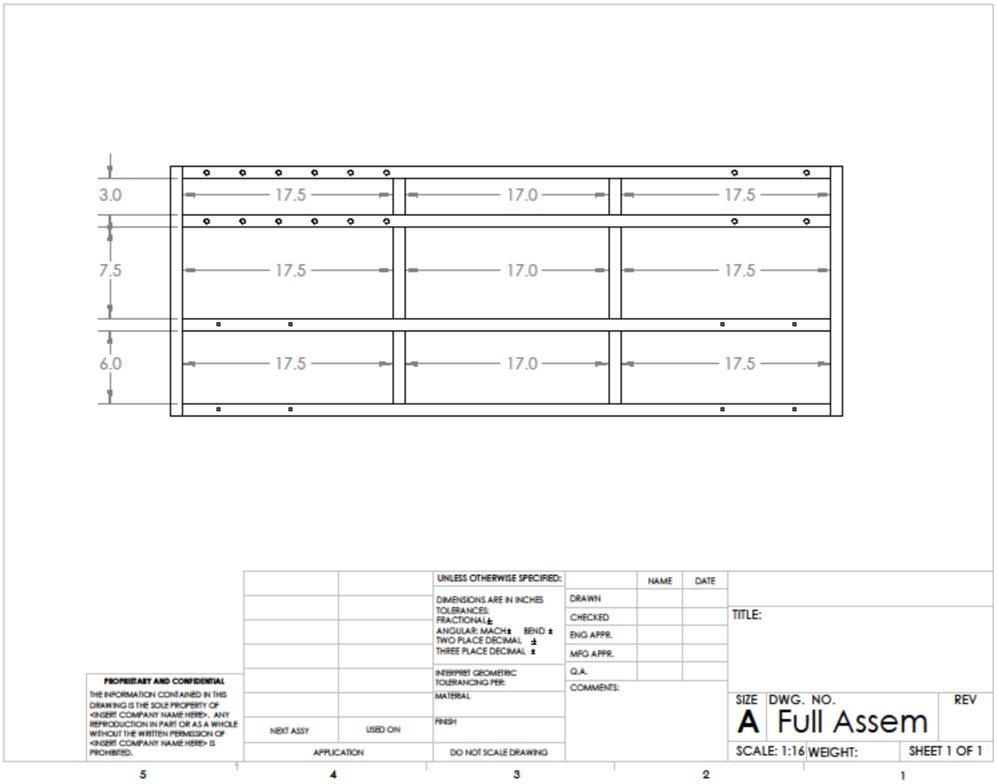


Figure 5: Assembly drawing of Mechanism Base

The Camera Stand, Figure 3 (pg. 46), is made up of the pieces described in drawings (k) through (m) in section 4 above. The Camera Rod End Support and Base, Figure 3 (pg. 46), is made up of the pieces described in drawings (g) and (h). The Light

Mounting Bracket, Figure 3 (pg. 46), is made up of pieces described in drawings (n) and (o). The Crankshaft Motor Mount Bracket, Figure 4 (pg. 47), is made up of pieces described in drawings (s) through (u). Lastly, the Stepper Motor Mount Bracket, Figure 4 (pg. 47), is made up of pieces described in drawings (q) and (r). All of these components are welded together as seen in their corresponding Figures.

6.2 Press-fits

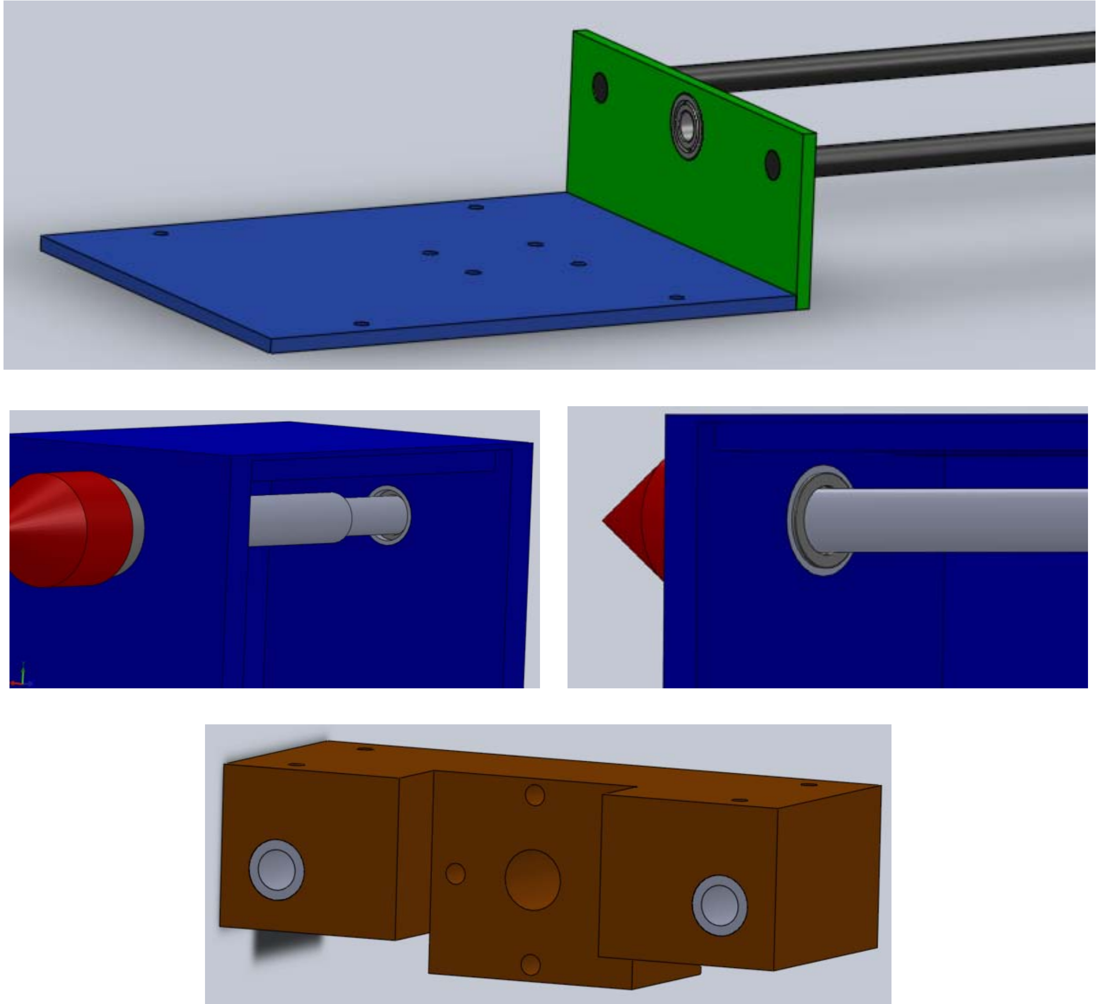


Figure 6: Top: Press-fits of the Slider Rods and Screw Bearing into the Camera Rod End Support, Middle: Press-fit of the 3/4” ID and 1” ID Shaft Bearing into Driven Stand, Bottom: Press-fit of Bushings into Camera Base.

Press-fits account for the least amount of assembly operations; however these are the most important. These fits, all seen in Figure 6, need to be very secure as they will be bearing the most weight. The Slider Rods and Screw Bearing are pressed into the Camera Rod Support End. This is the reason why the holes here, made with the Water Jet, must be much more precise than any other holes cut with the Jet. The Driven Stand will also have two bearings pressed into it in order to ensure that the Driven Shaft will rotate correctly without any slack. The Holes in the Driven Stand are already there, as they came with the donated stand. We only need to press the bearings into the holes to complete this assembly. Lastly, the Bushings must be pressed into the Camera Base. These brass bushings provide much less friction against the Slider Rods than Aluminum would allow.

6.3 Fasteners

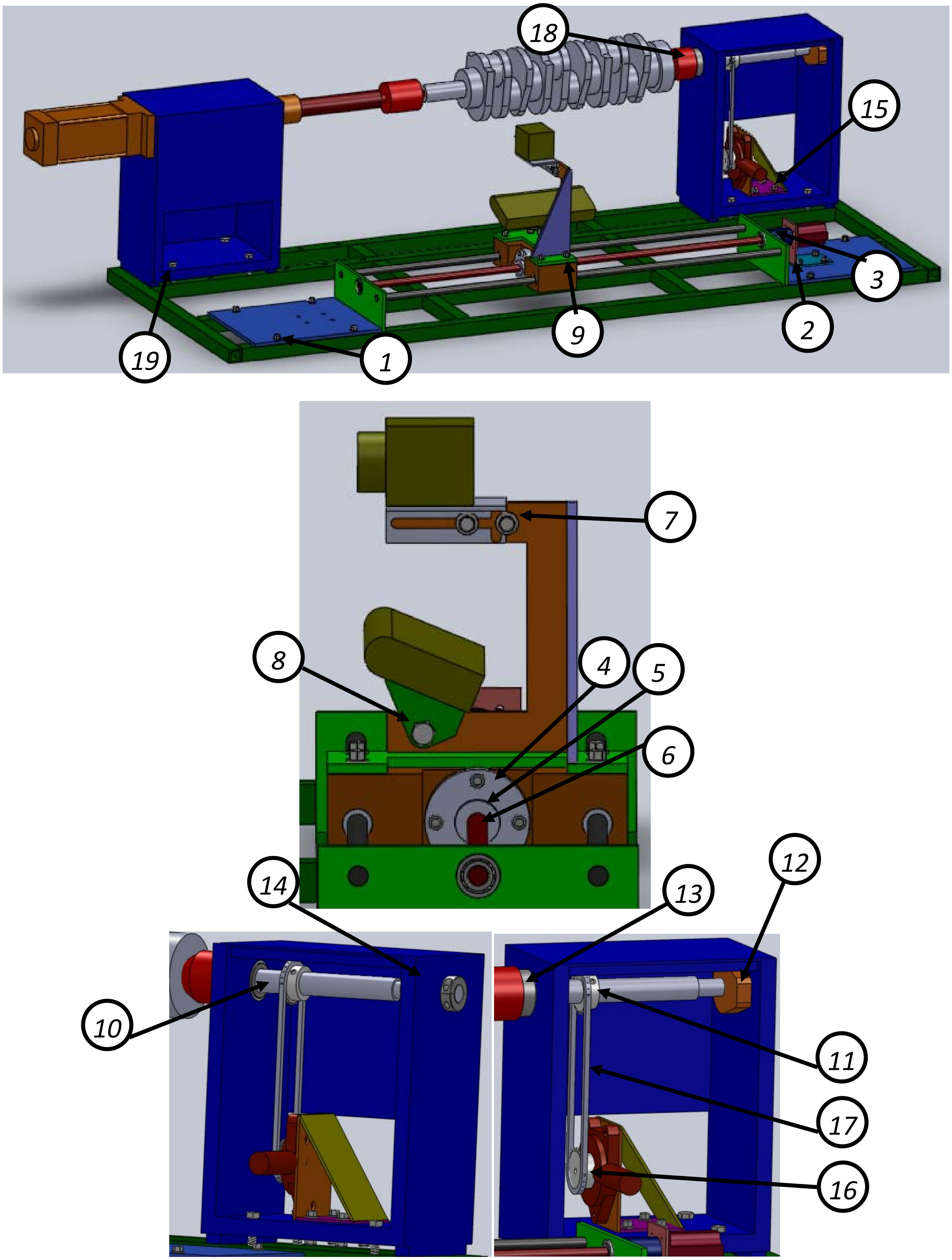


Figure 7: Top: Complete Isometric View showing assembly features. Middle: Camera/Light Assembly showing assembly features. Bottom: Driven Stand showing assembly features.

The Entire Mechanism will be Assembled in the following order (Numbers refer to Figure 7, pg. 50):

i. All pieces will be welded together as described above in section 6.1.
ii. All pieces will be press-fit as described above in section 6.2 except for one side of the Camera Rod End Support.
iii. Camera Base with press-fit bushings will be slid onto the Slider Rods.
iv. The last side of the Camera Rod End Support will be press fit to the Slider Rods.
v. (1) The entire Camera Rod End Support, Rods, and Camera Base will be bolted to the Mechanism Stand with ¼-20 bolts and lock nuts.
vi. (2) The Stepper Motor Mount Bracket will be bolted to the Camera Rod End Support Base using ¼-20 bolts and lock nuts.
vii. (3) The Stepper Motor will be bolted to the Stepper Motor Mount Bracket and will also be connected to the Connecting Collar.
viii. (4) The Mounting Flange will be bolted to the Camera Base. (5) Then the Screw Nut will be screwed into the Mounting Flange. (6) Lastly, the Camera Screw will be put through both Screw Bearings, the Screw Nut, and into the Connecting Collar.
ix. (7) The Camera and Camera Mounting Bracket will be bolted to the Camera Stand using ¼-20 bolts and nuts.
x. (8) The Light and Light Mounting Bracket will be bolted to the Camera Stand using a 3/8-24 bolt and two nuts for locking power.
xi. (9) The entire Camera Stand assembly will be bolted to the top of the Camera Base using ¼-20 bolts.
xii. (10) The Driven Shaft will be put through the 1” ID Driven Bearing with the shaft’s smaller diameter going first. Before it is put through the ¾” ID Driven Bearing, the Shaft Sprocket (11) and the Optical Encoder (12) must be put on it, being secured with set screws. Once these are installed the Shaft can be placed through the ¾” ID Shaft Bearing.
xiii. (13) The Thrust Bearing will be installed on the 1” OD side of the Driven Shaft.
xiv. (14) The Locking Collar will be installed on the ¾” OD side of the Driven Shaft.
xv. The Crankshaft Motor is bolted to the Crankshaft Motor Mounting Bracket, which is then bolted to the Driven Stand with three ¼-20 bolts and nuts.
xvi. (16) The Motor Sprocket is then placed on the output shaft of the Crankshaft Motor and secured with two set screws.
xvii. (17) The Chain is then put around the Shaft and Motor Sprockets, being fastened together with a Master Link.
xviii. (18) The Driven Cone is then placed on the 1” side of the Driven Shaft, secured with a pin going through the cone and the shaft.
xix. (19) Both the Driven Stand and Rolling Stand assemblies are then bolted to the Mechanism Base using 1/8-24 bolts and nuts.

xx. The Final Mechanism assembly is then clamped to the top of a cart, as seen below in Figure 8. An Air tank is bolted to the bottom of the cart, and an Emergency Stop bottom is glued to the top of the Driven Stand. Wheel Chocks will be used to keep the cart from rolling.

