Semi-Automated System for Quality Assurance of the CRV7 Bridge Filter Circuit

Final Design Report

Bristel

A Consulting Company

MECH 4860: Team 11

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Dr. Paul Labossiere P.Eng
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Dear Dr. Labossiere P.Eng

The attached report, "BFC Resistance Measurement Automation" is submitted in accordance with the requirements laid out on the University of Manitoba's MECH 4860 course website.

The following report was created to present and elaborate on the details of Team 11's final design. The client "Magellan Aerospace, Winnipeg" has set out a list of criteria, which this report thoroughly addresses in the final design. The report includes detailed part drawings, descriptions of each part, each part's integration and implementation in the design, and operational procedures for the new process. Team 11 has also included an overall cost analysis, and process analysis to compare the old process to the new process.

We would like to acknowledge Jacquie Hewson B.Sc Eng, and Les Mayor Propulsion Engineering Manager at Magellan Aerospace for allowing us to visit the site and for providing our team with valuable input throughout the project.

Our hope is that this report will provide you with all necessary details of our design, and exceeds the expectations of this course. If you have any questions, please feel free to contact us by email.

Sincerely,

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Johnathon Nixon
Team 11 Manager

1 TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Glossary of Terms

Batch – Manufacturing unit, quantity of 500.

Bobbin – Spindle or cylinder with flanges to which wire wraps around. Interchangeable with BFC.

Bridge Filter Circuit (BFC) – Circuit that filters particular frequencies to eliminate unwanted frequencies from other devices. Interchangeable with bobbin.

Canadian Rocket Vehicle 7 (CRV-7) – Ground attack rocket produced by Magellan Aerospace.

Electromagnetism (EM) – Fundamental interactive force that requires no medium.

Fixture - Device used to hold bobbin in place and connect wires during resistance measurement.

Mag-mate – Sharp connecting piece that simultaneously strips two magnet wires of the same size in one terminal for splicing or bi-filing.

Serial Port – Physical interface to which information travels in or out one bit at a time.

Tool bit - High speed steel lathe cutter used for pinching bobbin wires.

Ultra-high molecular weight (UMHW) – Polyethylene material with high abrasion resistance and low friction properties.

EXECUTIVE SUMMARY

This report describes the process undertaken and results obtained by Bristel Consulting (hereinafter "the team") in analyzing and redesigning the Bridge Filter Circuit (BFC) testing process currently in use at Magellan Aerospace, Winnipeg (hereinafter "the client"). To complete this project, the team communicated closely with the client to identify needs, constraints, and the project objectives. This information was used throughout the entire design process.

The BFC is a component of the electronic ignition system contained within C15 and C17 rocket motors produced by the client. Dangerous inadvertent rocket firings due to electromagnetic interference are prevented by the BFC. For proper function of the BFC, the resistance values of four coiled wires must be within a specified range. Quality assurance of the rockets requires that each BFC must be tested for proper resistances before assembly into the rocket. Currently, the testing process is performed by an operator stripping eight wires individually in a machine, attaching multimeter test leads to four pairs of wires, typing the multimeter reading into a spreadsheet, applying a masking tape label marked with a hand written serial number, and storing the BFC in a bag to await the next assembly process. The problem with the current process is that it is both overly time consuming and labour intensive.

To meet the client's needs of a faster and less labour intensive BFC testing process, the team set out to design a new process. Design was constrained to the existing work area, and costs were limited to not exceeding that of the current process. During the conceptual design phase of the project, these constraints and limitations were used to screen out a fully automated BFC testing process.

Results of the concept selection process showed that the optimal solution to the client's problem is a semi-automated system using a hand lever actuated fixture for connecting BFC wires to the multimeter, a custom computer program written to upload resistance measurements automatically from the multimeter, and a tray for organizing the storage of tested BFCs. All of these system components were incorporated into the final design of the new process with the following features.

The measurement fixture eliminates the need for wire stripping and manual attachment of resistance test leads. This is accomplished by the tool bit pinching mechanism that electrically

connects all BFC wires simultaneously to the ohm meter by having the operator pull on a single lever.

Once the BFC wires are all connected, there is no need to read resistance values off of the display and retype them into the spreadsheet, as these actions are performed automatically by the software program. BFCs which fall outside the tolerable resistance range are flagged by the software program, and are separated from the other BFCs. BFCs which have acceptable resistance values are then assigned a sequential serial number through the use of adhesive backed pre-numbered labels, eliminating the need to write numbers on masking tape. The serial numbers are in series of 500, with each series covering an entire batch of BFCs.

After testing, the BFC is stored in a specific compartment of a 100 BFC capacity tray corresponding to the serial number, instead of being placed in a bag along with other tested BFCs. The tray allows for quick retrieval of BFCs with specific resistance values during the squib matching process. Through elimination of several steps in the current process procedure and improving organization, the new process meets the basic needs of the client.

To evaluate how well the client's needs were met, the new process was compared to the current process in terms of both time and cost. Time trials of the new process performed by the team using mock components showed that the total time for testing each BFC is 29 seconds, an 88% time reduction compared to 251 seconds for the current process. Additionally, manual labour intensity is reduced with the new process by decreasing time spent on manual tasks by 92%. The upfront cost for the new process is $5893, which will be paid back in cost savings to the client after two batches of BFCs are tested. After the payback period, the new process will save the client $4936 per batch of BFCs tested.

In addition to making the BFC testing process faster, less labour intensive, and more cost effective than the current process, the new process also improves reliability of the test. This is accomplished in several ways. First, a three phase implementation plan is incorporated into the final design. The three phases allow the operator to become gradually familiar with the equipment and procedure instructions, then audit the process for any erroneous results. Between phases, the operator's feedback with regards to ergonomics and unforeseen issues will be addressed. In addition, test reliability is improved from the current system by reducing the chance of human error by reducing the amount of human operator input into the process. By doing so, the probability of data entry typographical errors and improper test lead connections becomes zero. Also, human error due to fatigue is reduced through improvement of operator ergonomics.

To assist Magellan Aerospace, Winnipeg with moving forward in the fabrication and implementation of the new process, a thorough cost analysis and a set of technical part drawings are provided. By incorporating concept exploration, physical testing, material selection, manufacturing principles and economic analysis into the engineering design process, the team is confident that the proposed design will meet the client requirements of a faster and less labour intensive BFC testing process.

1 INTRODUCTION

The purpose of this report is to define the recommended new process which our team has developed for the system of measuring, storing, and accepting Bridge Filter Circuit (BFC) resistance data for a quality assurance program at Magellan Aerospace, Winnipeg (hereinafter "the client"). The new process aims to optimize the system currently used by the client through reduction of the total process time and labour intensity. Our design team is made up of four diverse students, enrolled in the Mechanical Engineering Program at the University of Manitoba. Each of the four students brought their own talents to the project, resulting in a well-rounded design. In order to comprehensively present the redesigned system, this report is divided into the following sections: the problem description, the details of the new design, design integration and operation, implementation, results, cost analysis, conclusion and recommendations for the client, a list of the team's referenced materials, and, finally, the appendix.

1.1 BACKGROUND

The client manufactures a variety of aerospace products, one of which is the CRV7 (Canadian Rocket Vehicle 7) rocket motor, shown in Fig. 1. These unguided rockets have a 2.75" diameter and are used to propel various warheads.

[redacted]

Figure 1: CRV7 rocket motor cutaway, warhead not pictured [1].

The CRV7 has an electronic ignition system that is protected from electromagnetic (EM) interference by a Bridge Filter Circuit (BFC). EM interference poses a high risk to the function and safety of the rocket, and presents a vulnerability which may be exploited by potential military targets. EM interference may cause the inadvertent firing of a rocket, which can be extremely dangerous in a military application. Additional to inadvertent firing, an ignition system that does not function is a potential risk. An inoperable rocket can contribute to a failed military mission and create further issues with the safe disposal of the unit containing explosive materials.

Once assembled, the rocket cannot be disassembled for repair of a faulty ignition system, and must be disposed of in an appropriate manner. For quality assurance purposes, the BFC must be tested before rocket assembly to avoid producing rockets with faulty ignition systems. A single BFC, also referred to as a bobbin, is shown in Fig. 2.

Figure 2: Bobbin with wires pulled back.

Each BFC consists of a cable containing four wires spooled onto a glass reinforced thermoplastic polyester bobbin. Each wire is coated with an insulating dyed Kapton Polyimide film for identification by colour and is separated from the cable housing at one end of the bobbin. The wires are colour coded as green, yellow, red, and black. Each wire has one of two approximate resistance values, which allows the BFC to function correctly; the first resistance value (R1) is within moduli of 9 to 12.83 ohms for the red and black wires, and the second resistance value (R2) within 1.19 to 1.87 ohms for the yellow and green wires.

Fig. 3 shows the BFC electrical diagram. The four resistors have two different resistance values, R1 and R2, which correspond with the approximate resistance moduli stated in the previous paragraph. The difference in resistance comes from the different wire material used. R1 is comprised of a solid stainless steel wire, whereas R2 is comprised of a wire with a copper core surrounded by stainless steel.

[redacted]

Figure 3: BFC diagram [2].

The squib, as shown in Fig. 3, is a component that is connected after the BFC is tested. The squib contains a small incendiary charge that detonates when the filament is heated by electrical current passing through the device. The squib detonation begins the rocket motor firing sequence. When a DC signal is applied to the Electrical Launcher Interface (ELI), current flows through the squib due to the imbalance of resistance between the two sides of the bridge. However, when an alternating current is induced into the BFC from EM interference, R1 and R2 are equal since alternating current travels around the outside of the conductor. This causes the bridge to be balanced, not allowing any current to flow through the squib, and therefore eliminating the chance of inadvertent squib detonation.

1.2 Current Process

The current process requires an operator to perform all measuring, data entry, and passing/failing BFCs manually. The current process uses the equipment shown in Fig. 4.

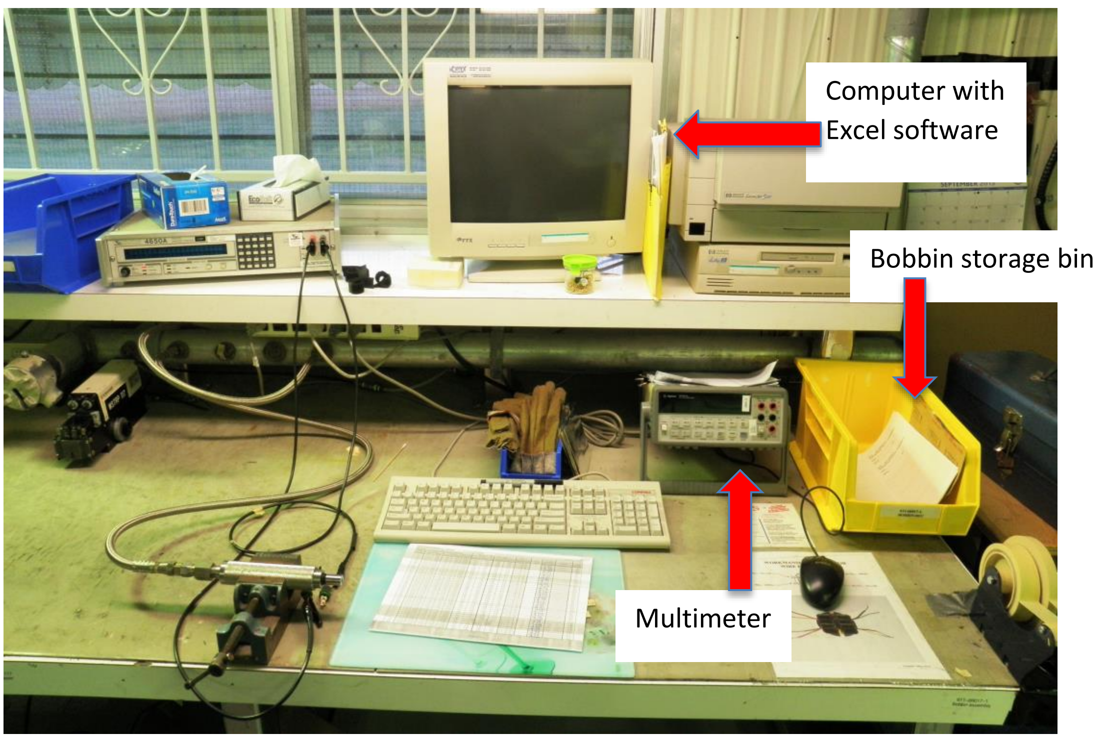

Figure 4: Current Process Equipment.

The current process that is conducted at Magellan Aerospace is as follows, in sequential order:

1. Unmarked bobbins are received in bags (capacity of 50 bobbins) from the manufacturer and are placed into a bin.
2. The operator picks up one bobbin from the bin, visually assesses the bobbin for any visible damage, and checks for proper wire arrangement. The orientation of each pair of

wires is shown in Fig. 5. The bobbin is either kept for further processing or put in a separate bin marked as failed bobbins. Bobbin failure can be justified if the bobbin is chipped, broken, or resistance readings do not lay between the resistance criteria.

[redacted]

Figure 5: Wire arrangement, BFC top view [3].

3. Each end (eight in total) of the four wires on the bobbin must be manually stripped of its insulation using a wire-stripping machine. The amount of insulation required for removal is just enough to fit alligator clip test leads onto the bare metal wire.
4. The operator must then manually attach two alligator clips, one on each end of a particular wire to complete the circuit. The alligator clips are electrically connected to a digital multimeter where the operator can visually see a digital readout of resistance on an LCD screen.
5. The resistance readout on the multimeter is immediately recorded on an excel spreadsheet. (The operator repeats the multimeter reading and recording to excel spreadsheet process for the remaining three wires on the bobbin)
6. Once all four wires on the bobbin have been measured and recorded, a ball point pen is used to mark a piece of masking tape with a serial number obtained by the excel spreadsheet, and adhered to the side of the bobbin for proper matching with squibs in a later process.
7. The labelled bobbin is finally placed into the bag which initially held the unmarked as-received bobbins.
8. Process steps 2 through 7 are repeated until all bobbins received have been processed.

Performing the current process costs the client a total of $12.80 per unit and each unit takes an average of 4 minutes and 48 seconds to test [4]. Magellan receives a delivery of 500 bobbins (one batch), and processes them within approximately a week's time. The current process is slow and tedious, with many chances for the worker to make a mistake that would affect rocket performance. Therefore, an optimized semi-automated system for the measurement and acceptance of BFC wire resistances must be designed and implemented.

1.3 Problem Statement

The problems with the client's current process of BFC testing stem from the following:

1. Time taken for the operator to complete the process.
2. Difficulty of performing the process.
3. Expense incurred when performing the process.

The current process requires too much time to complete, meaning that both shop time and labour are wasted as a result of conducting the quality assurance process. The current process is also extremely tedious, involving fine work done by hand, where the operator must develop a skilled workflow and pay special attention when recording data to ensure the process is completed reliably. This increases the chance of human error in the quality assurance process and results in a reduction in the worker's productivity. Finally, the cost of the current process is unacceptably high due both to the time, and productivity factors. All of these issues contribute to a reduction in the client's operational efficiency for production of rocket motors, and result in the need for the current process to be re-designed.

1.4 Client Needs

Through the client's collaboration with the University of Manitoba in putting forth this project, and through interactions with the team, the client has expressed a list of needs (without specification), which the new process has addressed. These needs are as follows:

- Less labour intensive process
- Reduce process time
- Maintain process reliability

The operator requires a less labour intensive process, allowing precious hours of operator time to be allocated to other critical areas of production. The client also expects that our design will reduce the total amount of budgeted labour hours required in order to complete each batch of BFCs. Additionally, the client has expressed very clearly that the integrity of the current testing regime is paramount. Therefore, the team's re-design must maintain the existing precedent for reliability and add merit to the client's product manufacturing standards. Therefore, the new process must be reliable, while increasing throughput rate, and maintaining a safe work environment for all personnel.

Taking ergonomics into consideration, the operator should feel a reduction in strain of mind and body. Ergonomics evidently were not high priority during the design of the current process. The result of a non-ergonomic process is a frustrated operator, which can further result with an unreliable and unsafe process. The current process is tedious and time consuming, thus open to human error. The client would like to reduce human error, which could be accomplished by addressing the preceding needs. Many other needs have been considered during the problem-defining phase of this project; however, they are of lower importance than the needs stated. For further information on the steps taken by the team to identify client needs refer to Appendix A.

1.5 Target Specifications

Specifications for each need were not provided to the team by the client, so the team developed their own target specifications during the problem definition phase of the project. The first target specification set is that the new process shall take 30 seconds to completely test a BFC. The next target specification is that the new process shall consist of a maximum of four steps to complete, with three of these steps requiring direct human input. The last target specification is that no amount of incorrect BFC test results are acceptable.

1.6 Project Objectives

The primary objective of this project was to design a new BFC testing process to replace the current process used by Magellan Aerospace, Winnipeg. The team focused on designing the new process to optimize Magellan's current operation in terms of both labour hours and cost. Before designing, the objective was to collect information on the current process. This was accomplished by visiting Magellan's Rockwood Propellant Plant, where the team observed the current process being performed. Through this site visit and conversation with employees at Magellan, the team was able to identify key issues with the current process. Research was then performed to gain background knowledge in Magellan's product and different methods of quality assurance.

Once the team gained familiarity with the current process, conceptual redesign was started. The team reached a final goal of creating several concepts for the BFC resistance measurement process, and converging said designs. The main objective was to define a final concept, and the team converged concepts into a final conceptual design that met all of the client's needs. The concept generation and selection process report, which details how the concept selection process was conducted can be found in Appendix B.

During development of the final concept into a final design, the objective was to make the implementation of the design as straight forward and issue-free for the client as possible. This was accomplished by dividing the design into four major components that can be implemented progressively in three phases.

The final design has been completed with fully dimensioned drawings, all equipment, processes, and materials specified, and a thorough cost analysis. The major goal for this report was to present a design that is desirable to the client, portray the methods used for reaching the final design, and conclude with recommendations for the client.

2 Overview of Design

Our team's re-designed process meets all client needs and improves on the current process metrics. Our design is a semi-automated BFC testing system, which utilizes four major components for full functionality. The four components are a measurement fixture, automation software, electronic hardware, and an organizational tray (shown in Fig. 6). Each component plays a necessary role in the integration of the improved process. The fixture eliminates the need for wire stripping and operator-assisted attachment of resistance test leads. The operator pulls a lever on the measurement fixture, clamping high-speed tool steel bits on the bobbin wires with enough force to break through the electrically insulating Kapton layer. With electrical conductance between the tool steel bits and bobbin wires, a hardwired ohmmeter measures the resistance values of all bobbin wires.

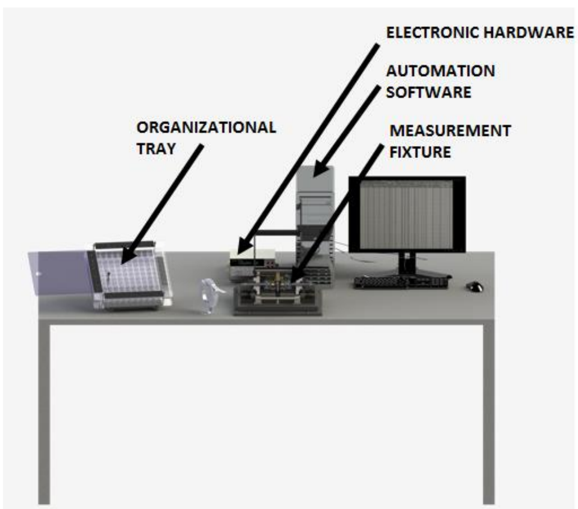

Figure 6: Major components of new process.

The software is designed to limit operator interaction throughout the process and prompt the operator for process steps and protocol. The software interfaces with incoming measurement readings from the ohmmeter, and an Excel spreadsheet designed to present process data. The process data includes catalogued wire resistance readings, bobbin integrity (flagging of failed bobbins), and bobbin integrity trends to analyze the reliability of the new proposed solution. The described abilities of this software eliminate a current process step, which involves the operator manually entering ohmmeter readings into an Excel spreadsheet. The ohmmeter being used possesses only one channel for data transfer, thus electrical relaying hardware is required to further eliminate operator interaction. The software is further developed to interact with a mechanical relay connected between the fixture and the ohmmeter. The software checks all four bobbin wires sequentially by switching between wires with said relay. All interaction with the mechanical circuit relay and ohmmeter are automatically performed by the software, and depend on minimal operator input.

Catalogued data will be cross-referenced with the address of the bobbins physical whereabouts. A tray with compartments will be used to hold 100 bobbins, which are specifically placed where the software catalogues them. Numbered labels will be adhered to each bobbin, containing a serial number specific to its address. The new bobbin order regime will greatly decrease the tedious time consuming job of locating specific bobbins in a bag as per the current process. Fig. 7 shows a flow chart of the new process.

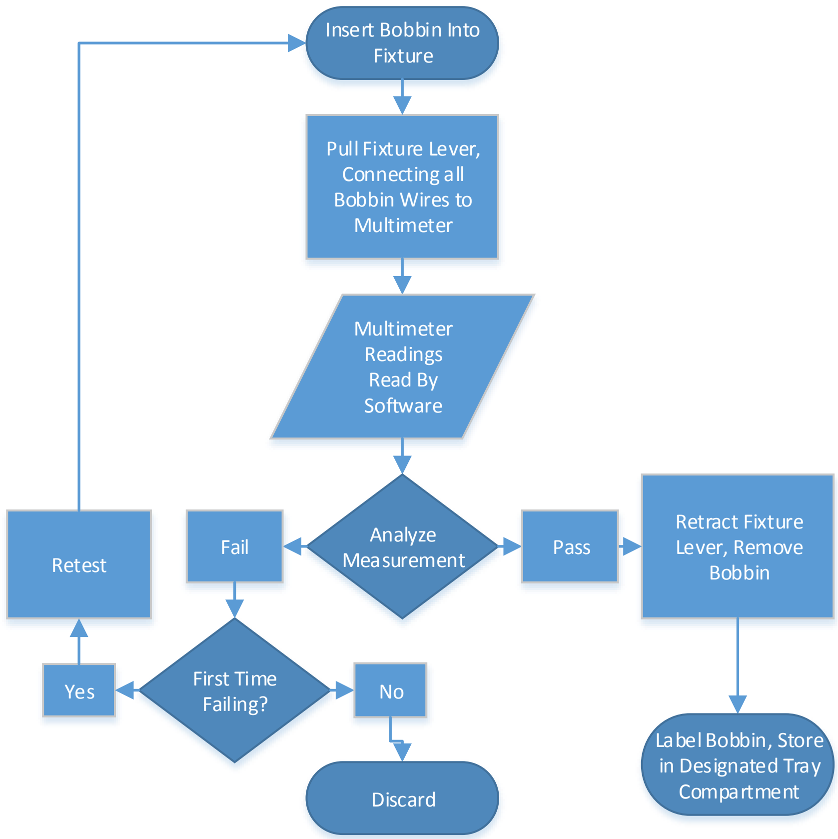

Figure 7: Flow chart of new process.

The process followed to measure a single bobbin in the proposed solution is as follows:

1. The operator is prompted by the computer to insert a bobbin for resistance measurement, and proceeds by pulling on a lever to disengage the wire clamping mechanism while inserting a bobbin into a slot in the fixture.
2. The operator then closes the fixture by slowly releasing the lever, keeping their other hand away from the clamping mechanism. This step pinches the bobbin wires for electrical conduction. The pinching mechanism creates a circuit between each bobbin wire and the ohmmeter. The software then reads the information, processes the data to detect any flaw or failure, and catalogues the data.
3. The operator then retrieves the measured bobbin by pulling the fixture lever again, while pulling the bobbin out of the fixture slot with their other hand, and releasing the fixture lever when their other hand is clear of the apparatus. The final step is to adhere a label with a serial number onto the side of the bobbin and place it in its designated slot in the tray, as per the catalogued address assumed by the software.

Each step listed is for the case where the bobbin resistance measurement or physical integrity does not fail. If an unnatural resistance reading occurs, the software follows protocol to re-test the bobbin and prompts the operator to interact accordingly.

The expected result of the proposed solution is an improved process that meets all of the client's needs. Testing of all components interacting with one another is vital for success of implementation. Our team is confident that with a thorough debugging process, the proposed solution will successfully go above and beyond the client's expectations.

3 DETAILED DESIGN

The detailed design explanation of the semi-automated BFC quality assurance process is broken into its separate components for clarity. Beginning with the measurement fixture, all of the mechanical parts which work together to accomplish wire probing automatically are described individually, then the electronic components which perform their function alongside the measurement fixture are described in a similar fashion. These two sections are followed by the automation software section in which each feature of the software is described. Finally, the construction and implementation of the organization tray are described in full detail. Manufacturing drawings of all non-standard parts are provided in Appendix C.

3.1 MEASUREMENT FIXTURE

The mechanical parts of our design are all contained in the measurement fixture. The overall dimensions of our fixture are 15.25" L x 13" W x 11" H in the lever-raised-configuration, as shown in Fig 8. Dimensions of key features of our design are shown throughout this section, and complete technical drawings of all the components of the design are found in Appendix C.