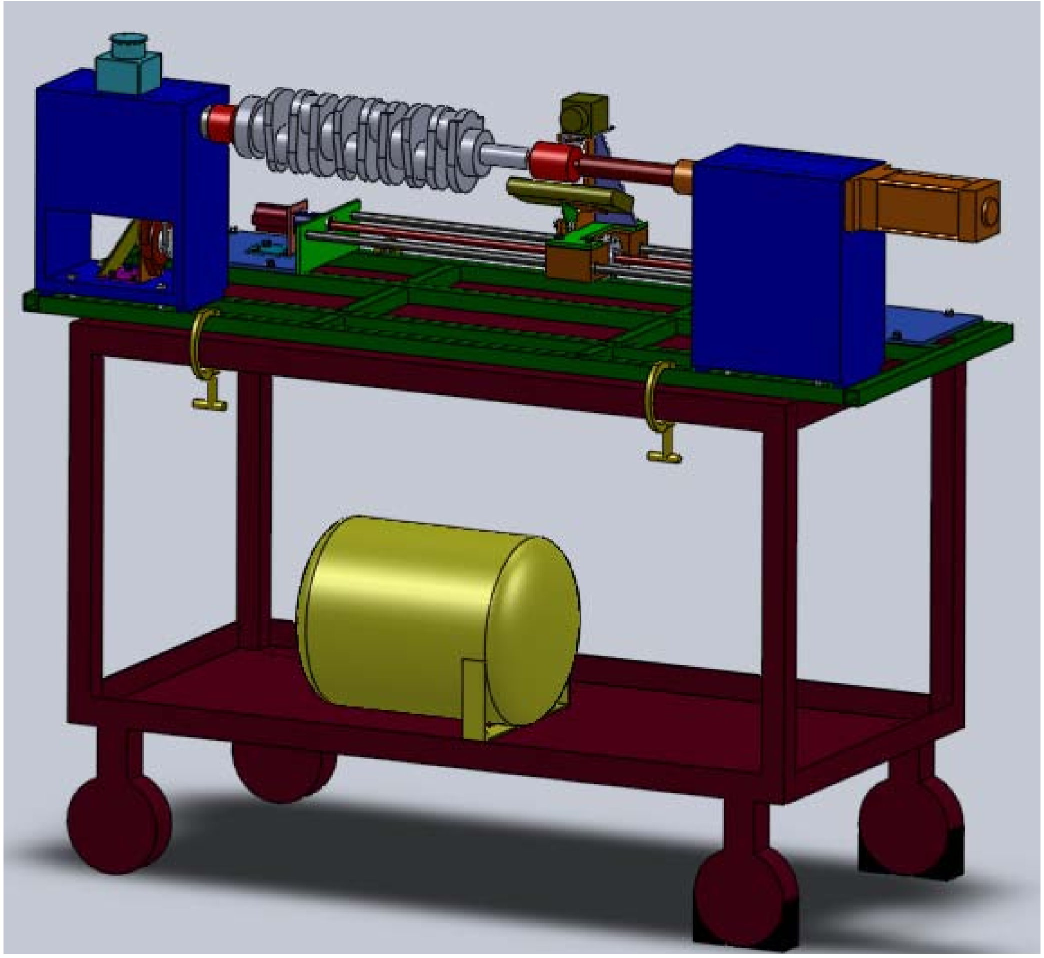


Figure 8: Entire Assembly showing the Mechanism mounted to a portable cart with air supply tank and emergency stop button attached.

7. <u>Design Testing and Validation</u>

Upon completion of our prototype fabrication, several critical tests will be conducted in order to verify that all the engineering specifications have been met. Many of these tests will be incorporated directly into our LabVIEW user interface. All testing will be done in the Engineering Research Center for Reconfigurable Manufacturing Systems. Although some testing can be done prior to prototype completion, most testing will be done after all assembly is complete. It should be noted that the system as a whole will be tested using a wooden block in place of the crankshaft for its initial test. This will ensure that the program is working as we expect, and will pose no serious hazard should the mechanism go out of control. This section describes the specifications that we will test for in order of decreasing priority and how these tests will be conducted.

7.1 Total inspection time to be less than 36 seconds

The technical requirement with the highest priority for our project is keeping the total test duration under 36 seconds. Fortunately, the validation process for this requirement is very straightforward and will be implemented directly into our LabVIEW user interface. When the test operator clicks the start button to run the inspection, a stopwatch will start timing the total test duration and the time will be displayed right on the LabVIEW front panel. After a picture is taken of the last crankshaft inspection surface, the camera and light source returns to its zero position, and the crankshaft spins down to a stop, the timer will stop and the total inspection time will be displayed on the screen. Once the user visually verifies that this total inspection time is less than the 36 second limit, we will have validated the most important requirement for our project.

7.2 Camera centered with pins/journals within 10 mm

In order for us to validate that the camera is centered with the pin and journal surfaces when each picture is taken, we will have to demonstrate that we can control the translational distance of the camera and light course as it moves along the length of the crankshaft. The camera and light source translation is driven by the number of pulses sent to the stepper motor, and due to the geometry of our mechanism 2000 steps will correlate to one inch of translation for the camera and light source. Thus, we will conduct a test that directly measures with a ruler how far the camera and light source actually translated and compare it to how far we told it to translate. We expect this to be accurate to 0.01 mm due to the resolution of the stepper motor. This test will demonstrate that we can control the position of the camera, and will validate that each picture will be taken well within 10mm of the surface center.

7.3 Picture of each journal taken from same distance ± 1mm

Due to the geometry of both our final design and the crankshafts we will test, the distance from the camera to each journal will be constant throughout our tests. Journals are always positioned on the central axis of the crankshaft, and the screw and slider beams that the camera will translate on are parallel to this central axis. Thus, no testing will be required to validate that we have consistent distance with our pictures.

7.4 Picture of each pin taken from same distance ± 1mm

In order for us to validate that the distance from the pin to the camera is consistent when each picture is taken, we will have to demonstrate that we can successfully indicate the rotational position of the crankshaft using the optical encoder. The validation process for this requirement will be implemented directly into our LabVIEW user interface. The distance from the pin that is to be inspected next to the camera depends on the rotational angle of the crankshaft; this rotational angle will be dynamically displayed on the screen as well as the desired angle to indicate when the pin is in the right position. When the angle read from the optical encoder matches the desired angle inputted by the operator, an on-screen LED indicator will light up. The operator will be able to manually rotate the crankshaft past the desired angle and visually verify that the LED lights up on the screen. Finally, when it is confirmed that we can accurately monitor the current crankshaft rotation angle, the LED indicator will also signal the camera to take a picture.

7.5 Angle between the camera and light source fixed

The camera and light source support includes adaptable features that allow the angle between these devices to adjust based on the type of crankshaft being tested. These adjustable features of the support once tightened and secured in place will remain fixed throughout the duration of the tests. The only thing we will need to verify for this requirement is that any vibrations that occur from the dynamics of the system don't cause the adjustable plates to loosen and cause the angle to change slightly. A very straightforward test will be conducted to validate this requirement; we will measure the angle directly before and after an inspection using a protractor and confirm that the angle did not change.

7.6 Picture tracking

Validation of this requirement will be implemented directly into our LabVIEW user interface. We will have specific output areas in proper order for the pictures to display once taken, so no actual experimentation or testing will be needed.

7.7 Weight of crankshaft to stay between 100 and 300 N

We spoke with QPAC Micropolishing, the company who provided us with the head and tail stock pieces used to secure and rotate the crankshafts, and they confirmed the structural integrity of these donated parts being able to support crankshafts between 100 and 300N. Validation of this requirement, however, will involve a demonstration of the versatility of our mechanism. We will load and run inspections for three different types of crankshafts of varying weight, so no actual experimentation or testing will be needed.

7.8 Other Requirements

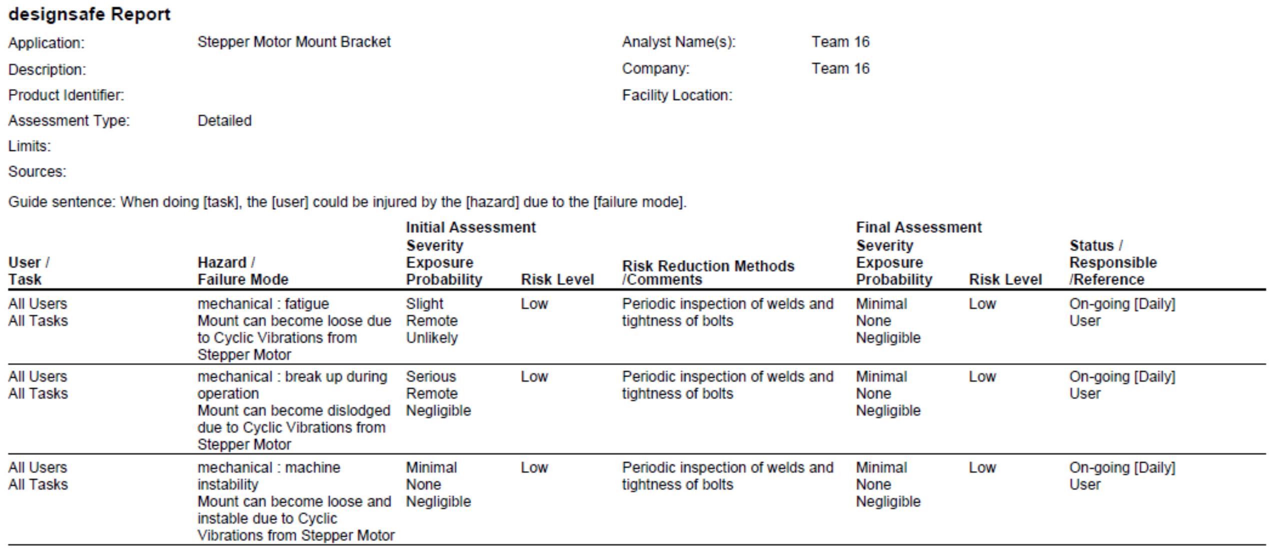
There are three other requirements that will need to be visually verified during our inspection: Ensuring no contact with the journals and pins, no more than two people are required to maneuver the mechanism, and avoiding the oil holes when taking pictures. The operator will be able to validate these requirements by wheeling the mechanism around with the cart, keeping off of the journals and pins when loading the crankshaft into the mechanism, and looking at the images after the test to ensure that no oil holes were photographed.

SUB: Appendix A: FMEA

Project #:	16	Report Version:	1.00	Date:	11/15/2009				
Project Title:	Automated Crankshaft Inspection Mechanism								
Team Members:	Mike Luginbill, Joe Shaktman, Ian Lind, Tony Nalli								

Part #, Name, and Functions	Potential Failure Mode	Potential Effect(s) of Failure	**Severity (S)**	Potential Cause(s)/Mechanism(s) of Failure	**Occurrence (O)**	Current Design Controls / Tests	**Detection (D)**	Recommended Actions	**RPN (=SXOXD)**
Air Tank	Fracture / Parts Separate	flying debris, gas leak, noise	8	manufacturing defects	1	built to withstand 125K psi	1	Inspect each purchased part. Test assembly by slowly increasing pressures. Watch/ listen for leaks.	8
	Leak / Incomplete Seal	Loss of air system pressure, noise	4	Assembly defects / component defects	4	visual inspection of connections	2	Inspect each assembled joint. Test assembly with slowly increasing pressures. Watch / listen for leaks.	32
Air Connections	Fracture / Parts Separate	flying debris, gas leak, noise	8	manufacturing defects	1	built to withstand 125K psi	1	Inspect each purchased part. Test assembly by slowly increasing pressures. Watch/ listen for leaks.	8
	Leak / Incomplete Seal	Loss of air system pressure, noise	4	Assembly defects / component defects	4	visual inspection of connections	2	Inspect each assembled joint. Test assembly with slowly increasing pressures. Watch / listen for leaks.	32
Pneumatic Piston	Fracture / Parts Separate	flying debris, gas leak, noise	8	manufacturing defects	1	built to withstand 125K psi	1	Inspect each purchased part. Test assembly by slowly increasing pressures. Watch/ listen for leaks.	8
	Leak / Incomplete Seal	Loss of air system pressure, loss of clamping force, noise	8	Assembly defects / component defects	4	visual inspection of connections	2	Inspect each assembled joint. Test assembly with slowly increasing pressures. Watch / listen for leaks.	64
Stepper Motor	Loss of control	Rapid movement of Camera Base and Stand	4	Programming Defects or Electrical Short	2	Programming Dry Run	1	Conduct a dry run of the programming without anything connected to motor	8
Crankshaft Motor	Loss of control	Excessive spinning of the crankshaft	4	Programming Defects or Electrical Short	2	Programming Dry Run and an integrated Emergency Stop Button	1	Conduct a dry run of the programming without anything connected to motor	8