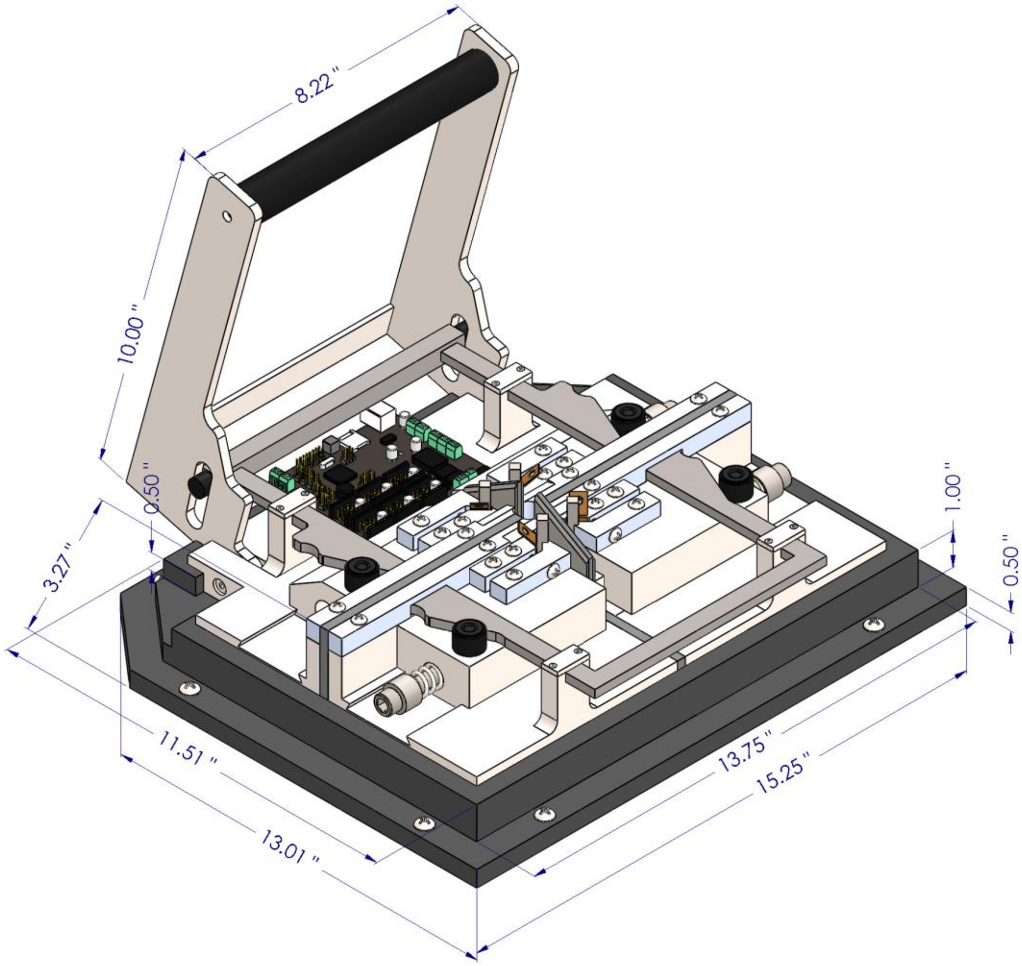

Figure 8: Overall Dimensions of Measurement Fixture.

The measurement fixture constrains the BFC in place and pierces the Kapton insulation on the lead wires to enable resistance measurement. To accomplish this, our design has the following key features:

- A BFC placement slot and wire spreading features;
- Tool steel bits and backing plates for pinching the BFC wires;
- Sliders and slider base fixtures to provide linear motion to the tool bits;
- Springs and spring adjustment bolts to apply the required force to the sliders;
- A cam and follower system to actuate the motion of the sliders;
- A lever to actuate the motion of the cam;
- Adjustment blocks to arrest the motion of the sliders in the correct position;
- A plastic base to house all the components of the measurement fixture.

These features are all indicated in Fig. 9 and described in detail in the following sections.

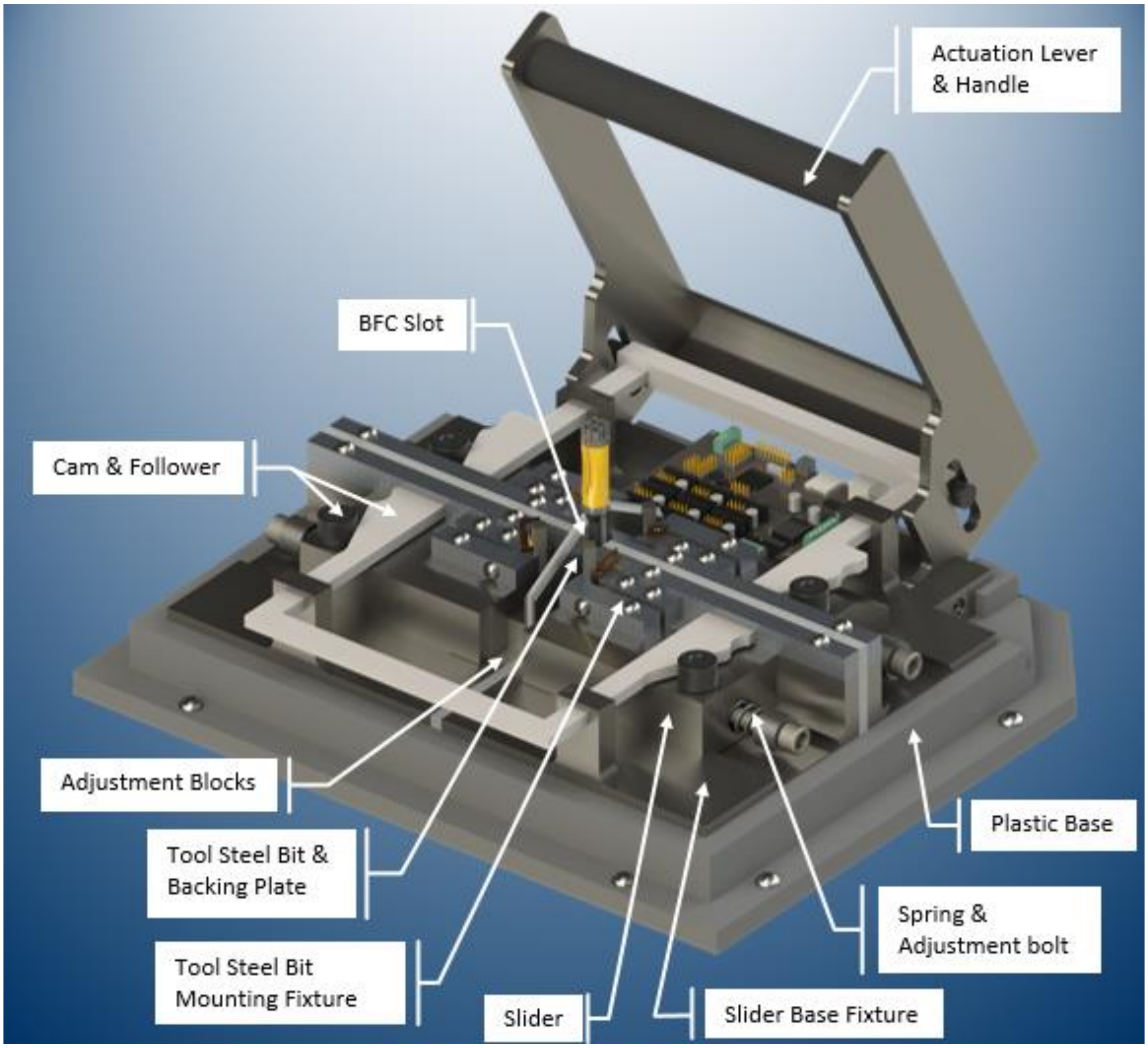

Figure 9: BFC wire resistance measurement fixture.

3.1.1 BFC Placement and Wire Spreading

In order to reduce the amount of time the operator spends adjusting the position of the BFC to take resistance measurements, our design holds the BFC in one position and spreads the wires out into a configuration in which they can then be tested. To fix the BFC's position, the team took advantage of a hole in the centre bobbin, shown in Fig. 12. We designed a square peg, shown in Fig. 10, that fits inside this hole, and keeps the BFC from rotating in the fixture. The peg is tapered so that the bobbin can easily slide onto it while still having a tight tolerance at the bottom so that it holds its position.

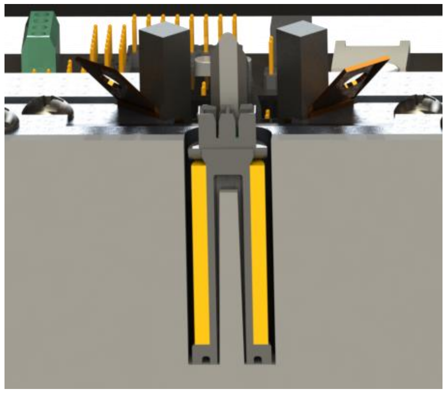

Figure 10: Cutaway showing square, tapered bobbin peg.

The peg's taper increases the ease of inserting the BFC into the fixture. We designed a 0.6" diameter hole around the peg for the 0.545" diameter bobbin in the fixture, thus ensuring that the bobbin wires will not follow the bobbin into the hole due to their natural tendency to spring outwards from the bobbin body. The peg and slot as well as the bobbin are shown in Fig. 10 and 11, with relevant dimensions displayed.

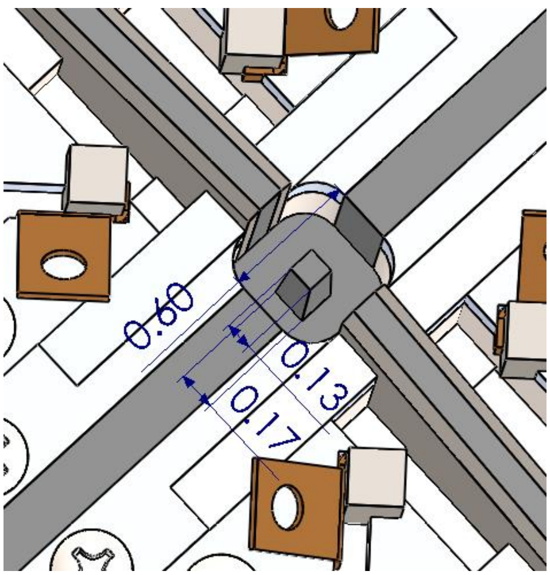

Figure 11: BFC slot and peg dimensions.

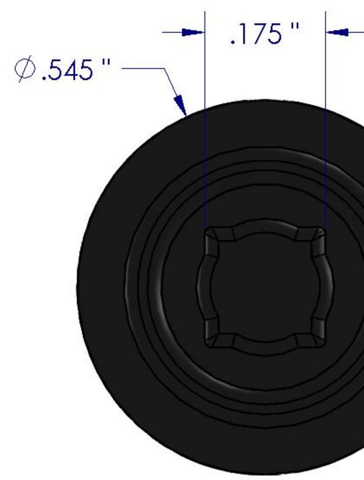

Figure 12: Bobbin bottom view showing diameter and hole width.

As the BFC slides down into position, the slanted tops of the tool steel and Garolite plates, shown in Fig. 13, force the lead wires to splay out into a position where they can be pinched and measured for resistance.

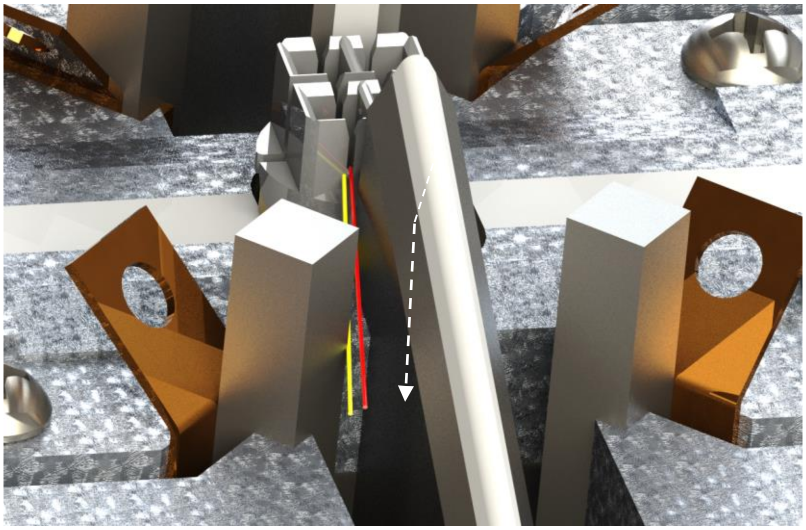

Figure 13: Red and yellow BFC wires spreading as the BFC is inserted.

The BFC wires will not follow the bobbin into the hole due to their natural tendency to spring outwards from the bobbin body.

3.1.2 Tool Steel Bit and Backing Plates

Our design also reduces process time by pinching into all eight lead wire ends simultaneously with a tool steel bit, shown in Fig. 14, while keeping all necessary parts of the fixture electrically insulated from each other using a Garolite plate.

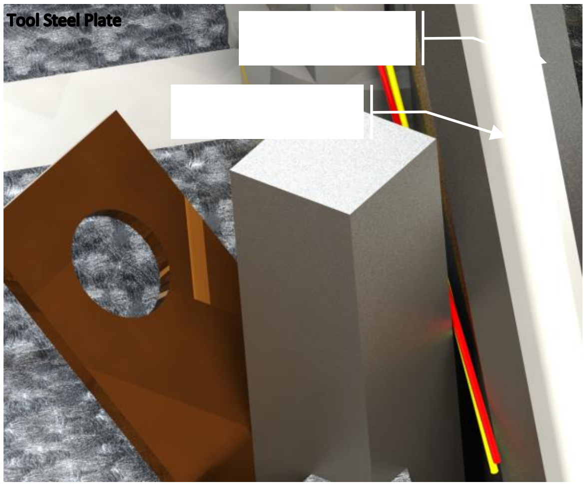

Figure 14: Tool steel bit pinching wires.

Pinching of the wires eliminates the need for the operator to strip each wire, since the bits pinch through the Kapton insulation and make contact with the wire underneath. High speed tool steel was chosen for this application because of its hardness and ability to keep a sharp edge after repeated use. In addition, the tool bits are commonly used for lathe cutting tools, ensuring that they can be easily procured. Another advantage of the tool steel bit design is that their factory precision ground 90 degree edges are used as the working edge, eliminating the need to custom grind an edge into them. The bits pinch the wires against backing plates, which are also made of tool steel. This backing plates is fastened to the slider base fixture with countersunk screws to allow for a Garolite plate to be slid in between the tool steel plates. The Garolite plates keep each fixture quadrant electrically insulated from each other. Garolite was chosen as the material for this part based on its high strength properties since it will be subjected to compressive forces from the converging steel bits, as well as its low electrical conductance. The slanted shape at the top of the tool steel-Garolite sandwich ensures that the BFC wires will slide down onto the correct side of the plates. Our team chose a curved surface for the top of the Garolite plate rather than a straight slanted peak to reduce the number of pointed surfaces around where the operator's hand will be. We also ensured that the spacing between the tool steel bits was sufficient for the operator's fingers to fit in between when inserting the bobbin. The tool steel and Garolite parts are manufactured from readily available stock and machined into as simple as possible shapes to reduce cost and increase manufacturability.

3.1.3 Tool Steel Bit Mounting Fixture

The tool steel bits are mounted into fixtures that are bolted to sliders, which facilitate the required linear motion of the bits. The fixtures, shown in Fig. 15, are milled out of 6061 Aluminum and feature a pivot point and a horizontal screw to clamp the bits into place. A copper plate is wedged in between each bit and the fixed portion of the fixture acts as the contact point for the ohmmeter wires. We selected copper as the material for these plates based on its negligible electrical resistance and low cost. The ohmmeter wires are attached to the copper plates via a banana plug inserted into the hole at the top of the plate.

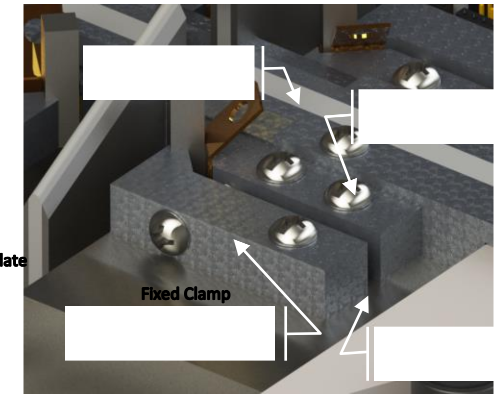

Figure 15: Tool steel bit holder.

The clamps were designed to clamp the tool steel bit at a 45° to the slider to produce the required pinching action. The dimensions of the two parts are shown in Fig. 16 and 17.

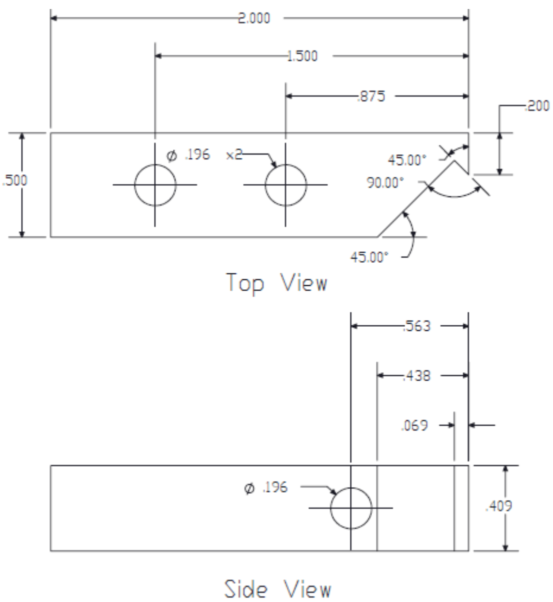

Figure 16: Fixed clamp dimensions.

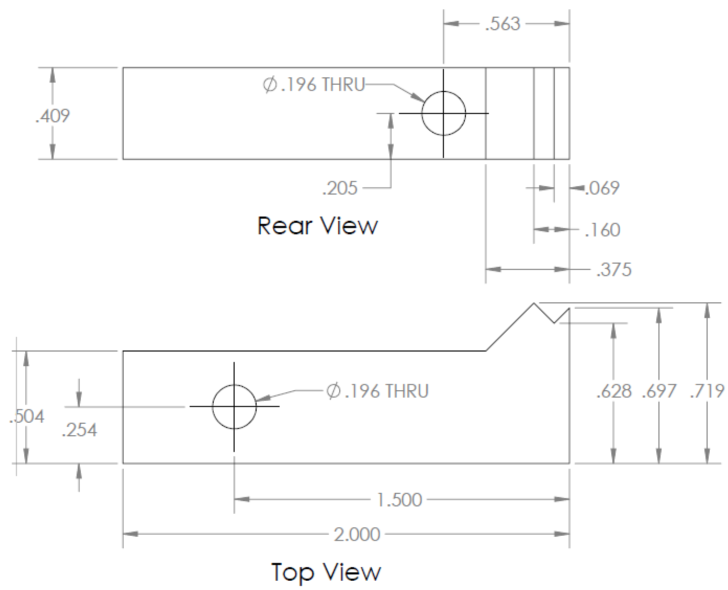

Figure 17: Pivot clamp dimensions.

3.1.4 Slider and Slider Base Fixture

The linear motion of each bit is provided by a slider, shown in Fig. 18. The sliders feature a dovetail which fits into a mating groove milled into the slider base fixture.

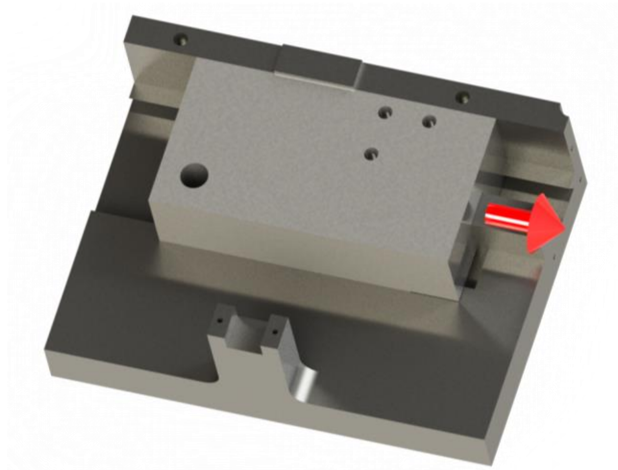

Figure 18: Slider and slider base fixture

The overall dimensions of the slider and slider base fixture are shown in Fig 19 and 20. We chose to use 0.005" for the spacing between the inside edge of the sliders and the wall of the slider base fixture to allow for low friction motion of the slider while still maintaining consistently straight tracking. The dovetail is designed to have a total of 0.002" of clearance between the male and female ways. This allows for the parts to be machined with a general surface finish, while maintaining parallelism between the tool steel bits and backing plate. Parallelism here is essential for consistent electrical contact between the pair of wires and tool steel bit.

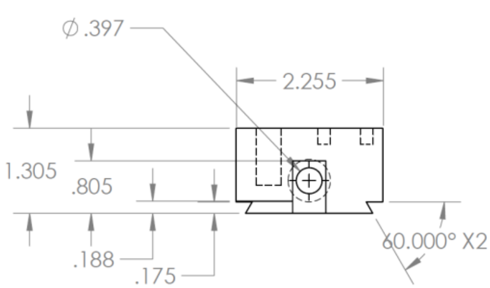

Figure 19: Slider Dimensions.

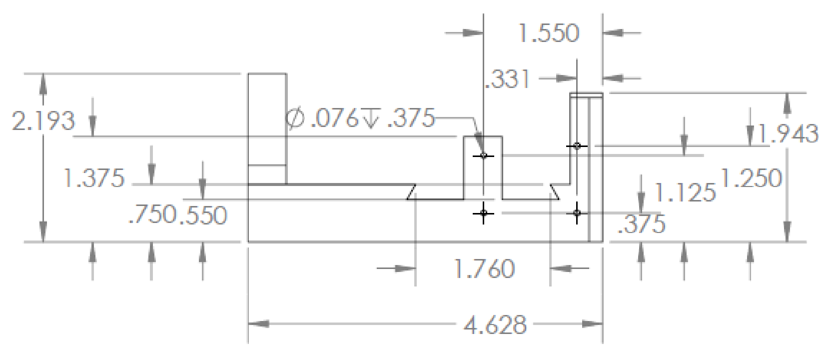

Figure 20: Slider base dimensions.

In dimensioning the slider and slider base fixture, we ensured that considerations for required tool clearance for milling operations were taken into account. The sliders are set in motion by a compression spring and a cam-follower plate system, which are discussed in Cam and Follower and Spring & Spring Adjustment sections of this report.

3.1.5 Spring and Spring Adjustment Bolt

Successfully pinching through the Kapton insulation of the BFC wires every time is an essential requirement of our design. Through trystorming, our team discovered that approximately 10 lbs of force is required for a tool steel bit to bite through the insulation and contact the wire.

Appendix D contains a test summary of the determination of wire pinch force. We then had the challenge of determining a method of simultaneously applying this amount of force to all eight BFC wires with minimal effort required from the operator. After discussing various methods of supplying the required force including pneumatic actuators and multiple levers, we decided that using compression springs constrained by a bolt would be the cheapest and simplest option. At the same time, this option requires minimal effort to calibrate, requiring only tightening or loosening of the adjustment bolt.

This system guarantees consistent force application to the wires independent of the operator. The operator opens the pinching mechanism against the force of the spring, inserts the BFC, then the springs provide the pinching force.   The compression spring we selected has a k value of 21 lbf/inch. The spring is held in place by a 3/8"-16X5 bolt, which passes through a clearance hole in the slider and is threaded into a block in the slider base fixture, shown in Fig. 21.

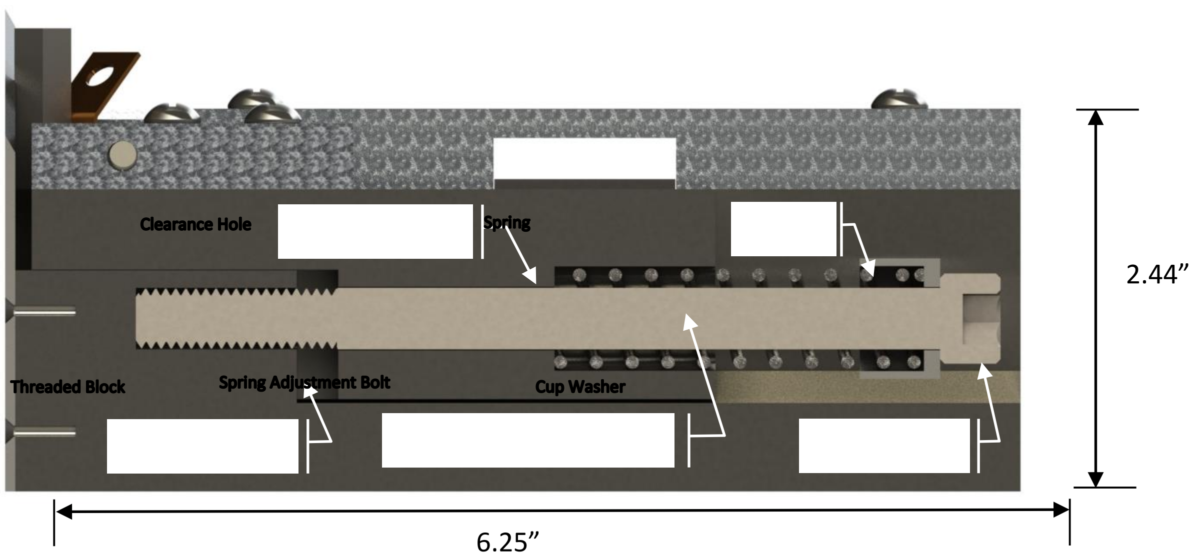

Figure 21: Spring Assembly

This bolt has an allowable range of 1 to 2 inches of threaded length. The spring is constrained on one end by a custom fabricated cup washer at the head end of the bolt, shown in Fig. 21, and fits into a hole milled into the back face of the slider on the other end, allowing it to push the slider as required. Pre-compression of the spring is achieved by advancing the bolt into the fixture block. The operator is required to open the fixture to place the bobbin in and let it close so that the tool steel bits pierce through the wire insulation to allow the wires to be tested.