SUB: Appendix B: Component Designsafe Reports

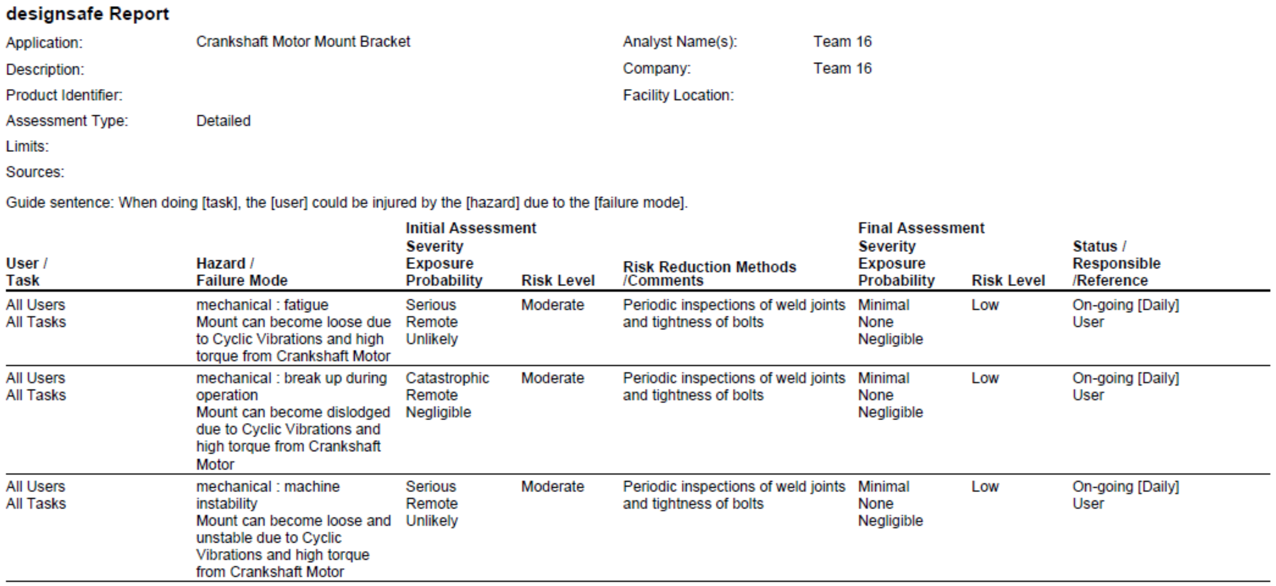


designsafe Report

Application:	Stepper Motor Mount Bracket	Analyst Name(s):	Team 16
Description:		Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : fatigue Mount can become loose due to Cyclic Vibrations from Stepper Motor	Slight Remote Unlikely	Low	Periodic inspection of welds and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : break up during operation Mount can become dislodged due to Cyclic Vibrations from Stepper Motor	Serious Remote Negligible	Low	Periodic inspection of welds and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : machine instability Mount can become loose and instable due to Cyclic Vibrations from Stepper Motor	Minimal None Negligible	Low	Periodic inspection of welds and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User



designsafe Report

Application:	Crankshaft Motor Mount Bracket	Analyst Name(s):	Team 16
Description:		Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : fatigue Mount can become loose due to Cyclic Vibrations and high torque from Crankshaft Motor	Serious Remote Unlikely	Moderate	Periodic inspections of weld joints and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : break up during operation Mount can become dislodged due to Cyclic Vibrations and high torque from Crankshaft Motor	Catastrophic Remote Negligible	Moderate	Periodic inspections of weld joints and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : machine instability Mount can become loose and unstable due to Cyclic Vibrations and high torque from Crankshaft Motor	Serious Remote Unlikely	Moderate	Periodic inspections of weld joints and tightness of bolts	Minimal None Negligible	Low	On-going [Daily] User

designsafe Report

Application:	Camera Rod Ends	Analyst Name(s):	Team 16
Description:	Camera Rod End Support and Base	Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : fatigue Rod Ends can become loose due to Cyclic Vibrations from Stepper Motor and translational movement of Camera Base.	Serious Remote Unlikely	Moderate	Periodic Inspection of weld points and bolt tighness, along with tightness of press-fits	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : break up during operation Rod Ends can become dislodged due to Cyclic Vibrations from Stepper Motor and translational movement of Camera Base.	Catastrophic Remote Negligible	Moderate	Periodic Inspection of weld points and bolt tighness, along with tightness of press-fits	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : machine instability Rod Ends can become loose and unstable due to Cyclic Vibrations from Stepper Motor and translational movement of Camera Base.	Serious Remote Unlikely	Moderate	Periodic Inspection of weld points and bolt tighness, along with tightness of press-fits	Minimal None Negligible	Low	On-going [Daily] User

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designsafe Report

Application:	Camera Base	Analyst Name(s):	Team 16
Description:		Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : pinch point Camera Base can pinch fingers between itself and the Camera Rod Ends	Slight Occasional Possible	Moderate	Keep hands away from the Mechanism when in use	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : fatigue Camera Base can become loose on the Slider Rods creating instability in the system	Serious Remote Unlikely	Moderate	Periodic inspection of Camera Base fit to Slider Rods	Minimal None Negligible	Low	On-going [Daily] User

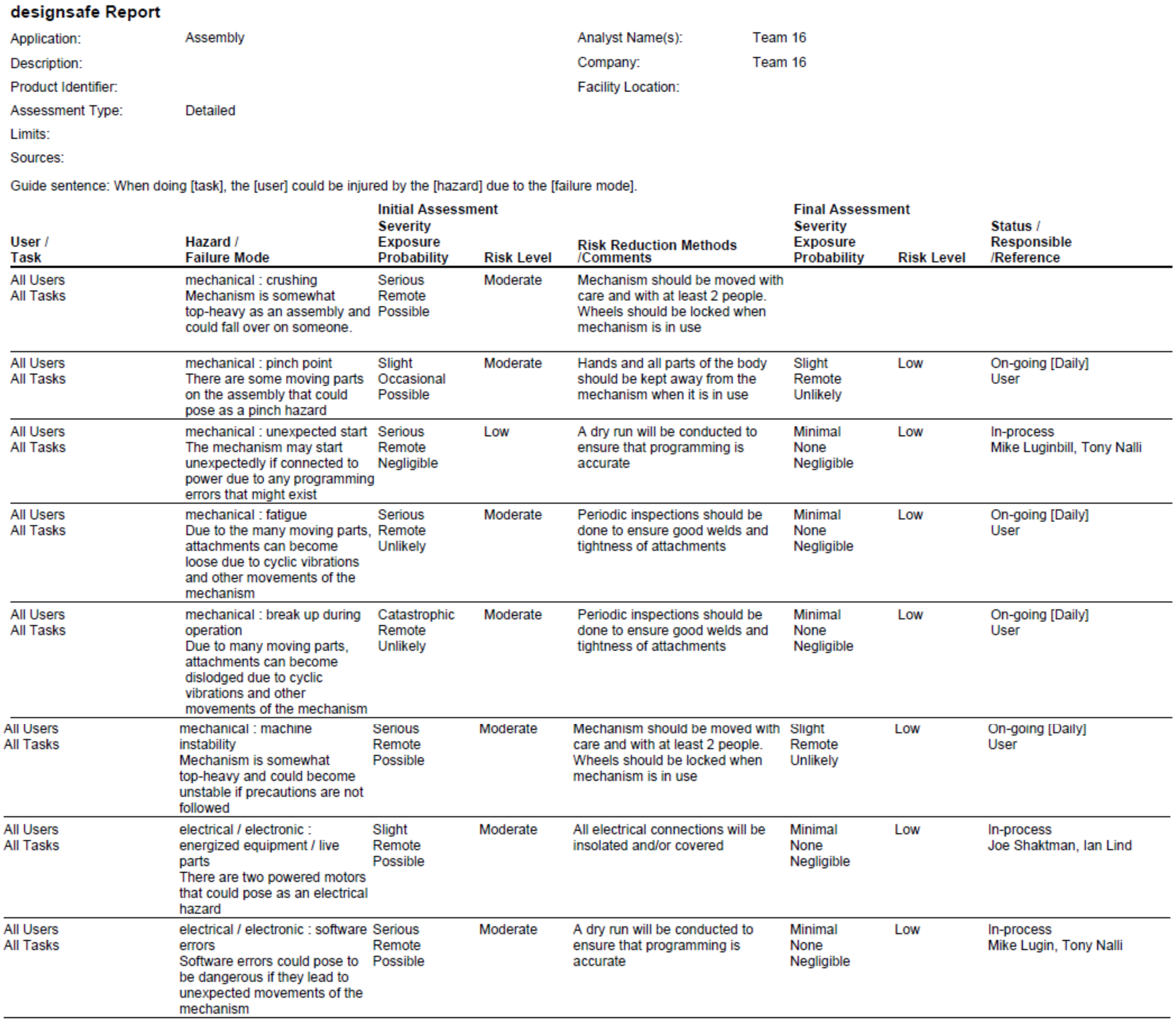
designsafe Report

Application:	Camera Stand	Analyst Name(s):	Team 16
Description:		Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : fatigue Camera Stand can become loose from constant translational movement	Slight Remote Unlikely	Low	Periodic Inspection of welds and bolt tightness	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : break up during operation Camera Stand can become dislodged from constant translational movement	Serious Remote Negligible	Low	Periodic Inspection of welds and bolt tightness	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : machine instability Camera Stand can become loose and instable due to constant translational movement	Serious Remote Unlikely	Moderate	Periodic Inspection of welds and bolt tightness	Minimal None Negligible	Low	On-going [Daily] User

SUB: Appendix C: Assembly Designsafe Report



designsafe Report

Application:	Assembly	Analyst Name(s):	Team 16
Description:		Company:	Team 16
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : crushing Mechanism is somewhat top-heavy as an assembly and could fall over on someone.	Serious Remote Possible	Moderate	Mechanism should be moved with care and with at least 2 people. Wheels should be locked when mechanism is in use			
All Users All Tasks	mechanical : pinch point There are some moving parts on the assembly that could pose as a pinch hazard	Slight Occasional Possible	Moderate	Hands and all parts of the body should be kept away from the mechanism when it is in use	Slight Remote Unlikely	Low	On-going [Daily] User
All Users All Tasks	mechanical : unexpected start The mechanism may start unexpectedly if connected to power due to any programming errors that might exist	Serious Remote Negligible	Low	A dry run will be conducted to ensure that programming is accurate	Minimal None Negligible	Low	In-process Mike Luginbill, Tony Nalli
All Users All Tasks	mechanical : fatigue Due to the many moving parts, attachments can become loose due to cyclic vibrations and other movements of the mechanism	Serious Remote Unlikely	Moderate	Periodic inspections should be done to ensure good welds and tightness of attachments	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : break up during operation Due to many moving parts, attachments can become dislodged due to cyclic vibrations and other movements of the mechanism	Catastrophic Remote Unlikely	Moderate	Periodic inspections should be done to ensure good welds and tightness of attachments	Minimal None Negligible	Low	On-going [Daily] User
All Users All Tasks	mechanical : machine instability Mechanism is somewhat top-heavy and could become unstable if precautions are not followed	Serious Remote Possible	Moderate	Mechanism should be moved with care and with at least 2 people. Wheels should be locked when mechanism is in use	Slight Remote Unlikely	Low	On-going [Daily] User
All Users All Tasks	electrical / electronic : energized equipment / live parts There are two powered motors that could pose as an electrical hazard	Slight Remote Possible	Moderate	All electrical connections will be insolated and/or covered	Minimal None Negligible	Low	In-process Joe Shaktman, Ian Lind
All Users All Tasks	electrical / electronic : software errors Software errors could pose to be dangerous if they lead to unexpected movements of the mechanism	Serious Remote Possible	Moderate	A dry run will be conducted to ensure that programming is accurate	Minimal None Negligible	Low	In-process Mike Lugin, Tony Nalli

APPENDIX D – Design Analysis

1. Material Selection Assignment (Functional Performance)

To begin our material selection of functional performance we first choose two major components of our final design. We choose to focus on the material that will be composing the base and the material that supports our light. The objectives of both parts are to support their respective components while allowing for rigidity and strength. With the base component we wanted to minimize the mass to help two people move it around while with the light source also needs a small mass so we can use a small motor. Both of these components have the same material indices. Both components are a beam with minimum weight and the stiffness prescribed. Using the CES software our team was able to narrow down the proper material choices starting with 2920 total choices. First one our team looked at was the base support. After applying the constraints listed below, it was down to 7 choices.

The Constraints:
Maximum density 0.5lb/in^3
Maximum price .4 USD/lb
Non-Flammable
Young's Modulus 29 Mpsi
Bulk Modulus 26 Mpsi
Yield Strength 36 ksi
Tensile Strength 55 ksi
Compressive Strength 36 ksi

Our Top Seven Choices
-Carbon Steel, AISI 1025, annealed
-Carbon Steel, AISI 1025, normalized
-Low alloy steel, AISI 4130, air melted, normalized
-Low alloy steel, AISI 4130, air melted, quenched
-Low alloy steel, AISI 4135, normalized
-Low alloy steel, AISI 8630, normalized
-Low alloy steel, AISI 8735, normalized

Based on these results we narrowed the choices down to one really quickly since the low alloy steel 4130 is really easy to buy so that seemed like the best choice since we could get it at the best price.

Next our team looked at the material for the light source bracket. After applying the constraints listed below, it was down to 10 choices.

The Constraints:
Maximum density 0.2 lb/in^3
Maximum price 1 USD/lb
Non-Flammable

Excellent fresh water durability
Excellent salt water durability
Excellent weak acids durability
Excellent strong acids durability
Excellent UV radiation durability

Our Top Ten Choices
-Alumina (85)(410)
-Alumina (85)(H880)
-Alumino silicate – 1723
-Borosilicate – N16B
-Cement (high alumina)
-Ceramic tile
-Concrete (high alumina cement)
-Granite (2.63)
-Lithium aluminosilicate
-Reactive powder concrete

Based on these results some of the choices were crossed off the list immediately. Due to the machining capabilities and the ease of purchasing we eliminated, Cement (high alumina), Ceramic tile, Concrete (high alumina cement), Granite (2.63), and Reactive powder concrete. With the final five choices left we realized that we can't buy Lithium aluminosilicate, Borosilicate – N16B, and Alumino silicate – 1723 very readily. This left both of the Alumina choices. When trying to decide between the two the Alumina (85)(410) stood out because the CES program had a foot note that read, "high mechanical strength and abrasion resistance". In doing our best to comply with the program we made both of our camera support and light support out of aluminum.

2. Material Selection Assignment (Environmental Performance)

After using the CES in the material selection assignment we were asked to see how the materials we selected stacked up against the environment. Using SimaPro software we were able to calculate the total mass of air emissions, water emissions, use of raw materials, and solid waste created due to our materials. The bar chart below has our results. One thing to point out is the huge raw materials waste coming from the aluminum. Also to note that since the scale is logarithmic in nature the amount of water emissions from steel are really quite low compared to aluminum.

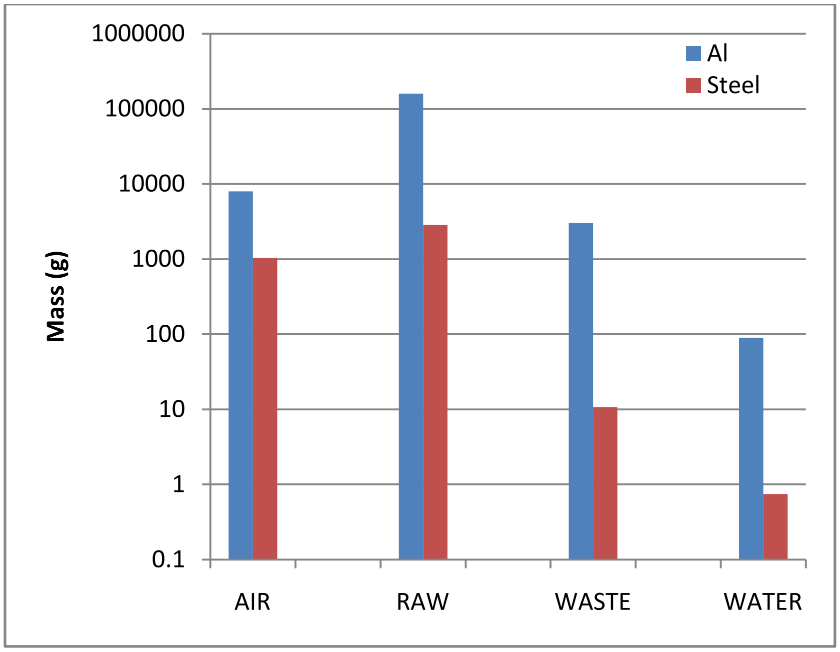


Figure: Emmisions and waste

After looking at the raw numers we wanted to take a look at how these values effected the world. We were specifically asked to determine which of the three catagories, “human health”, “ecotoxicity”, “resources”, is most likely to be important based on the EI99 point values. By looking at our first bar graph produced by the SimaPro software seen below, were believe that the human health element would have the highest point values. The next chart shown below has the normalized values based on whatever normalizing process is embedded in the SimaPro software. These new results show that the resources category has the most importance. When asked which of the three catagories is the most important we believe they are all of equal importance because if we neglect one the will still be large effects around the world.

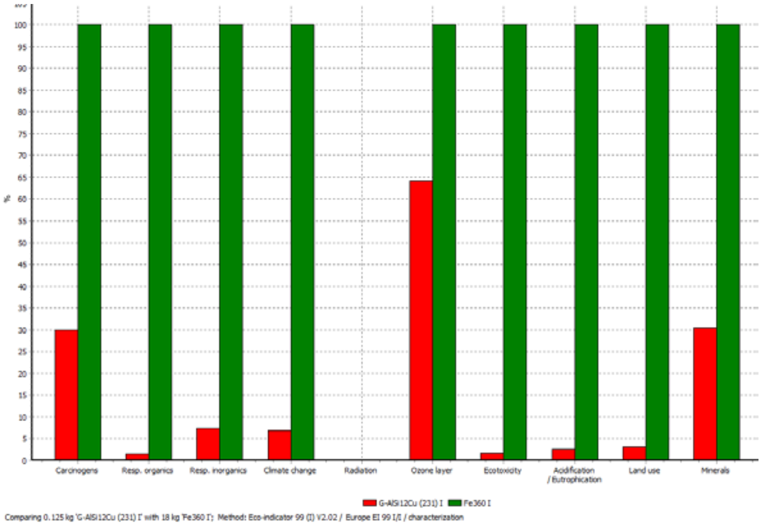
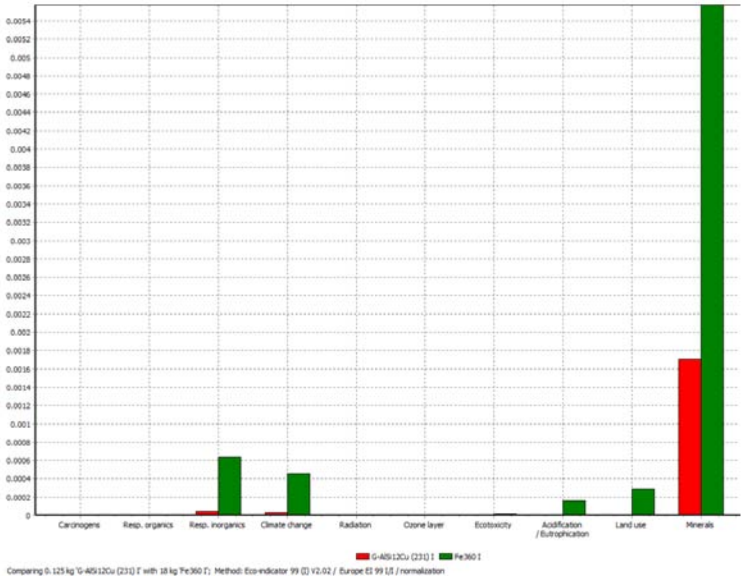


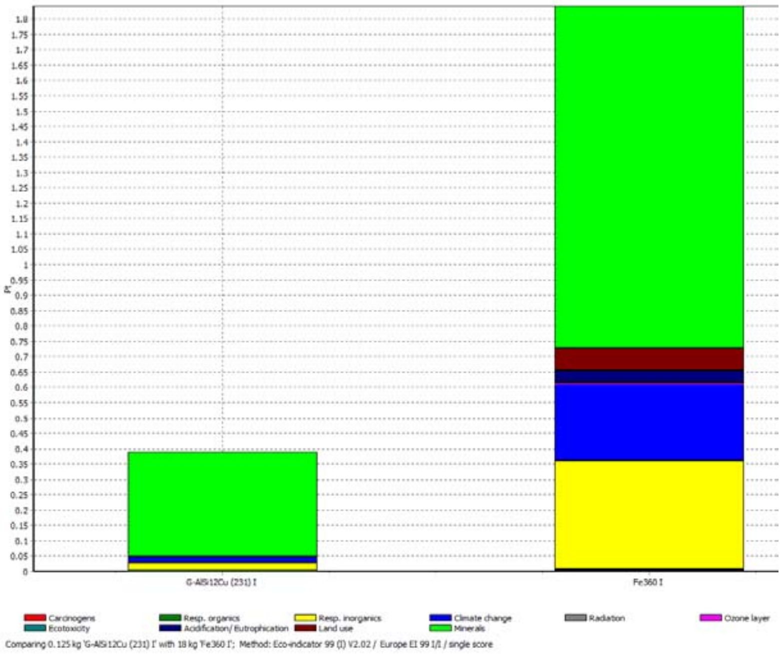
Figure: The non normalized chart



Comparing 0.125 kg 'G-AlSi12Cu (231) I' with 18 kg 'Fe360 I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / normalization

Figure: The normalized chart

The final piece of information we hoped to discover is which category has the highest overall point value according to the EcoIndicator 99. From the graph below the answer is clearly the minerals. Depending on the mass production rate of the new design has a large effect as to which category plans the largest impact role on the environment. For our case we will only be producing 300 so the economic impact will be the largest in the materials category. This is mostly due to the fact that all of the economic impacts all come back to procuring the materials and not manipulating them into the components of our design.



Comparing 0.125 kg 'G-AlSi12Cu (231) I' with 18 kg 'Fe360 I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

Figure: The final points tally

3. Manufacturing Process Selection Assignment

To begin this portion of the manufacturing process selection we need to understand how many units will be built for production. Since our machine will be input into an assembly line we are estimating the total sale to be around 300 units. When we begin to manufacture the 300 machines the base component that is made out of steel (based on the CES program) will most likely be welded together after being cut to length. Finally the production components will need to be coated to keep from rusting. To better understand why our base components will be welded together one needs to remember that we designed our base to be as light weight and strong as possible. The only way to build our base is to weld the individual tubes together in the set pattern to obtain the correct base platform. The coating of the base can be tackled two different ways. One way to protect the base is to paint it but some would argue that powder-coating is better. Since our base is mounted on a cart upon completion it could be explored to make the cart and the base one part.

Our other material that the CES program suggested we use was aluminum. To manufacture the light support bracket out of aluminum we are planning on cut the pieces on a water jet and then weld them together. In a mass production approach this might be the approach but it might be more beneficial to machine them out of a solid block of aluminum. Another approach to making the light support would be to stamp the whole part out of sheet aluminum and then bend it to make the final part. This would be cause for a slight re-design but that can be expected when considering mass production.

APPENDIX E – User Manual

Automatic Crankshaft Inspection Machine

User Manual

Ian Lind
Mike Luginbill
Tony Nalli
Joe Shaktman

SOFTWARE MANUAL: LABVIEW USER INTERFACE(S)

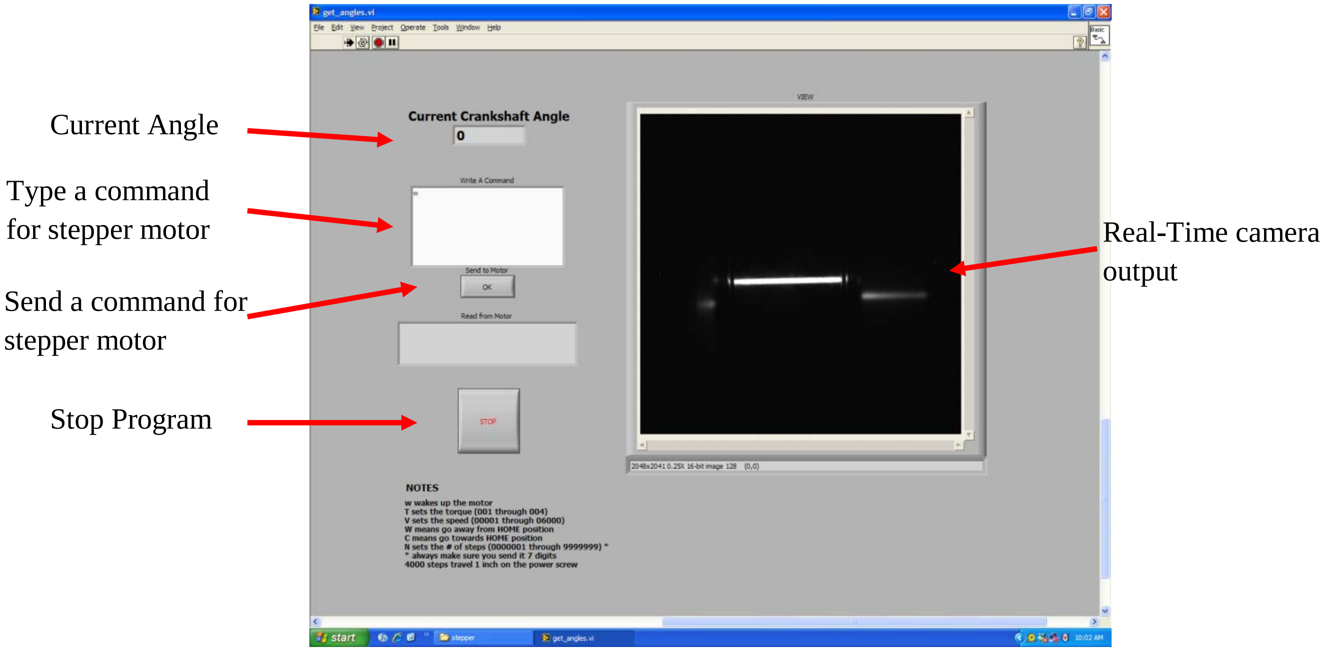
We have developed two main programs through LabVIEW software to control our machine as well as set up a new type of crankshaft for inspections. They are explained in detail below.

Start Up

When first starting the computer and software, there is a bit of a glitch. To overcome this glitch, start the program as you would normally. It is expected to run extremely slowly or not at all. Stop the program, and restart the procedures. This should fix the glitch and will be fine until the computer is restarted. It should also be noted that when the program is running, the **mouse should not be moved** at all. Any input from the mouse will slow the program down and will invalidate the results.