3.1.6 Cam and Follower arrangement

The cam-follower arrangement, seen in Fig. 22, actuates all four individual wire probing slides simultaneously by actuating along a single direction of planar motion. Each slider has its own roller bearing which rides along the cam as it moves. The cam is designed to be confined to its linear motion on the fixture by journals on each of the four quarters of the probing interface. Two inches of cam movement translates to one half inch of clearance between the tool steel bit on the slider and its end plate. The cam progression is linear, and the cam plate itself is made from ultra-high molecular weight (UMHW) plastic for its lubricating properties and electrically insulating properties.

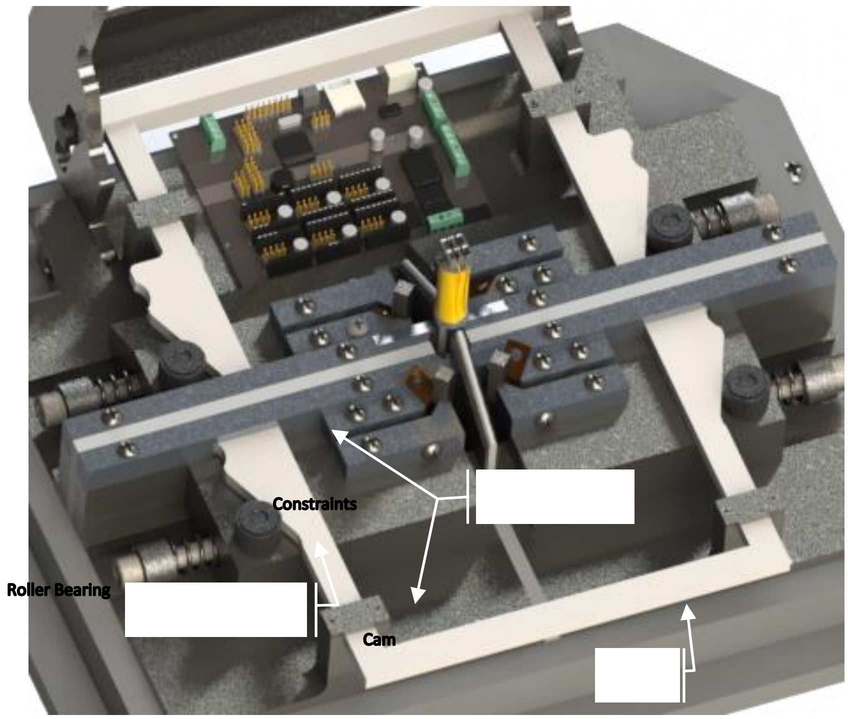

Figure 22: Cam-follower arrangement.

3.1.7 Actuation Lever

The actuation lever is used to create the linear motion of the cam plate along its journals from rotational motion of the lever, created by the operator. The lever consists of two parallel bars adjoined by a handle. Fig. 23 shows the lever arrangement and the adjoining cam plate interface.

Figure 23: Actuation lever and cam plate

The design of the cam plate interface on the actuation lever is another cam-follower arrangement which actuates another roller-bearing interface. This time the roller bearings are mounted into the cam plate, and the corresponding cam is laser cut into the profile of the lever bars (Fig. 24).

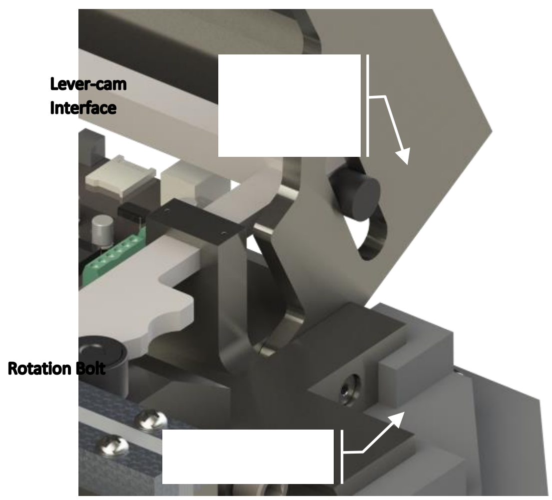

Figure 24 : Lever Interface

The lever bars are created from steel and affixed to the measurement fixture using a set of bolts threaded through a single bar about which each lever plate may rotate. The handle is made from round UHMW bar stock, providing a wide smooth grabbing surface.

3.1.8 Adjustment Blocks and Shims

The stopping positions between the tool steel bits and backing plates is vital to our design so that the resistance measurement process is reliable for each bobbin measured. If the bits stop too soon, they will not penetrate through the wire insulation and therefore will not measure the wire resistance correctly. Conversely, if the bits travel too far, they will cut right through the wires which would also result in a false resistance measurement, as the bit would now be in contact with the backing plate instead. We therefore implemented an adjustment block and shim arrangement which fit into the slider base fixture, shown in Fig. 25. One block is bolted in a fixed position, while the second block is bolted into a slot to allow for shims to be placed in between the blocks.

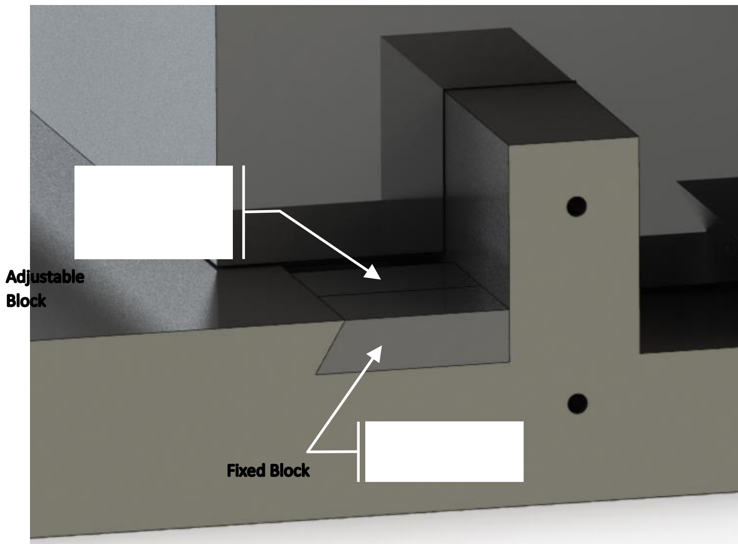

Figure 25: Adjustment blocks.

Figure 26: Adjustment block bolts

Pieces of automotive feeler gauges can be conveniently used for shims, as they come in a variety of pre-labelled thicknesses (0.002-0.030”). The slider has a matching groove milled into it. The slider is stopped when the vertical face of the groove comes into contact with the adjustment block. The tool steel and Garolite plates extend to the outer edge of the blocks so that they bear some of the load transferred from the slider to the adjustment blocks.

3.1.9 Plastic Base

The plastic base of the measurement fixture provides an electrically insulated, rigid, flat surface for all mechanical components to be mounted to. The complete probing interface, consisting of the BFC probing “quarters” are affixed to the plastic base using #10 machine screws in 18 corresponding holes), as shown in Fig. 27. Four slots are milled into the plastic base in order to accommodate the adjusting blocks which occupy a portion of the dovetail slide, as shown in Fig. 27. There are also slots milled ½” deep into the upper face of the base, into which the Garolite plates and bobbin peg are epoxied. All bolts used to secure the measurements fixture are counterbored into the plastic base. Eight holes around the perimeter of the plastic base are provided to mount the fixture to the work table, eliminating the need to support the fixture with a second hand when pulling the handle.

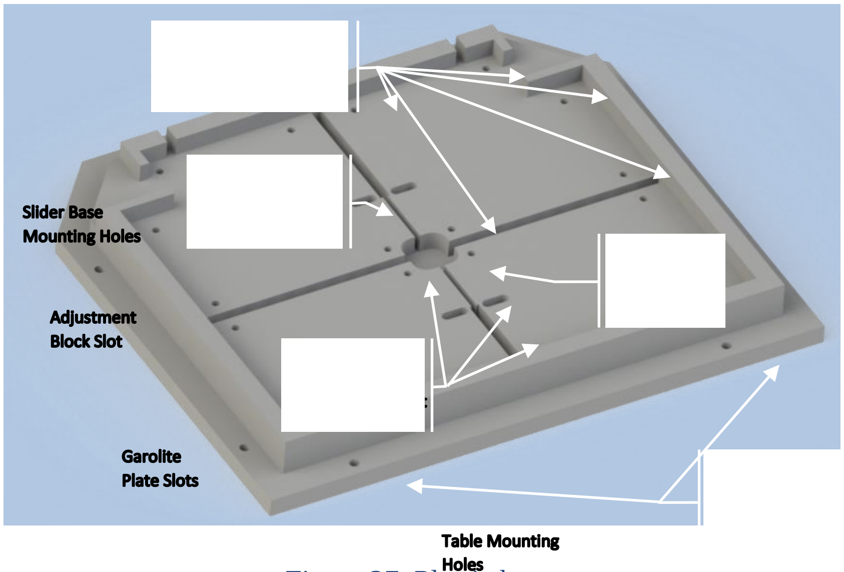

Figure 27: Plastic base.

The measurement fixture uses a hand lever to spread four sets of tool bits away from tool steel backing plates, allowing for a bobbin to be inserted into the center. During insertion, pairs of bobbin wires are guided in between the tool bits and backing plates by the fixture. When the hand lever is released, spring force causes the tool bits to pinch through the Kapton wire insulation, connecting the wires to the multimeter for measurement through the use of several other electronic hardware components.

3.2 Electronic Hardware

The hardware in this project makes up the entire interface between the fixture and the software that manipulates serial input data. Each part in the electronic hardware has been designed or picked specifically to meet the projects criteria. All electronic parts are connected to form the bridge between software and mechanical components. The following is a list of hardware necessary for the proper function of the design:

1. Relay Controller
2. Digital Multimeter
3. Serial Cable
4. Wire Connectors
5. Power Supply
6. Wire
7. Personal Computer
8. Serial Card

The following subsections discuss the function and specification of each piece of hardware.

3.2.1 Relay Controller

Figure 28: RS232 relay control with terminal block and RS232 interface [5].

Fig. 28 shows a networking device that consists of four mechanical relays, and an RS232 serial jack. This device uses a multiplexing method which measures each wire on the bobbin separately, but one at a time. In electronics, multiplexing is a way of selecting one of several analog or digital input signals, and forwarding the selected input to a single line. The multiplexing method allows the process to achieve its goal of measuring all four wires on the bobbin with only one channel for information to flow through; this means that the one-channel multimeter used in the current process by the client will continue to be used in the new process.

To gather data in a multiplexed system, a decision must be made as to which wire is first chosen for measurement, and what order to choose the other wires thereafter. These decisions are ultimately made by the software, but must be physically chosen by a mechanical relay. The mechanical relay is given the acronym DPDT, which stands for double pole, double throw. The idea behind this digitally actuated mechanism is to control the path of information flow commanded by software. The double pole means that there are two separate identical sets of contacts controlled by the same knob. The double throw means there are two positions the switch can assume. The new process will be utilizing digital commands from a PC and a contact ready sensor in order to close circuits; this creates continuity in the system, and allows for analog measurements from the multimeter to be read.

3.2.2 Digital Multimeter

Figure 29: Digital multimeter, Agilent model 34401a [5].

There is a need to measure four different circuit resistances without physically swapping connections to the multimeter. This can be accomplished by either having a four channel multimeter or using the aforementioned relay controller to switch channels sequentially, allowing all resistances to be read through a single channel. Since a single channel multimeter is used in the current process (Fig. 29), reusing it in the new process will reduce costs at no sacrifice to performance. The precision and accuracy of the measurements will remain the same as those recorded by the current system, making comparison of data sets (current vs. new) easy.

3.2.3 Serial Cable

Data is gathered on a PC by importing analog readings from the digital multimeter. The data is transferred via an RS232 serial cable. This cable transfers data one bit at a time at a maximum rate of 160 kbits/s [6]. This means that it takes several bits of information to be consecutively sent from the digital multimeter to the PC. The order of the bits are transferred in such a way that an Arabic numeral representation of a resistance reading will be stored in an excel spreadsheet, and at such a high speed that time for data transfer is negligible to the process.

3.2.4 Banana Plug to Alligator Clip Chord

Figure 30: Banana plug to alligator clip 18" chord [7].

The banana plug to alligator clip chord shown in Fig. 30 is used to connect the ohmmeter to the relay controller. Banana plugs simply insert into the front ports on the multimeter, while the alligator clip ends will be clamped onto wires that are inserted into the relay controller. This item is already in possession of the client, so no purchase is necessary.

3.2.5 Power Supply

A power supply is required for the relay controller. The power being supplied to the building is from a standard 120 Volt AC wall outlet, which is stepped down by the power supply to 12 volts DC at 1.25 amps for the relay controller.

3.2.6 Insulated Wire

Conductive wire provides the medium to which data can be transferred between electrical components. There are 3 different wire colors that come in the suggested purchase package. The reason for this is to use color-coding when arranging wires for specific tasks, thus helping provide a better understanding of the working equipment.

3.2.7 Personal Computer (PC)

A new PC allows for ease of software implementation, and decrease the likelihood of process failure. With a new PC, technicians would have a better understanding of software and hardware limitations during implementation and testing.

3.2.8 Serial Card

A dual serial port card shown in Fig. 31, is required so that the computer can interact with both the multimeter and the relay controller. This modular card is compatible with the specified computer and can be easily inserted into its motherboard.

Figure 31: 2S1P native PCI express parallel serial combo card with 16550 UART [8].

3.2.9 Contact Ready Sensor

The contact ready sensor is used to initiate the process of measuring BFC resistance values. The sensor has two states, on and off. In the off position, the two wires leading into the sensor are separated. In the on position, the two wires are connected to create continuity in the circuit created beyond the sensor's exterior wires.

The flow and logic of data in the electrical equipment of this process will be discussed thoroughly in the design integration section of this report. When all electrical components are completely integrated in the apparatus, the electrical equipment resistance must be tested as a system. The intermediary electrical equipment all have their own resistance to add to the multimeter's reading, and so this excess resistance must be known in order to have an accurate reading of the test specimen (the bobbin wires). This excess resistance can then be truncated (offsets instead) by the software.

3.3 Software

The automation of both the BFC resistance measurement and data entry portion of the design is carried out by a Windows based software program.

The details of our software design are broken down into four distinct sections and each section is further broken down into sub-requirements. The program must interface with each separate component in our design, the program must perform calibration of all components, the program must conduct the semi-automated BFC quality assurance, and the program must monitor and troubleshoot the process for quality assurance.

A requirements based breakdown of the software is provided in Appendix E.

3.3.1 Component interfacing

The design of the new process requires that a computer be used to collect and manage all of the quality assurance data, the computer program controls the entry of all resistance data into a Microsoft Excel spreadsheet. Upon start-up, the operator is prompted to select an existing spreadsheet or to create a new spreadsheet. In the event that a new spreadsheet is selected, the program will open a new Microsoft excel spreadsheet and format that spreadsheet with the appropriate row and column titles. The program will save the new spreadsheet according to the existing naming convention used in the current process, including data about the batch number of the BFC's being tested, the BIN number of the order of BFC's from the supplier, and the number of BFC's to be tested in this production run. After a spreadsheet has been opened or created, the program will fill the spreadsheet with the appropriate values obtained from the quality assurance process. Access to information obtained from BFC's is password restricted after collection.

The design requires that two serial protocol external devices, a multimeter and a Relay controller, be used to collect resistance data. The Program will interface with each of these devices via the computer's serial bus COMM ports upon program start-up. The program will maintain this connection for the duration of its runtime, and terminate the connection when it closes. If for some reason the connection is lost, the program will halt the measurement process and re-connect. The program will also prompt the operator to conduct manual tasks such as re-starting equipment in order to aid in achieving a connection with each device.

The relay controller also requires initialization. Once a serial connection established with the relay controller, the initial configuration will be read by the computer program and then the initial relay state will be set for measurement. If a fault is detected during the initialization process, an error will be flagged, and the relay may be replaced.

3.3.2 Calibration

The program will adjust the value of the resistance it receives from the multimeter over the serial connection by calibration values it creates during the calibration process. There are two sets of adjustable values which will be stored in permanent memory. The first set is manually entered during the calibration process and corresponds to the minimum and maximum acceptable resistance values for each circuit to be tested within the BFC. The second set corresponds to a correction value which each resistance reading is offset by due to the electrical resistance of the probe used to measure the BFC. The second set of calibration values are obtained automatically by the program when the calibration process is performed. Program prompts the operator to proceed through each step of the calibration process and will detect erroneous calibration readings.

While conducting the calibration function, the operator may choose to set a Steady Resistance Timeout period. This means that if the value of the resistance obtained from the multimeter does not stabilize to within a tenth of an Ohm within the timeout period, an error is flagged, and the BFC will be failed or require re-measurement. If this value is zero, no timeout period will be used.

3.3.3 Process Automation

The program is the sole component of our design which controls the automation of the resistance measurement process. The program must first determine whether or not the measurement fixture is ready for measurement, and then proceed through the process of BFC measurement by controlling the serial relay, multimeter, and Microsoft spreadsheet program. The program will continuously check to see if the measurement fixture is ready to read BFC resistances. When the measurement fixture is ready, the program will use its active COMM link with both the Ohmmeter and the relay controller to control the steps of the BFC measurement process detailed in the Component Integration and Operation section of this report. When the measurement process is complete, the program compares the readings obtained (adjusted by its calibration data) to the acceptable limits defined by the calibration process. If the BFC resistance values are within tolerance, the values are recorded by the program into the spreadsheet automatically, and the operator is prompted to label the bobbin with its serial number. If the BFC fails inspection, the program records its resistances into the failure table in the spreadsheet, and prompts the operator to place the BFC into the reject bin.

3.3.4 Troubleshooting

The program allows our design to become more intuitive in order to provide a more reliable quality assurance program. The computer program will be given a set of common or plausible errors to test for and for which a solution has been defined in order to mitigate operator or mechanical error.

The computer program will detect if the resistance value of any circuit of the BFC is fluctuating greatly for a longer period of time than the timeout period set in the calibration function. If it is found that resistance values fluctuate un-acceptably, the program will prompt the operator to open and shut the measurement fixture so as to attempt to obtain a better probing connection on each wire. If the timeout period is exceeded for a second time, the operator is prompted to manually measure the resistance of the bobbin. If the fixture fails to obtain steady resistance values for five separate bobbins in a row on the first measurement attempt, an error is flagged and the program will require the calibration function to be performed before the process of BFC quality assurance may continue.

The program will identify potential systematic measurement errors. If 5 out of 500 BFCs fail inspection during a batch, an error will be flagged, and the program will require the calibration function to be performed before the process of BFC quality assurance may continue. If 20 out of 500 BFCs fail inspection, each of the twenty failed BFC's must then be inspected manually. If it is found that the device is in err, the computer program will immediately flag the fixture, multimeter, and serial relay for inspection by an equipment technician, and all components are re-calibrated. All BFCs tested in that batch will be flagged for re-inspection by the program automatically.

The program will also generate quality assurance reports automatically at the end of each batch. The program will plot the standard deviation of the difference between the expected and actual values of BFC resistance for each batch and indicate the percentage of BFC's failed by the process for that production run. The program will periodically prompt the user that a randomly selected BFC is to undergo manual inspection. The Program will not allow the Spreadsheet to be flagged as completed until each randomly selected BFC has been tested manually and values have been recorded alongside those obtained from the measurement fixture. The Program will then complete a reliability report which includes a trend line of previous reports which may be used in scheduling maintenance for the device.

3.4 ORGANIZATIONAL TRAY

A simple organizing tray was designed to store bobbins after they have been tested and assigned a serial number. Bobbins which fail the test are to be placed in a separate bin. During the design of the tray, special attention was paid to reducing process labour, hastening the process of bobbin retrieval, and improving ergonomics. Many features are incorporated into the design, all serving to resolve issues with the current process. The tray, built from acrylic sheet stock, has a capacity of 100 bobbins, each held in their own identifiable compartment (shown in Fig. 32). The sliding lid retains and protects the bobbins when transferring tested bobbins to the subsequent rocket assembly work area.

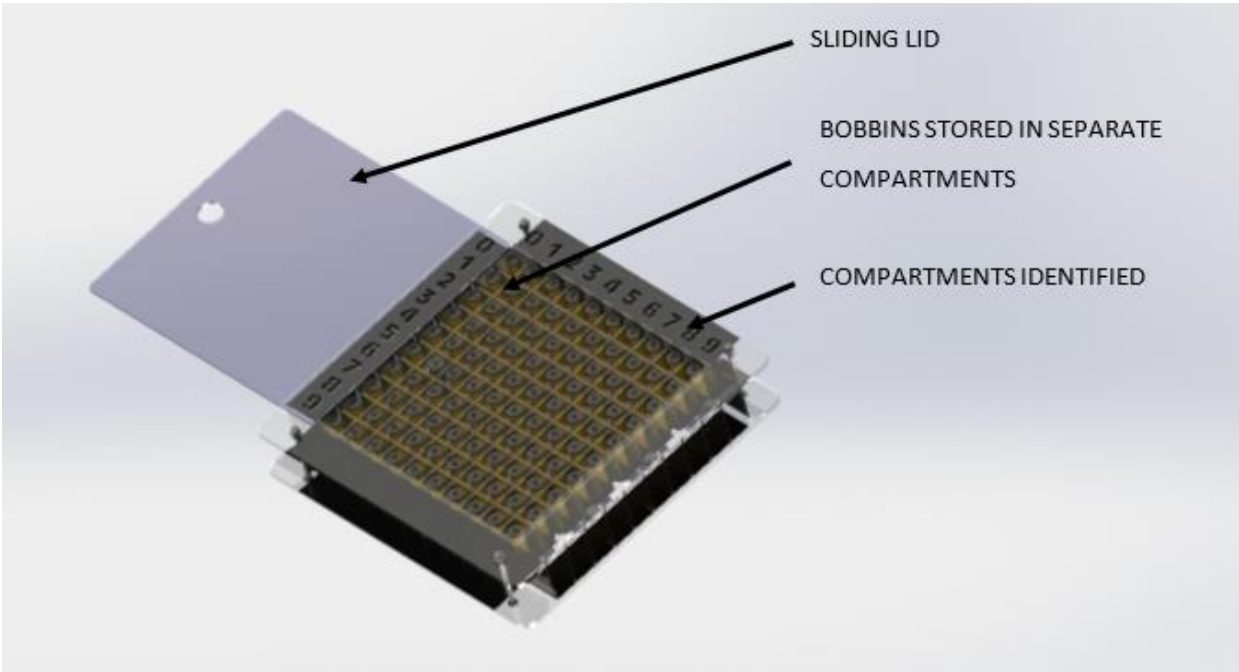

Figure 32: Labelled components of storage tray loaded with 100 bobbins.

Compartments are arranged in a 10 by 10 grid pattern, and are filled sequentially. Each of the three digits in the bobbin serial number are identifiers of bobbin location within the tray system. Before being inserted into the compartments, each bobbin is labelled with a serial number peeled off of a purchased roll of consecutively numbered stickers. The first digit corresponds to the tray number, the second refers to the column, and the third refers to the row in the tray. Incorporated into the border of the tray are easy to read laser-cut numbers which allow for row and column number identification (shown in Fig. 33). Black electrical tape sandwiched between the numbered plates provide contrast for the cut out numbers. Fig. 34 shows the location of a bobbin with serial number 181. The 100 bobbin capacity of the tray splits the batch of 500 bobbins into five trays, which prevents the operator from being overwhelmed by having to complete an entire batch at one time.

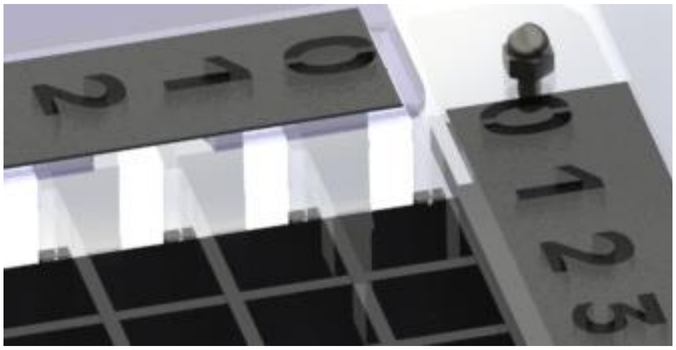

Figure 33: Laser cut numbers serve as row and column identifiers in each tray.

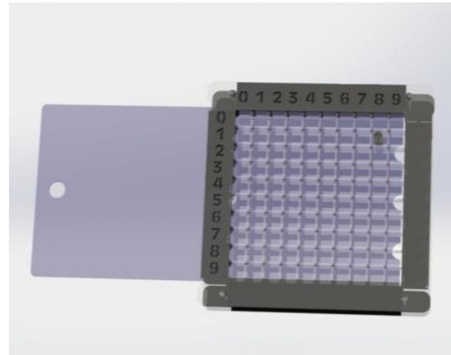

Figure 34: Bobbin with serial number 181 placed in corresponding compartment in tray 1.