Camera and Light Source Homing Procedure

While no programs are currently running and using the stepper motor, the operator can manually turn the power screw to translate the camera and light source along the length of the crankshaft. However, in order to properly 'home' the camera and light source to the center of the first crankshaft main surface, we have developed a LabVIEW program called "get_angles.vi". This program, when running, shows the real-time camera output so the operator can visually see when the camera is centered on the first main. Figure 1 below shows the LabVIEW front panel for get_angles.vi:



Current Angle

Type a command for stepper motor

Send a command for stepper motor

Stop Program

Real-Time camera output

NOTES
w wakes up the motor
T sets the torque (001 through 004)
V sets the speed (00001 through 06000)
W means go away from HOME position
C means go towards HOME position
N sets the # of steps (0000001 through 9999999) *
* always make sure you send it 7 digits
4000 steps travel 1 inch on the power screw

Figure 1: Front Panel for get_angles.vi

The same VI also has a text control where you can send commands directly to the stepper motor. Commands are sent one at a time, and the important ones are listed below:

- “w” – wakes up the stepper motor and then will start accepting commands. This should only be done once when the motor is first turned on.
- “T” – tells that you want to change the Torque setting of the motor
- “004” – sets the motor torque to the desired torque setting for our machine
- “V” – tells that you want to change the Speed setting of the motor
- “06000” – sets the motor speed to the desired steps per second for our machine
- “W” – tells the motor that you want it to move away from the home position for inspection
- “C” – tells the motor that you want it to move towards the home position after the inspection
- “N” - tells that you want to change the number of steps the motor should go
- “0000000 – 9999999” – sets the number of steps that the motor should go
    - Remember – this input needs to be a 7 digit number so make sure to include leading zeros until you reach 7 digits.
    - Remember – 4000 steps translates the camera and light source one inch along the length of the crankshaft. To send this, type “0004000” and send it to the motor
    - “G” – tells the motor to execute all the above settings and translate the camera and light source.

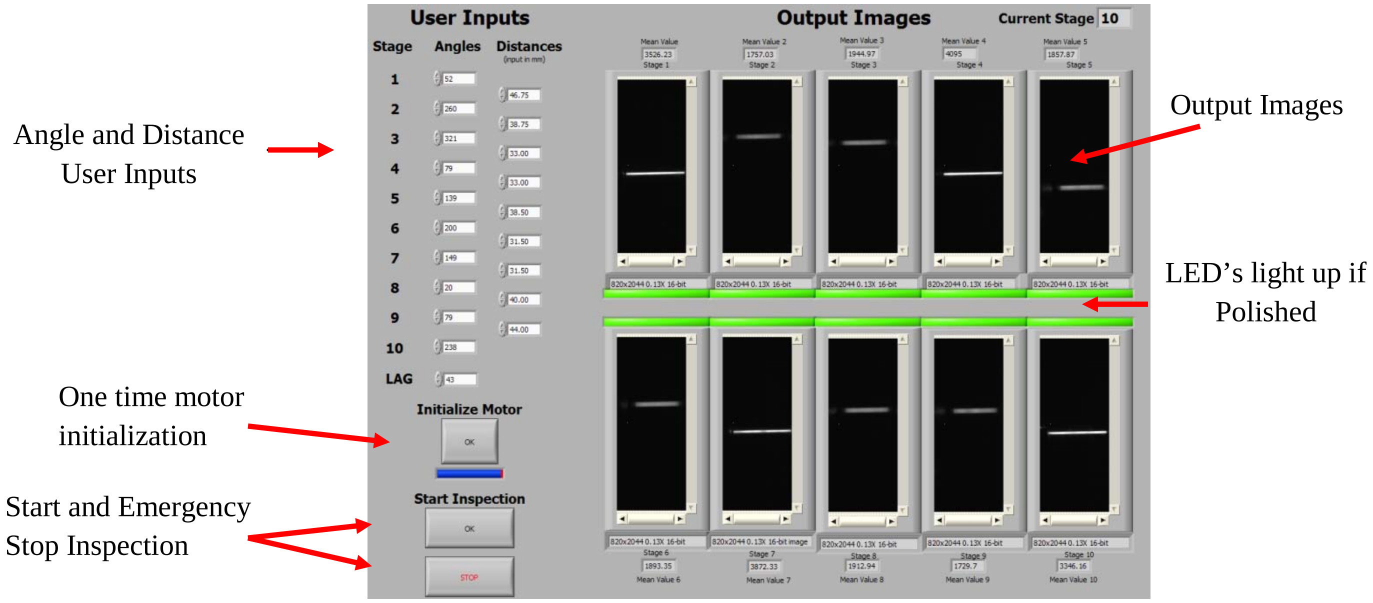
You can utilize the above commands to help you properly home the camera and light source. For a more complete description of commands please see the Excitron User Manual posted online at http://www.excitron.com/webdocs/Items/Details192.cfm.

Initializing Angle and Distance User Inputs

In order to properly initialize the desired angle and distance user inputs to the main inspection program, you can also use the previously described “get_angles.vi” program. This program, when running, shows the real-time camera output so the operator can visually see when the camera is centered on the first main. Furthermore, it also continuously reads the current crankshaft angle. If the operator undoes the set screw that connects the crankshaft dc motor to the driven shaft, they can manually turn the crankshaft until the camera output shows the image they’d like to capture, and record the angle for that stage. You can then send the motor steps to go to the next stage, and continue recording the desired angles and distances until every stage is recorded. As a sanity check, you can get a pair of calipers, measure the center-to-center distance you’d like the camera and light source to travel between each stage. After converting this from millimeters to motor steps by multiplying by 157.38105, you can send the motor the steps to each stage in sequence and visually verify that the inspection surface is centered in the camera’s real-time output images.

Running the Inspection

Once the operator has successfully homed the camera and light source, as well as recorded the desired angle and distance user inputs from the “get_angles.vi” labVIEW program, he/she is now ready to open “Inspection Perfection_faster.vi” for the actual inspection user interface. As you can see in Figure 2 below, the front panel of the VI shows where you input the previously recorded angles and distances, as well as another input labeled “Lag”. This input helps take into account that due to the processing speed of the computer, when our program signals the camera to take a picture, the crankshaft continues to rotate by the “Lag” amount until the picture is actually taken. For the current computer used in the demos, we have found this lag to be pretty constant around 43 degrees.



User Inputs

Stage	Angles	Distances (input in mm)
1	52	46.75
2	260	38.75
3	321	33.00
4	79	33.00
5	139	38.50
6	200	31.50
7	149	31.50
8	20	40.00
9	79	44.00
10	238	
LAG	43	

Output Images

Current Stage 10

Stage	Mean Value	Image
Stage 1	3526.23	820x2044 0.13X 16-bit
Stage 2	1757.03	820x2044 0.13X 16-bit
Stage 3	1944.97	820x2044 0.13X 16-bit
Stage 4	4095	820x2044 0.13X 16-bit
Stage 5	1857.87	820x2044 0.13X 16-bit
Stage 6	1893.35	820x2044 0.13X 16-bit
Stage 7	3872.33	820x2044 0.13X 16-bit image
Stage 8	1912.94	820x2044 0.13X 16-bit
Stage 9	1729.7	820x2044 0.13X 16-bit
Stage 10	3346.16	820x2044 0.13X 16-bit

Figure 2: Front Panel of Inspection_Perfection_faster.vi

Now the program should be ready for inspection. If you have not already done so, you can click the "Initialize Motor" button which will wake up the motor and set all the required motor Torque and Speed specifications for our demonstrations. Remember, if you have already woken the motor in the "get_angles" VI, you don't need to do this again. Then, click "Start Inspection" and confirm that you have correctly inputted the angles and distances. The inspection will execute, and will finish with the camera in its starting position and the crankshaft stationary.

Other Notes

It is also important to note that if the threshold values for the light intensity that determines whether a main or pin is polished or not should be changed, the operator will have to go into the block diagram portion of the "Inspection Perfection_faster" VI and manually change these values in the code. Also, the program will have to be modified if a different type of crankshaft is to be inspected that has a number other than ten inspection surfaces.

HARDWARE MANUAL: THE MACHINE

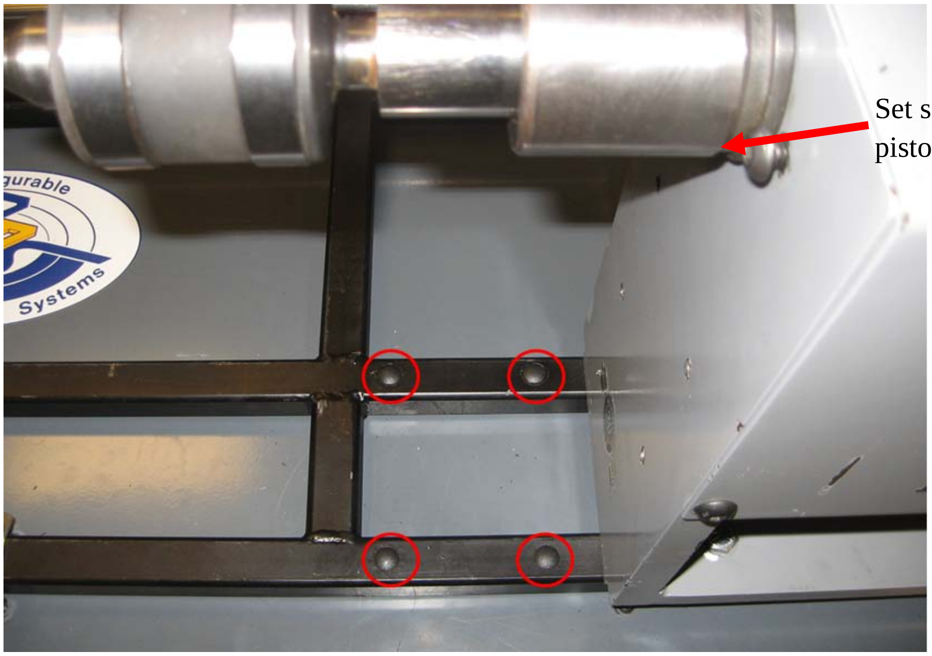
Now that the software side of our automated crankshaft inspection machine is described in detail, the hardware will also be explained in detail below.

Installing the Crankshaft

To install the crankshaft into the mechanism first you have to determine the rough adjustment for the overall length of the crankshaft. To adjust the rough adjustment setup of the crankshaft you need two 9/16 wrenches to remove the four bolts holding the right hand live center to the frame. Once you have chosen the correct placement of the support mounting box bolt it down to the frame. Check to make sure the air tank is turned on so air can flow. Next check the psi in the air tank. We suggest the air in the tank stay above 40 psi and not more than 80 psi. After checking the air pressure and before loading a crankshaft release the safety catch by the air lever. If the gap between the supports is correct and there is enough air in the tank hold the crankshaft up to the left cone on the driven shaft and line up the right end of the crankshaft with the height of the live center and actuate the air lever to drive the piston into the end of the crankshaft securing it in place. This is a two-man procedure. After seeing the crankshaft is securely in place make sure to re-engage the safety by the air lever to make sure the lever isn't bumped and the crank can't fall out.

Due to the fact that the tailstocks need to be aligned, a shim was added to the live center cone. This shim binds the pneumatic piston and will not allow it to move below 25 psi. Should one drop below 25 psi, the set screw closest to the user can be loosened to allow the piston to move. See figure 3 below.

Helpful Visuals:



Set screw to release piston

Figure 3: Rough adjustment holes

Figure 4: Bolts that need to be removed to make 3 inch rough adjustments

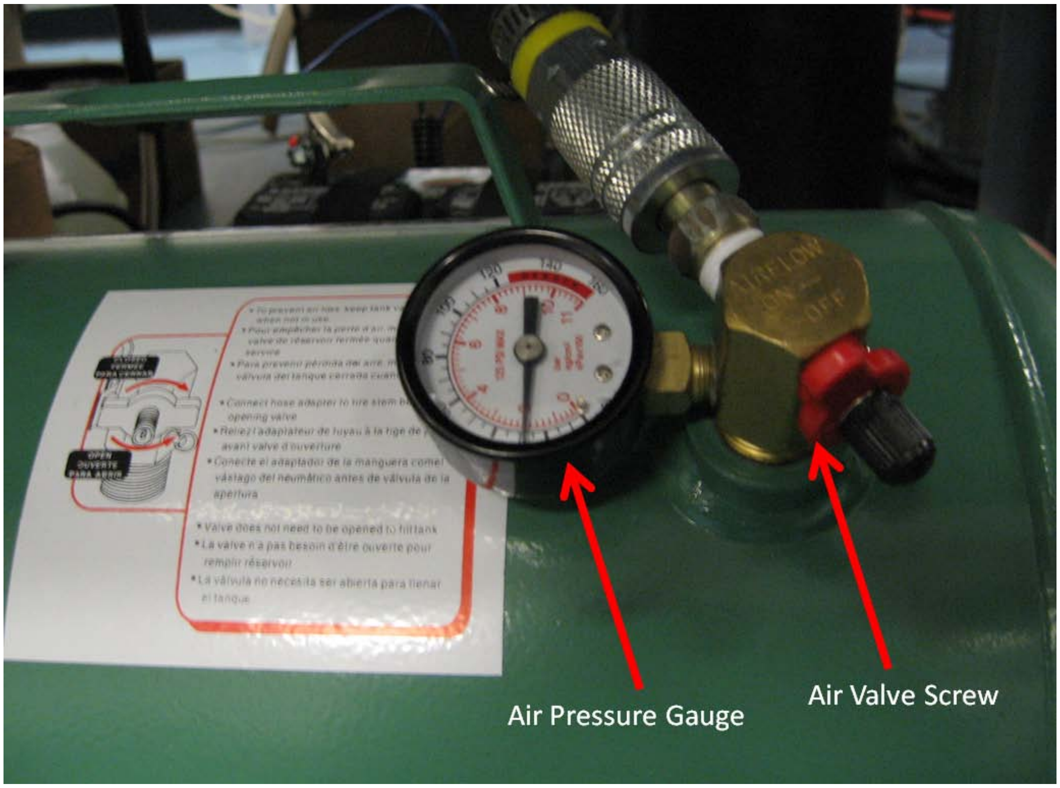


Figure 5: Air tank components

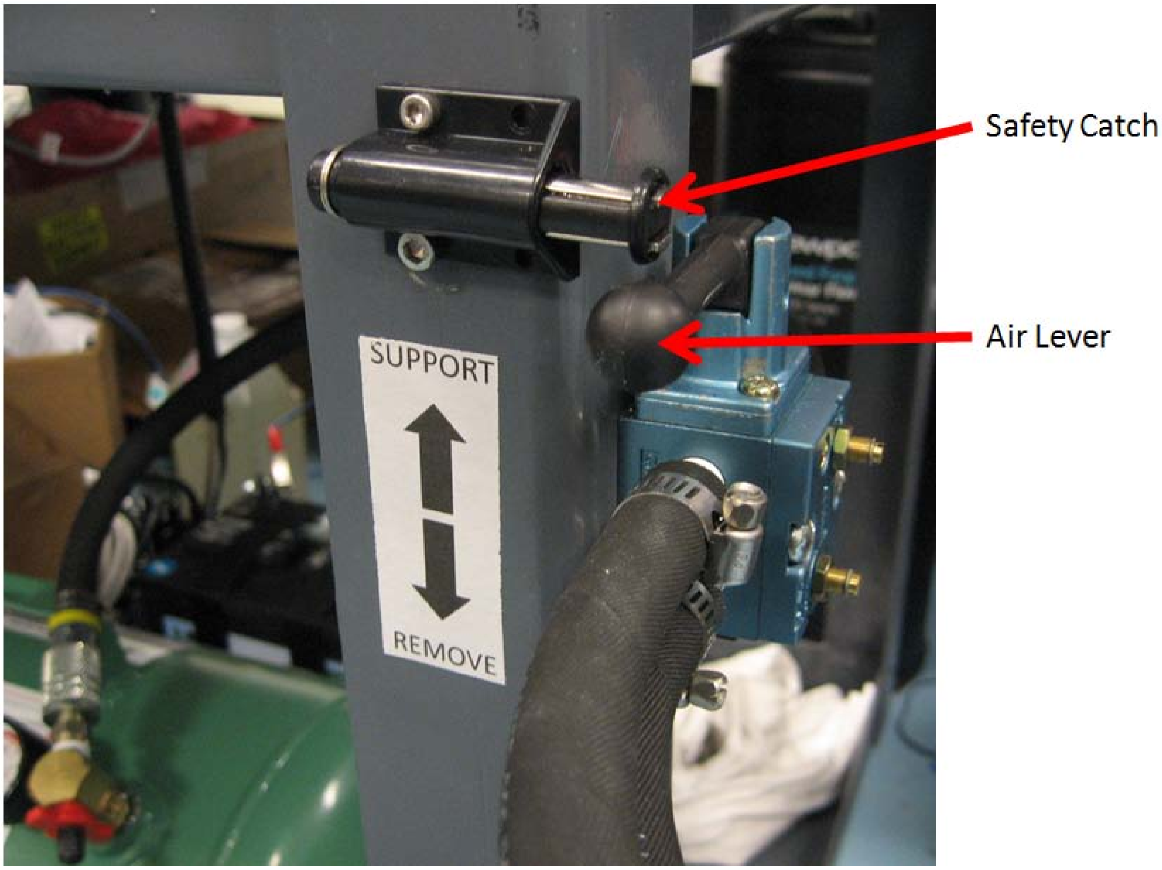


Figure 6: Air lever and safety catch

Homing the Crankshaft

To home the crankshaft with our mechanism is a two person operation. The first person has to hold the crankshaft up without touching the mains or the pins while the second person works the air lever. The crankshaft needs to be installed between the conical supports so the last pin (pin 9) is in the upright position. To do this the person holding the crankshaft will rotate the crankshaft while the other person slowly releases the pressure with the air lever. Note, the person working the air lever doesn't want to fully remove the conical support just let it move enough to allow the crankshaft to rotate. Once the crankshaft is in this position, put the air lever in the full support position. Next install the homing pin into the driven end of the crankshaft in the hole that is closest to the top of the crankshaft but slightly off to the right. Once this pin is installed place the aluminum homing plate over the edge of the driven box and rotate the crankshaft until the screw is just barely touching the bottom of the aluminum plate. Remove the plate and screw before running any tests.

Images:

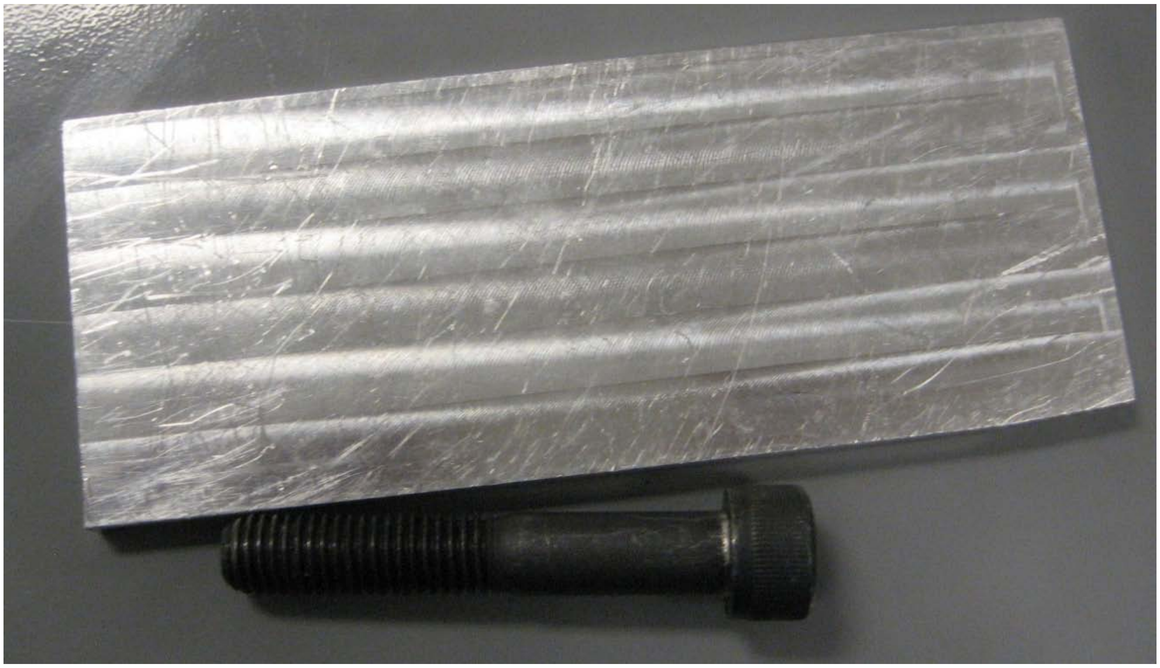


Figure 7: The homing pin and plate

Figure 8: Location of pin installation

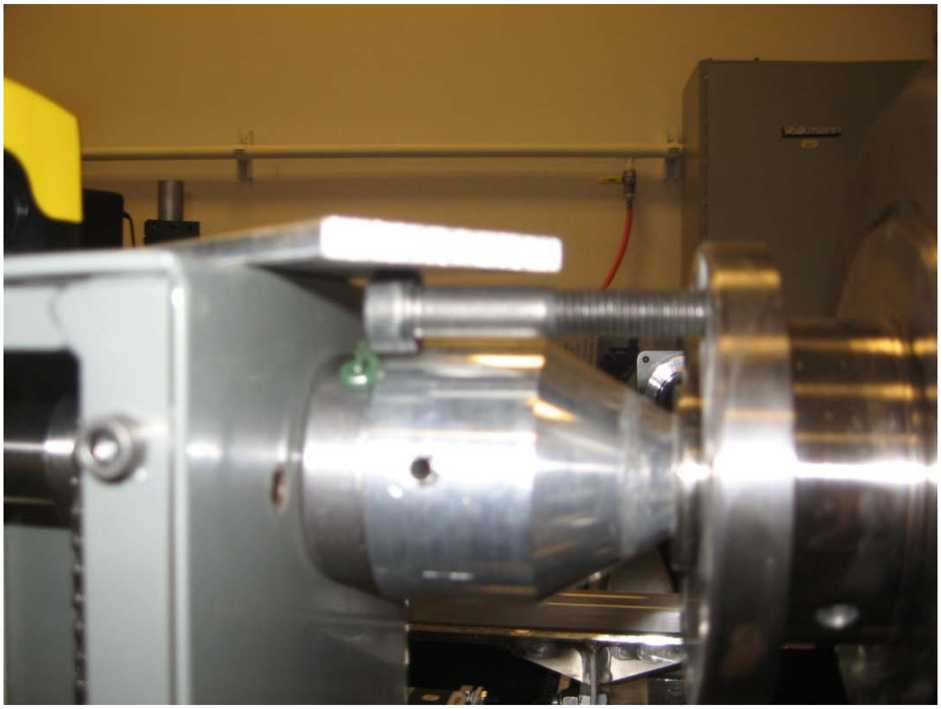


Figure 9: Plate just over pin to show homed

Working the Safety Catch

To actuate the safety catch by the air lever push the button that sticks out into the path of the air lever towards the cart until it clicks. Once it clicks the safety catch will stay in the open position until pushed toward the cart until it clicks again which releases the button into the path of the air lever.

Turning on and off and filling the Air Tank

To allow air to flow through the air lines you need to turn the red valve screw counter clockwise until it can't turn any more. To close the air off from the air lines turn the red valve screw clockwise until the valve is completely closed. To fill the tank, remove the black cover and fill using the correct fitting. This can be done with the red valve screw in the on or off position.

Image:

Figure 10: Air valve screw

Turning on the Light Source
At the center of the camera slider, mounted to the underside of the top of the cart is the light source box. On the side of the light source box is an on/off switch.

Images:

Figure 11: The switch

Figure 12: Location of the box

Adjusting the Light Intensity

To adjust the intensity of the light source get a flat head screw driver and on the box mounted to the underside of the cart turn the screw.

- Clockwise makes the light brighter.
- Counter clockwise makes the light dimmer.

Images:

Figure 13: Box to adjust intensity

Adjusting the angle of the Light Source

To adjust the angle of the light source get two 9/16 wrenches and loosen the bolt holding the light source plate. Pivot the light source to the desired angle and tighten the bolt to secure the light source in place.

Images:

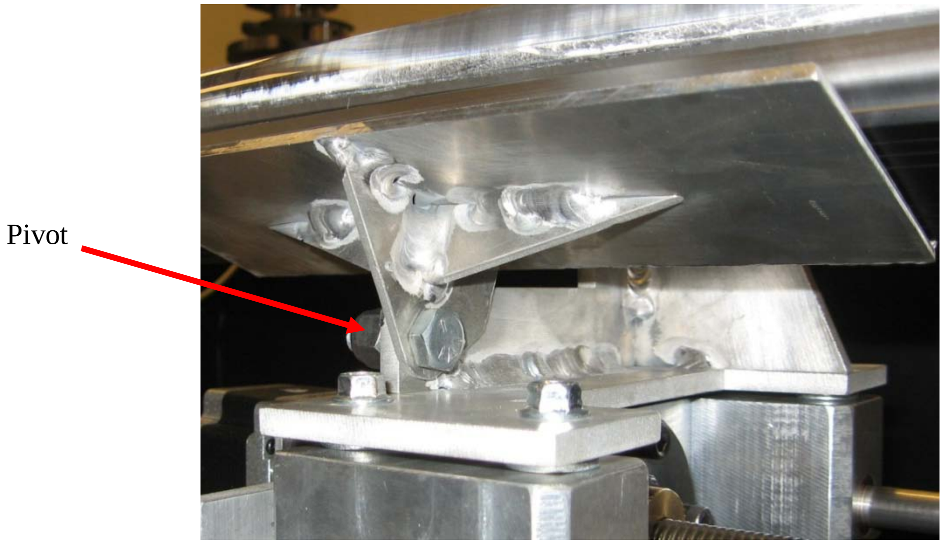
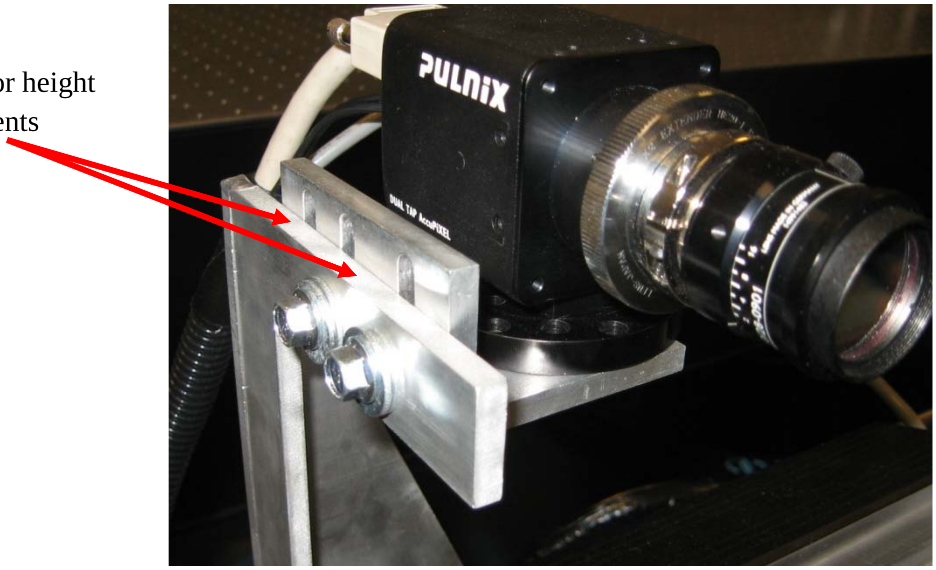


Figure 14: The pivot the light sits on

Adjusting the Height of the Camera

To adjust the height of the camera, loosen the bolts on the edge of the camera bracket. Adjust the camera to the correct height and tighten the bolts to secure the camera in place.