After testing, each bobbin is stored in a standard orientation (bobbin grooves facing down), in an assigned compartment. This storage method is in accordance to one of the 5S pillars, Set In Order [9]. This reduces time spent orientating the bobbin by hand at the beginning of the squib pairing process. Placing the bobbin in each compartment requires a relatively low amount of hand dexterity and movement, due to only needing to fit a round end having a 0.545 inch diameter into a large square hole measuring 0.900 inches along each side. In addition, reliability of the process is increased by introducing a form of bobbin identification additional to the label placed on each bobbin. If the label happens to peel off accidentally, the location in the tray serves as a back-up identifier.

Bobbins are stored in their own compartments, resolving several issues with the current process (50 bobbin capacity storage bag). The compartmentalization allows the operator to identify bobbins by location within the tray, reducing operator hand and eye strain caused by searching for a specific bobbin in a pile of bobbins and rotating each one so that the small serial number can be read. After retrieving the bobbin from the tray, a quick look at the label for serial number verification is all that is needed. The tray will therefore reduce the time spent for bobbin retrieval during squib matching, which is a subsequent rocket assembly step to BFC testing where bobbins must be matched to other components based on their resistance values. An estimate of the time reduction is discussed in the Results section of this report. Storing each bobbin so that it does not contact another eliminates the possibility for bobbin wires to become tangled with one another, a common issue with the current process as all bobbins are clumped together in a bag. Without tangling issues, wire orientation within the bobbin grooves is maintained which leads to increased functional reliability of the BFC. Furthermore, the hard walled compartments protect the bobbins from damage caused by accidents such as dropping the tray on the ground or placing weight on top of the tray.

Select features of the design include its ease of use, ergonomics, ability to be laser cut, and zero maintenance.

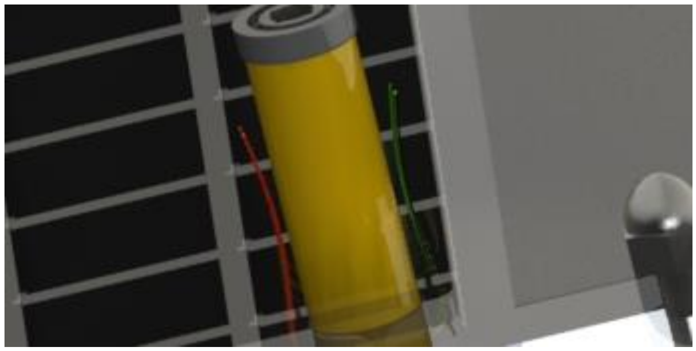

Figure 35: Bobbin inserted grooved side down to prevent wire ends from catching compartment walls.

One of the features of the tray its ease of use. Having a sliding lid on both sides allows the bobbin to be inserted and removed all in one continuous direction (wires bent backwards as shown in Fig. 35), eliminating the chance of the ends of the wires catching along the compartment walls. The bobbin is stored in the tray by opening the top sliding lid and inserting the bobbin with the wires bent back. When it comes time for retrieval of the bobbin, the top lid is closed, the tray is then flipped over, then the bottom lid is slid opened, gaining access to the bobbin. This procedure is illustrated in Fig. 36. Each compartment is a square measuring 0.900” along each side, making it physically impossible to insert two 0.545” diameter bobbins into one compartment, reducing the chance for human error.

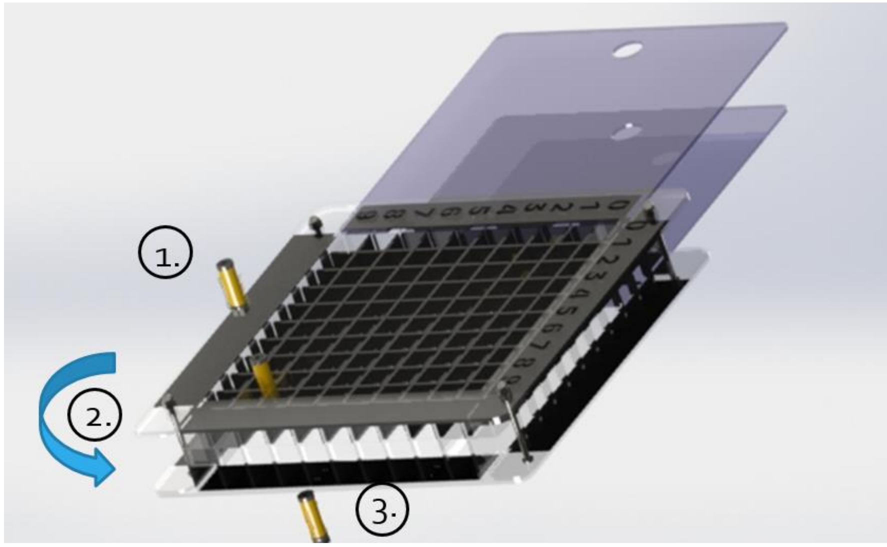

Figure 36: Two sliding lids allow for easy bobbin insertion and retrieval by eliminating chance of wire ends catching on compartment walls.

To increase the ergonomics, the tray is placed on an easel that elevates the tray off the work bench by 30 degrees towards the operator (shown in Fig. 37 and Fig. 38). This allows the operator to remain comfortably seated and not have to tilt their head down to look at the rows and columns of tray compartments. Having a clear, non-skewed view of the tray will help prevent human error in the process.

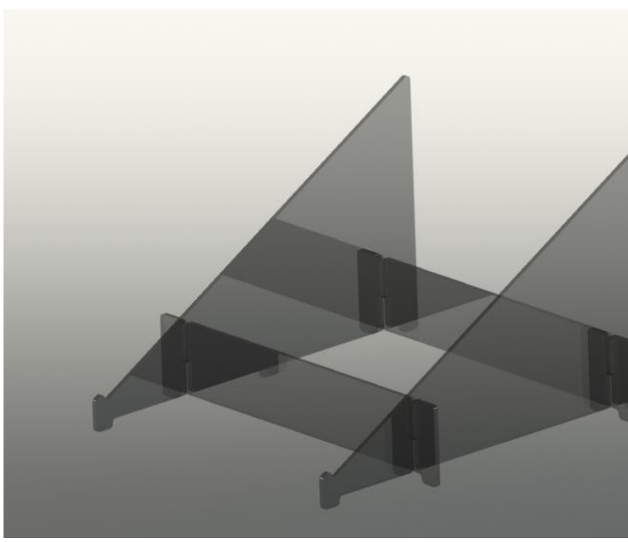

Figure 37: Easel support for ergonomic tray loading.

Figure 38: Tray angled towards operator by easel.

Another feature of the design is that all parts can be laser cut, then assembled using only four number ten machine screws and acorn nuts per tray. The compartments consist of vertical and horizontal slats, all of which interlock using slots cut into them (shown in Fig. 39). Fig. 40 is an exploded view of the tray assembly, showing all parts in the tray. The clear 1/8 inch thick acrylic sheet material used is lightweight and easily washable. Lifting individual trays or an entire batch worth of trays (five) does not violate ISO standard 11228 for safe lifting limits [10]. One more feature of the design is that no maintenance is required to be performed on the tray once in operation.

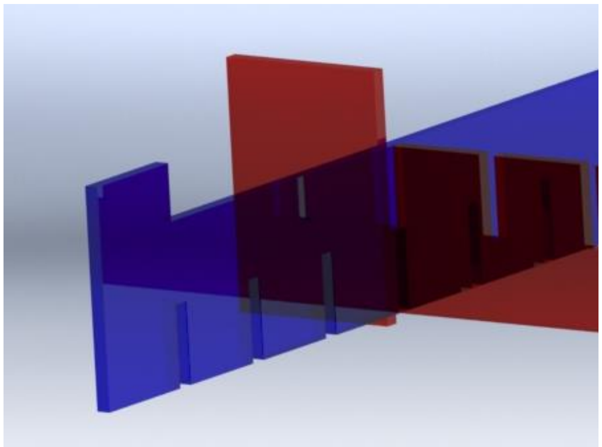

Figure 39: Laser cut slots allow for easy assembly of tray compartments.

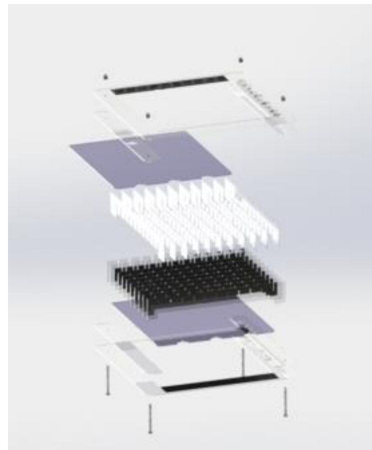

Figure 40: Exploded view showing all parts of tray.

The incorporation of the designed tray into the new process reduces the duration and labour intensity of storing and retrieving bobbins, helping to solve the problems associated with the current process. The compartmentalization of the tray will increase the time taken to store bobbins, however retrieval times of specific bobbins in the squib matching process will be much lower than the current process. In addition, the tray improves ergonomics by reducing hand and eye strain. Process reliability is also improved through the use of two bobbin identification methods. Finally, the tray was designed with focus on manufacturability, and requires only two tools to fabricate (laser cutter and screw driver).

4 Component Integration and Operation

Each separate component of the quality assurance process performs its own specific task, and all components must work in unison function as designed. A flow chart showing the interaction between components is shown in Fig. 41.

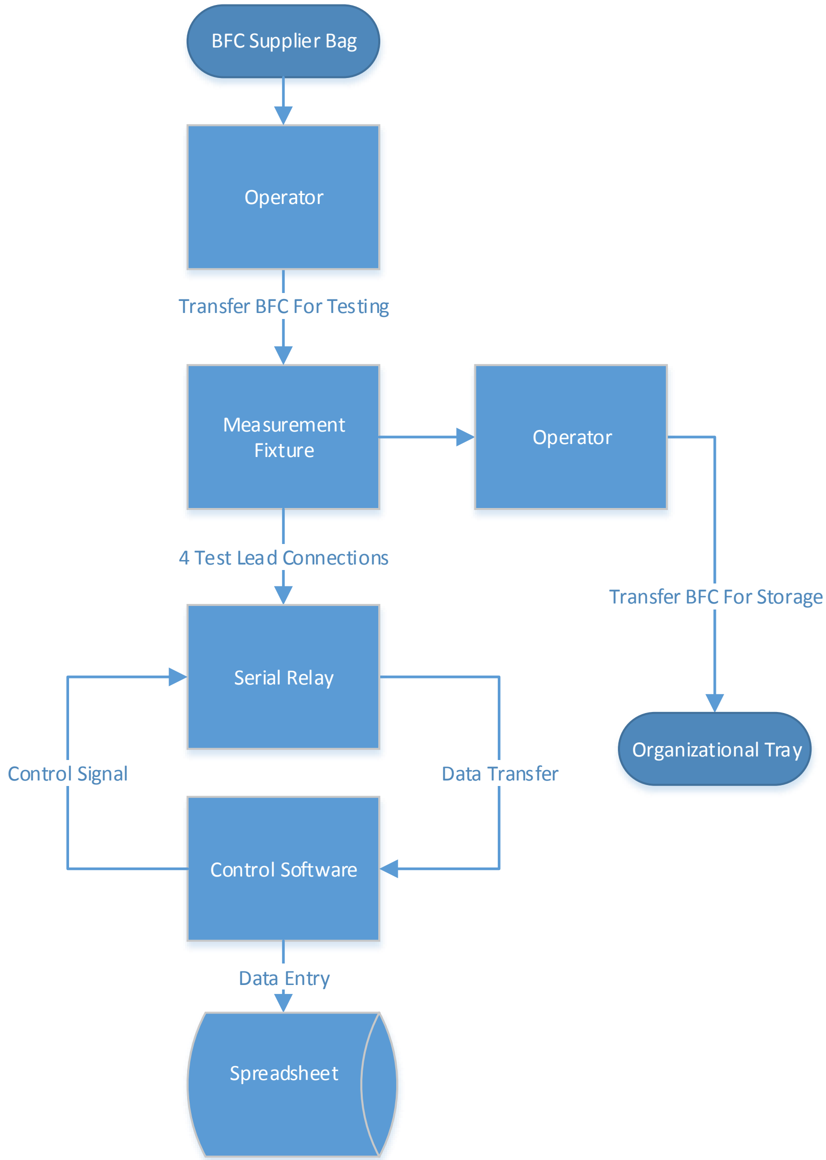

Figure 41 : Flowchart showing the function of all components in the final design and their interaction.

A schematic showing the electronic connections which allow all components to be linked together is shown in Fig. 42.