Images:



Slots allow for height adjustments

Figure 15: The angle bracket the camera sits on

Locking down the Cart

To lock down the cart roll the rear two wheels to where they need to be and then make sure the hole in the wheel and the hole in the bracket line up. Once the holes are lined up place the 3.5 inch bolts through the holes and add the nut to keep the wheels locked in place.

Images:

Figure 16: The holes in the wheels

Figure 17: The lock pins

Figure 18: The wheels locked down

How to Adjust the Rough Adjustment Box

Adjusting the Rough Adjustment Box, first and foremost, is a bit complex. First, the entire mechanism must be unbolted from the cart, see figure 19. This will allow access to the nut holes under the adjustment box. Once this is done, slide the mechanism so that the adjustment box is hanging off the edge of the cart, thus exposing the nuts. Be CAUTIOUS; although the mechanism should be stable, there is a potential hazard of it falling. Once the box is over hanging, use a ratchet with the appropriate socket on the bolt side. To hold the nut in place while you turn the bolt is also a bit complex. Due to the size of the through hole, it is not possible to get a wrench or a socket around the nut. Because of this, one must use pliers or a screw driver to prevent the nut from rotating. Once all bolts are removed, SLIDE (do not lift as this may be dangerous) the entire adjustment box to the desired position. Bolt the box down in the same way you unbolted it. Slide the entire mechanism back onto the cart and then bolt it down. You have now adjusted the rough adjustment box.

Images:

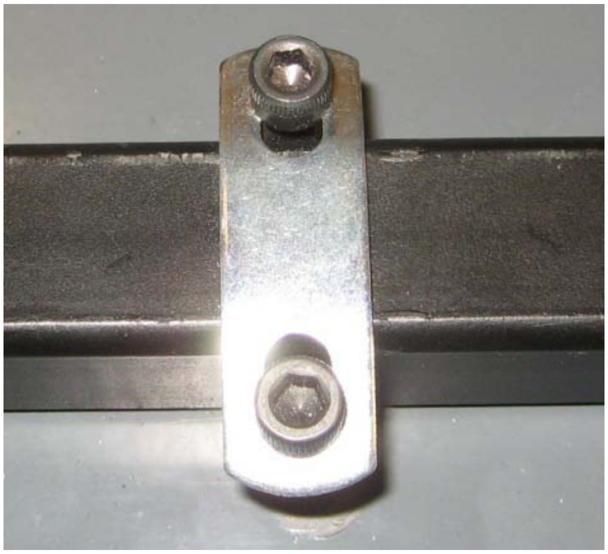


Figure 19: Fixtures keeping mechanism on the cart

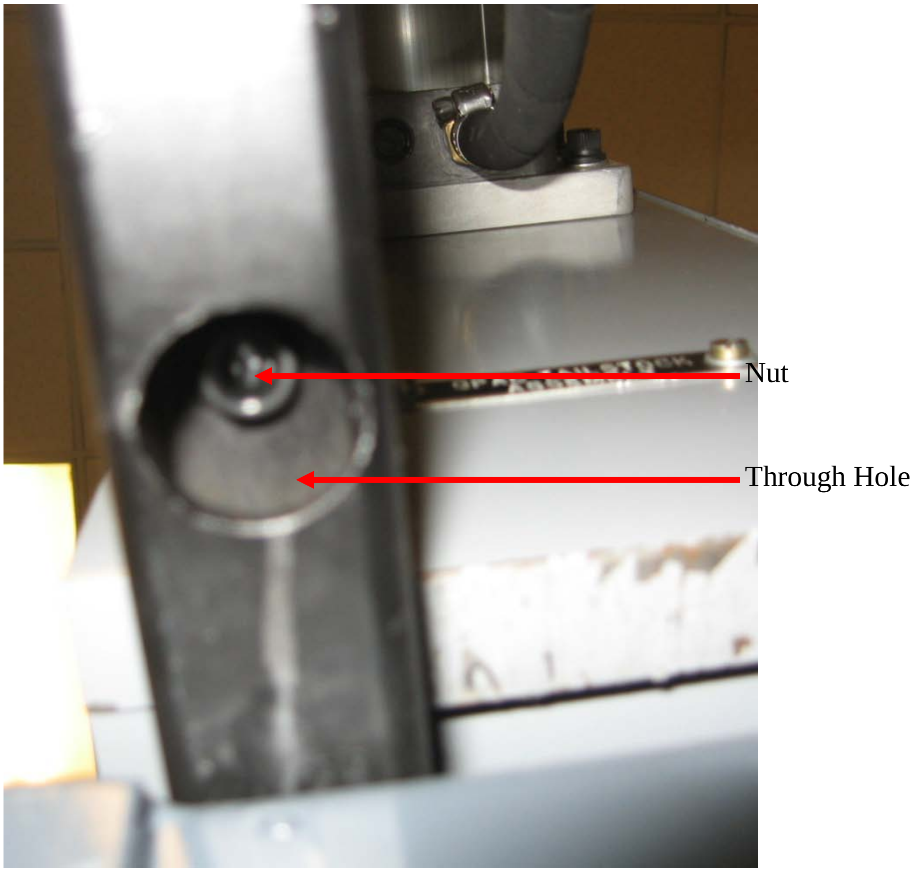


Figure 20: Bottom view of the nut holes under the tail stock

Removing the Crankshaft

Removing the crankshaft is a two person job. One person needs to release the safety catch and get ready to actuate the air lever into the remove position. The second person has to hold up the crankshaft without touching any of the mains and pins so that when the conical support is removed the crankshaft doesn't fall.

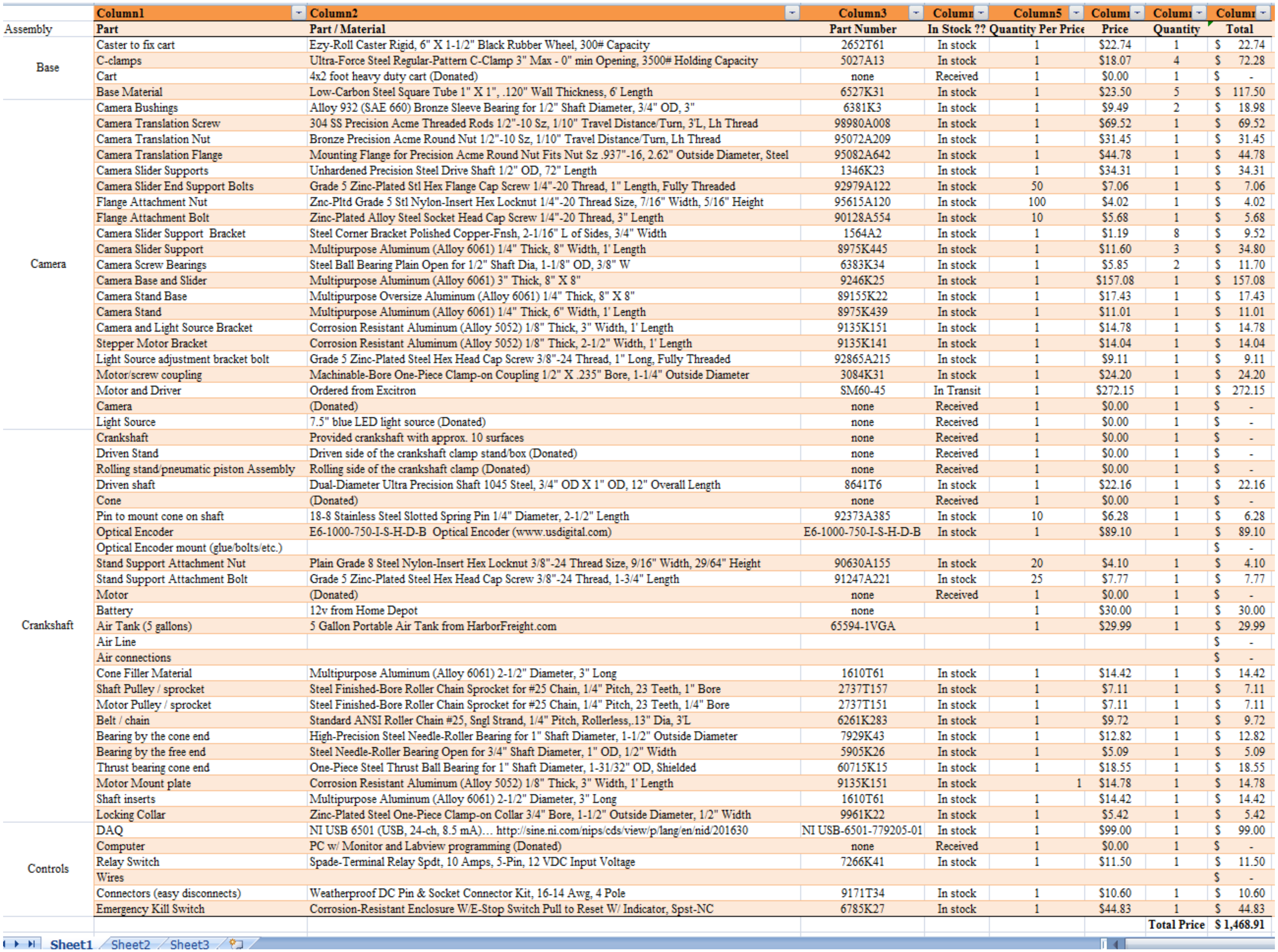
After Testing

Once the testing of the crankshaft is complete **remove the crankshaft**. This step is extremely important as, it is very dangerous to leave the crankshaft installed while unattended. Turn off the air tank using the air flow valve. Actuate the air lever several times to remove all of the air pressure in the air lines then lock the air lever in the removed position. Close LabVIEW. Turn off the computer and light source.

General Maintenance

After letting the machine sit for more than a week or so, dust can accumulate on the slider rods. Because this system involves friction sliders, any dust can be detrimental to the movement of the camera and light source. The slider should be wiped down with a clean cloth and then sprayed with a lubricant such as WD-40. This will ensure that the camera and light source translation system will operate efficiently.

APPENDIX F – Bill of Materials



	Column1	Column2	Column3	Column	Column5	Colum	Colum	Colum
Assembly	Part	Part / Material	Part Number	In Stock ??	Quantity Per Price	Price	Quantity	Total
Base	Caster to fix cart	Ezy-Roll Caster Rigid, 6" X 1-1/2" Black Rubber Wheel, 300# Capacity	2652T61	In stock	1	$22.74	1	$ 22.74
	C-clamps	Ultra-Force Steel Regular-Pattern C-Clamp 3" Max - 0" min Opening, 3500# Holding Capacity	5027A13	In stock	1	$18.07	4	$ 72.28
	Cart	4x2 foot heavy duty cart (Donated)	none	Received	1	$0.00	1	$ -
	Base Material	Low-Carbon Steel Square Tube 1" X 1", .120" Wall Thickness, 6' Length	6527K31	In stock	1	$23.50	5	$ 117.50
Camera	Camera Bushings	Alloy 932 (SAE 660) Bronze Sleeve Bearing for 1/2" Shaft Diameter, 3/4" OD, 3"	6381K3	In stock	1	$9.49	2	$ 18.98
	Camera Translation Screw	304 SS Precision Acme Threaded Rods 1/2"-10 Sz, 1/10" Travel Distance/Turn, 3'L, Lh Thread	98980A008	In stock	1	$69.52	1	$ 69.52
	Camera Translation Nut	Bronze Precision Acme Round Nut 1/2"-10 Sz, 1/10" Travel Distance/Turn, Lh Thread	95072A209	In stock	1	$31.45	1	$ 31.45
	Camera Translation Flange	Mounting Flange for Precision Acme Round Nut Fits Nut Sz .937"-16, 2.62" Outside Diameter, Steel	95082A642	In stock	1	$44.78	1	$ 44.78
	Camera Slider Supports	Unhardened Precision Steel Drive Shaft 1/2" OD, 72" Length	1346K23	In stock	1	$34.31	1	$ 34.31
	Camera Slider End Support Bolts	Grade 5 Zinc-Plated Stl Hex Flange Cap Screw 1/4"-20 Thread, 1" Length, Fully Threaded	92979A122	In stock	50	$7.06	1	$ 7.06
	Flange Attachment Nut	Znc-Pltd Grade 5 Stl Nylon-Insert Hex Locknut 1/4"-20 Thread Size, 7/16" Width, 5/16" Height	95615A120	In stock	100	$4.02	1	$ 4.02
	Flange Attachment Bolt	Zinc-Plated Alloy Steel Socket Head Cap Screw 1/4"-20 Thread, 3" Length	90128A554	In stock	10	$5.68	1	$ 5.68
	Camera Slider Support Bracket	Steel Corner Bracket Polished Copper-Fnsh, 2-1/16" L of Sides, 3/4" Width	1564A2	In stock	1	$1.19	8	$ 9.52
	Camera Slider Support	Multipurpose Aluminum (Alloy 6061) 1/4" Thick, 8" Width, 1' Length	8975K445	In stock	1	$11.60	3	$ 34.80
	Camera Screw Bearings	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/8" OD, 3/8" W	6383K34	In stock	1	$5.85	2	$ 11.70
	Camera Base and Slider	Multipurpose Aluminum (Alloy 6061) 3" Thick, 8" X 8"	9246K25	In stock	1	$157.08	1	$ 157.08
	Camera Stand Base	Multipurpose Oversize Aluminum (Alloy 6061) 1/4" Thick, 8" X 8"	89155K22	In stock	1	$17.43	1	$ 17.43
	Camera Stand	Multipurpose Aluminum (Alloy 6061) 1/4" Thick, 6" Width, 1' Length	8975K439	In stock	1	$11.01	1	$ 11.01
	Camera and Light Source Bracket	Corrosion Resistant Aluminum (Alloy 5052) 1/8" Thick, 3" Width, 1' Length	9135K151	In stock	1	$14.78	1	$ 14.78
	Stepper Motor Bracket	Corrosion Resistant Aluminum (Alloy 5052) 1/8" Thick, 2-1/2" Width, 1' Length	9135K141	In stock	1	$14.04	1	$ 14.04
	Light Source adjustment bracket bolt	Grade 5 Zinc-Plated Steel Hex Head Cap Screw 3/8"-24 Thread, 1" Long, Fully Threaded	92865A215	In stock	1	$9.11	1	$ 9.11
	Motor/screw coupling	Machinable-Bore One-Piece Clamp-on Coupling 1/2" X .235" Bore, 1-1/4" Outside Diameter	3084K31	In stock	1	$24.20	1	$ 24.20
	Motor and Driver	Ordered from Excitron	SM60-45	In Transit	1	$272.15	1	$ 272.15
	Camera	(Donated)	none	Received	1	$0.00	1	$ -
	Light Source	7.5" blue LED light source (Donated)	none	Received	1	$0.00	1	$ -
Crankshaft	Crankshaft	Provided crankshaft with approx. 10 surfaces	none	Received	1	$0.00	1	$ -
	Driven Stand	Driven side of the crankshaft clamp stand/box (Donated)	none	Received	1	$0.00	1	$ -
	Rolling stand/pneumatic piston Assembly	Rolling side of the crankshaft clamp (Donated)	none	Received	1	$0.00	1	$ -
	Driven shaft	Dual-Diameter Ultra Precision Shaft 1045 Steel, 3/4" OD X 1" OD, 12" Overall Length	8641T6	In stock	1	$22.16	1	$ 22.16
	Cone	(Donated)	none	Received	1	$0.00	1	$ -
	Pin to mount cone on shaft	18-8 Stainless Steel Slotted Spring Pin 1/4" Diameter, 2-1/2" Length	92373A385	In stock	10	$6.28	1	$ 6.28
	Optical Encoder	E6-1000-750-I-S-H-D-B Optical Encoder (www.usdigital.com)	E6-1000-750-I-S-H-D-B	In stock	1	$89.10	1	$ 89.10
	Optical Encoder mount (glue/bolts/etc.)							$ -
	Stand Support Attachment Nut	Plain Grade 8 Steel Nylon-Insert Hex Locknut 3/8"-24 Thread Size, 9/16" Width, 29/64" Height	90630A155	In stock	20	$4.10	1	$ 4.10
	Stand Support Attachment Bolt	Grade 5 Zinc-Plated Steel Hex Head Cap Screw 3/8"-24 Thread, 1-3/4" Length	91247A221	In stock	25	$7.77	1	$ 7.77
	Motor	(Donated)	none	Received	1	$0.00	1	$ -
	Battery	12v from Home Depot	none		1	$30.00	1	$ 30.00
	Air Tank (5 gallons)	5 Gallon Portable Air Tank from HarborFreight.com	65594-1VGA		1	$29.99	1	$ 29.99
	Air Line							$ -
	Air connections							$ -
	Cone Filler Material	Multipurpose Aluminum (Alloy 6061) 2-1/2" Diameter, 3" Long	1610T61	In stock	1	$14.42	1	$ 14.42
	Shaft Pulley / sprocket	Steel Finished-Bore Roller Chain Sprocket for #25 Chain, 1/4" Pitch, 23 Teeth, 1" Bore	2737T157	In stock	1	$7.11	1	$ 7.11
	Motor Pulley / sprocket	Steel Finished-Bore Roller Chain Sprocket for #25 Chain, 1/4" Pitch, 23 Teeth, 1/4" Bore	2737T151	In stock	1	$7.11	1	$ 7.11
	Belt / chain	Standard ANSI Roller Chain #25, Sngl Strand, 1/4" Pitch, Rollerless,.13" Dia, 3'L	6261K283	In stock	1	$9.72	1	$ 9.72
	Bearing by the cone end	High-Precision Steel Needle-Roller Bearing for 1" Shaft Diameter, 1-1/2" Outside Diameter	7929K43	In stock	1	$12.82	1	$ 12.82
	Bearing by the free end	Steel Needle-Roller Bearing Open for 3/4" Shaft Diameter, 1" OD, 1/2" Width	5905K26	In stock	1	$5.09	1	$ 5.09
	Thrust bearing cone end	One-Piece Steel Thrust Ball Bearing for 1" Shaft Diameter, 1-31/32" OD, Shielded	60715K15	In stock	1	$18.55	1	$ 18.55
	Motor Mount plate	Corrosion Resistant Aluminum (Alloy 5052) 1/8" Thick, 3" Width, 1' Length	9135K151	In stock	1	$14.78	1	$ 14.78
	Shaft inserts	Multipurpose Aluminum (Alloy 6061) 2-1/2" Diameter, 3" Long	1610T61	In stock	1	$14.42	1	$ 14.42
	Locking Collar	Zinc-Plated Steel One-Piece Clamp-on Collar 3/4" Bore, 1-1/2" Outside Diameter, 1/2" Width	9961K22	In stock	1	$5.42	1	$ 5.42
Controls	DAQ	NI USB 6501 (USB, 24-ch, 8.5 mA)… http://sine.ni.com/nips/cds/view/p/lang/en/nid/201630	NI USB-6501-779205-01	In stock	1	$99.00	1	$ 99.00
	Computer	PC w/ Monitor and Labview programming (Donated)	none	Received	1	$0.00	1	$ -
	Relay Switch	Spade-Terminal Relay Spdt, 10 Amps, 5-Pin, 12 VDC Input Voltage	7266K41	In stock	1	$11.50	1	$ 11.50
	Wires							$ -
	Connectors (easy disconnects)	Weatherproof DC Pin & Socket Connector Kit, 16-14 Awg, 4 Pole	9171T34	In stock	1	$10.60	1	$ 10.60
	Emergency Kill Switch	Corrosion-Resistant Enclosure W/E-Stop Switch Pull to Reset W/ Indicator, Spst-NC	6785K27	In stock	1	$44.83	1	$ 44.83
							Total Price	$ 1,468.91

APPENDIX G - Description of Engineering Changes since Design Review #3

There have been a few changes since the originally designed prototype discussed in our DR#3 report. The only engineering change notice (ECN) reported for the manufacturing section is that the c-clamps are not needed. A new method of clamping the welded base to the cart has been developed. Instead of c-clamps we used four brackets with two bolts each, drilled into the cart to hold down the stand. We also added a safety feature to our design. We added a safety latch to prevent the air piston from being accidentally actuated. The safety latch is shown below in Figure 1.

Figure 1: The safety latch and air lever

For the mechatronics section of our report a few changes have been made. Originally, we planned on using one 12V relay switch to trigger the DC geared motor on and off. A problem occurred because we only had a 5V signal from the DAQ device to accomplish this task. As you can see in Figure 2 below we added a 5V relay to trigger on and off the DC geared motor circuit. Of course a transistor or MOSFET could easily accomplish this task, but due to time constraints we went with what worked. Another reason we decided to have two separate relay switches because the 5V relay was rated to 1amp and we wanted to maintain a safe design.

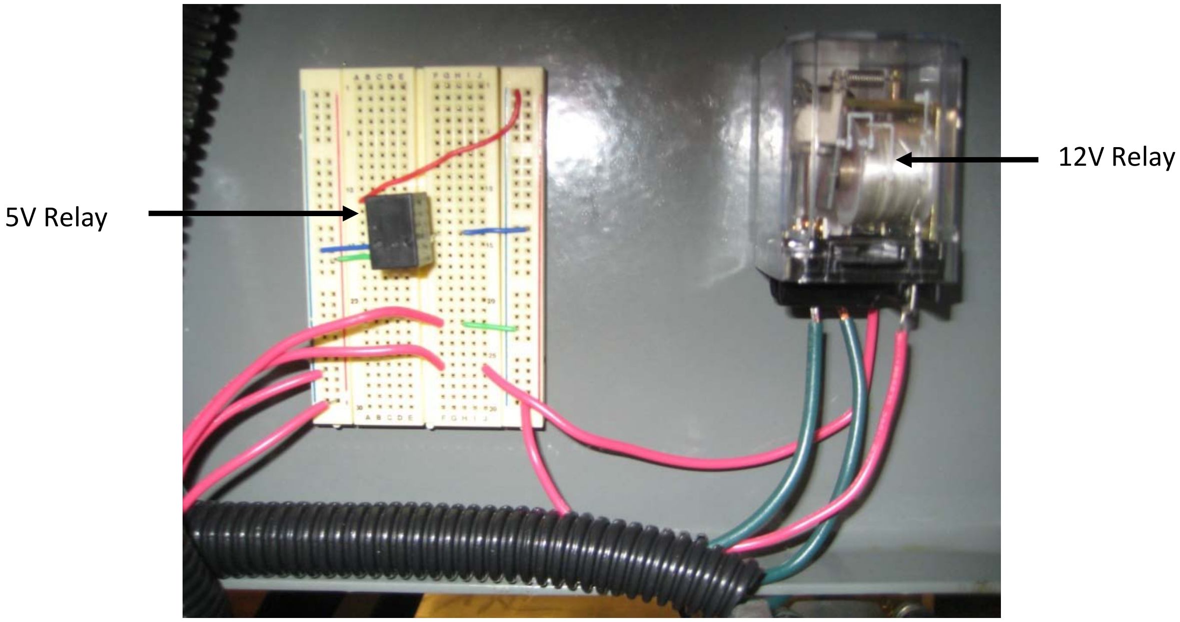


Figure 2: Relay Switches

Another added feature since DR#3 was that we used both A and B channels for the optical encoder. This addition was made because it allows us to specify angular positions of the crankshaft regardless if we go clockwise or counterclockwise. With only one channel the program would never know if directions were changed and thus always be counting up. Using this added feature we were able to pre-determine angular positions of the pins without much of a hassle.

As you can see in the Figure 3 below there have been a number of changes within the circuitry.

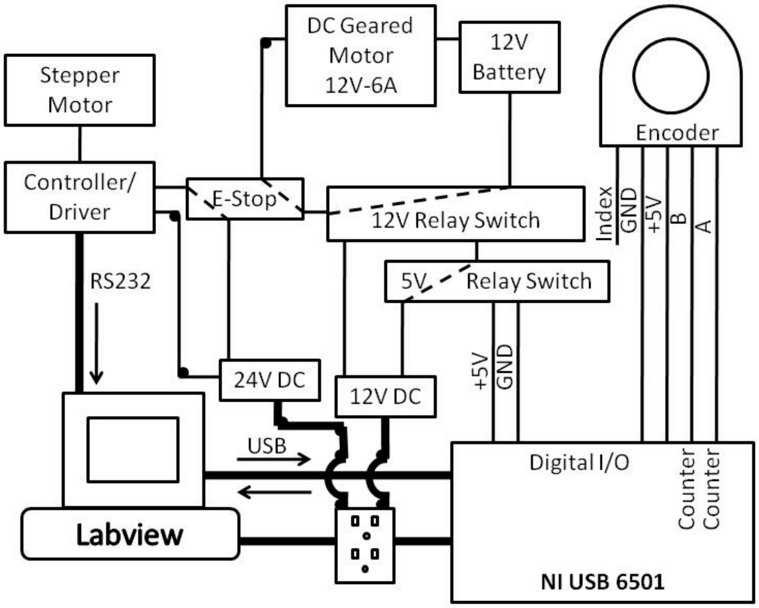


Figure 3: Updated Circuit Diagram

Most of these changes have already been discussed in the preceding paragraphs. Another important change was using a straight RS232 serial port connection to the computer from the stepper motor controller and driver. This change was made from the previously anticipated RS232-USB port because we had encountered a challenge during initial testing. After waking up the motor and sending a 'G' we would get a continuously streaming response of diagonal symbols. We discussed this dilemma with the supplier, Excitron, and after troubleshooting determined there was nothing wrong with the controller. Since there was an available serial port in the rear of the computer's modem we decided to try that and have not had a problem since.

It should also be noted that we had to solder many wires together to create safe and secure connections between lines and components. Each connection was made using quality soldering techniques. Once all wires were in place and connected we wrapped plastic tubing around them for aesthetics as well as safety. As you can see in Figure 4 the wires that connect to the DAQ are wrapped and then zip tied to the cart and grounded components.

Figure 4: Wrapped and Zip Tied DAQ Connections