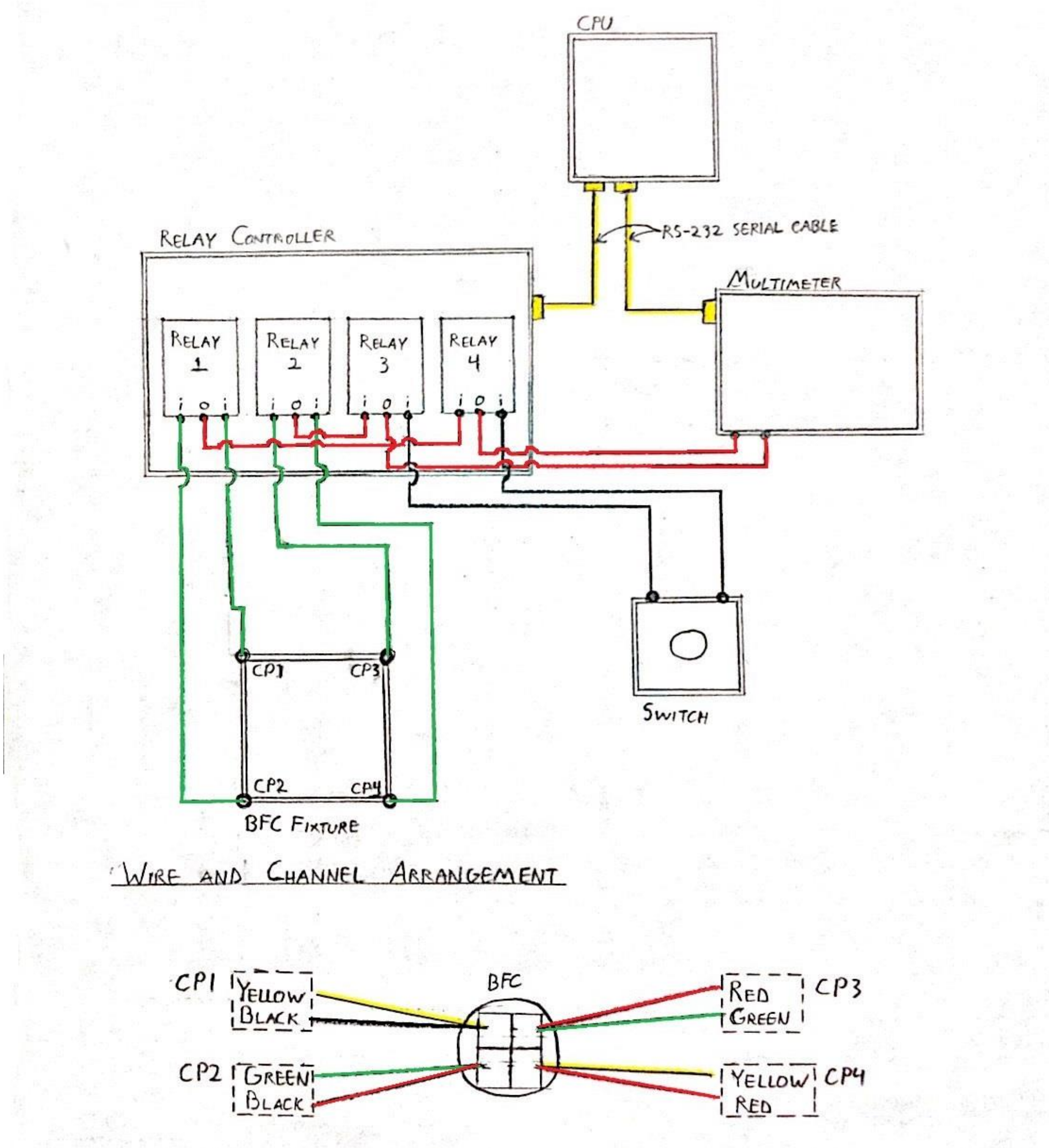

Figure 42: Electrical schematic for new process.

Before the logistics of the design of the BFC quality assurance process can be explained it is necessary to establish its physical configuration. A desktop computer acts as the central hub to which all facets of our design are connected. The custom automation software program and the Microsoft Excel program run simultaneously on the desktop computer, while the serial relay and ohmmeter are both connected to the computer via the serial bus. The automating program will control which circuit (either one of the bridge filters circuit or the “ready” sensor) is connected to the ohmmeter. The ohmmeter constantly polls whichever circuit it is connected to and reports that information to the computer continuously. The actual measurement fixture, having the bobbin inserted for measurement is connected by six wires (four from the BFC measuring probes, and two from the “ready’ sensor) to the serial relay. Two wires run from the serial relay to the ohmmeter, completing the circuit for measurement. All of this equipment is permanently located on the BFC measurement workbench.

The logistics of the quality assurance process follow a semi-automated regiment, starting with collecting the BFC product for measurement. BFCs are obtained from the manufacturer in bags of 500, the operator collects a bag from inventory and places it at the measurement station beside the fixture. The operator then aligns the rack of five organization trays to the right of the measurement station, ready to receive BFCs after they have passed inspection. A yellow bin, reserved for failed bobbins, is placed on the opposite side of the work station to hold rejected BFCs. The computer is then started up, and the automation program is opened. The automation program has a menu from which the operator may choose to either conduct a quality assurance inspection, generate an inspection report, or calibrate the fixture for measurement. The operator selects the quality assurance inspection option, and is then prompted to choose to continue a previous inspection batch or to begin a new one. The program will open a Microsoft Excel inspection spreadsheet, and adjust the entry cell of the appropriate row and column in order to begin entering resistance data. The automation program then prompts the operator to initialize both the serial relay and the ohmmeter. The program automatically connects to both devices, and reports that it is ready to receive measurement.

With the work station set up to inspect BFCs, the inspection process proceeds for the duration of the production batch. The operator takes a BFC from the supplier bag and, holding it by the top between their thumb and forefinger, inserts it into the measurement fixture with its wires falling on the correct side of the tool steel backing plates. The operator then closes the fixture by moving the fixtures lever from the upright to the horizontal position. Each of the eight wires are probed for measurement and the “ready” sensor is activated by the lever as it is closed. The computer program instructs the serial relay to connect the ready sensor to the ohmmeter, and waits for the ohmmeter to indicate nearly zero resistance, meaning that the fixture is ready for measurement. The program reports that measurement is being carried out, and instructs the serial relay to connect each of the four BFC circuits to the ohmmeter until a steady measurement is of each circuit is taken.

At this point, the process consists of three possible outcomes; The BFC may pass inspection, it may fail inspection, or the program may require a more reliable electrical connection in order to record the resistance accurately.

In the event that the BFC passes inspection, the program prompts the operator to open the fixture, remove and label the BFC with its serial number, and place it in the organizer for retrieval at a later stage in rocket assembly. The program automatically enters BFC resistance into the spreadsheet location with the appropriate sequential serial number, sets the serial relay to check for the “ready” sensor to be activated, and prompts the operator to insert the next bobbin for measurement.

In the event that the bobbin fails inspection, the program will report the reason for failure. The BFC will fail inspection when either a set of wires are in the wrong orientation on the bobbin or the resistance of a wire on the bobbin is outside the acceptable range. The program detects that wires are in the incorrect location when exactly two wires show infinite resistance.

When the program detects that a wire’s resistance is outside of the acceptable range, it will compare that wires resistance value to the alternate range of values. If it is detected that the failed wires resistance is compatible with the alternate range of resistances, the program will prompt the operator to check wire orientation and repeat the measurement process. When the program detects a steady resistance value outside of the acceptable range, the bobbin is failed and the operator is prompted to place the BFC into the failed bin for manual testing and quality assurance validation at a later date.

The program will also detect when an un-steady connection is made by the wire probes. When wire resistances do not achieve a steady value to one tenth of one ohm within the measurement timeout window, the program prompts the user to open and shut the fixture to attempt a more reliable connection. In the event that the BFC does not achieve a steady value after the second test, the BFC is failed.

5 COMPONENT IMPLEMENTATION

The design of the BFC quality assurance process is modular, allowing for only portions of the total new process to be implemented at a time in phases. This allows for the quality assurance process to be audited while the design is implemented to ensure that the integrity of the current process is maintained.

We divide the designs implementation into three distinct phases, each phase concentrates on isolating potential process failures in order to make the transition process adaptable and to increase the confidence in quality assurance upgrades incrementally. The first phase of implementation involves implementation of the computer system, organizational tray, and pre-printed labels. During the second phase, the automation program software is implemented, making use of manual wire probing. The third and final phase incorporates the remaining BFC measurement fixture and serial relay. Fig. 43 shows a summary of each phase.

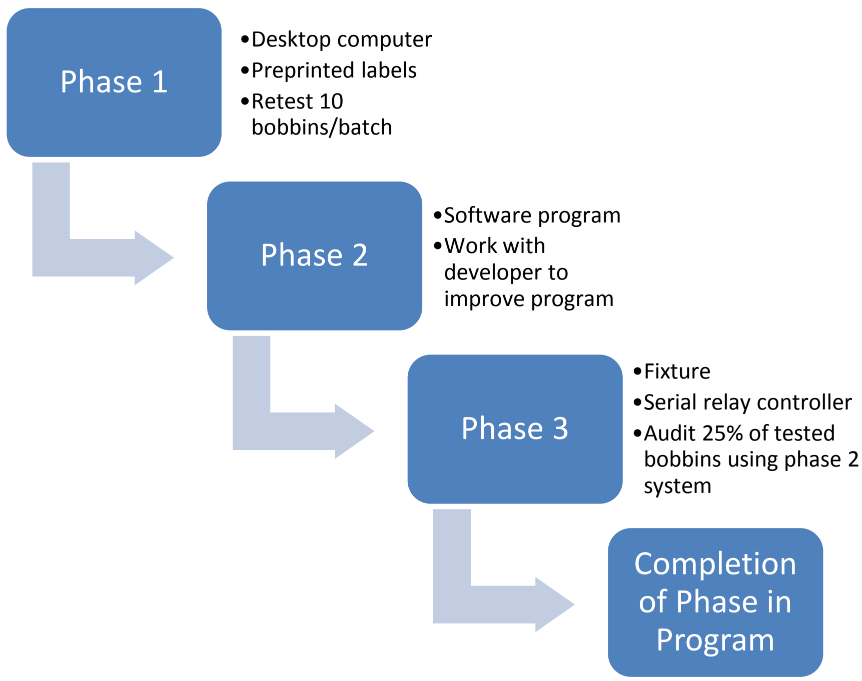

Figure 43: Summary of phases of implementation.

5.1 Phase 1

The first phase of the design's implementation allows all of the necessary basic upgrades in equipment to be made without having to test the performance of any of the prototype equipment. This phase concentrates on the processes within the BFC quality assurance program which are upgraded by our design rather than the BFC measurement device itself. Phase 1 begins by replacing the workstation with an adjustable work bench and ergonomic chair which serve both to reduce the fatigue of the operator and organize the workstation to receive phase 2 and 3 upgrades. The old process's outdated data-logging computer is replaced with the business machine as specified in the Electronic Hardware section of this report, and a wired Ethernet network connection is installed so that the new computer may be networked. Finally, the preprinted labels sourced as part of the fixture and the BFC organization tray are introduced into the process in order to speed up the retrieval of BFC's during later assembly processes. The first phase, which spans three production batches of 500 BFC's involves all of the simplest upgrades to the current process which do not alter the steps taken by the operator to be completed. Ten BFC's from each of the three production runs will be selected to be tested a second time so that they may be identified as having been labeled and stored in the location to which they were assigned by the spreadsheet. Access to the spreadsheets via the network connection may be tested periodically, and operator fatigue is evaluated by both time-trial and operator feedback.

5.2 PHASE 2

The second phase of the design's implementation involves the introduction of the software automation program. The software program will be contracted out to a software developer and will be tested for reliability incrementally before it may perform the quality assurance process. During phase 2 the operator is still responsible to manually probe wires, however data entry will be automated by the computer.

First, the operator starts the automation program and selects the manual circuit probing option. Once the program indicates that it is prepared to receive resistance data, the operator follows all instructions which appear on the screen without any manual data entry. During phase 2 the design's implementation, the software developer will meet regularly meet with Magellan to discuss which features they feel are lacking and which features need to be included, and to debug the program. Phase 2 will last until the operator and management are satisfied with the programs function under manual BFC probing. Phase 2 is especially important as it will be the configuration of the final design which is used to conduct quality assurance in the event of a mechanical failure of the complete design.

5.3 PHASE 3

Phase 3 is the final increment in our final design's implementation. In this phase, the measurement fixture, together with the serial relay controller are integrated into the quality assurance process's function, completely eliminating the need for manual wire stripping and probing. The automation program is switched into the fully automatic mode, and the operator simply inserts the BFC for measurement and closes the lever on the fixture. The computer program reads and records resistance values and prompts the operator to remove and label the measured BFC in the event that it passes inspection. This process is repeated until a batch is completed.

Phase 3 makes allowance for the first working prototype of the measurement fixture to be adapted and improved in order to complete the wire probing function. During this phase the last of the testing is conducted on the computer program to ensure it meets the requirements based design provided in Appendix E. Phase 3 is expected to take place over six production batches, during which 25% of BFC's which pass inspection are audited using the Phase 2 configuration, along with all BFCs which fail inspection. The completion of phase 2 marks the full implementation of the design and the beginning of the quality assurance audit regiment set forth in the Component Integration section of this report.

6 Results

To evaluate how well the new process reduces the time spent to test each bobbin, simple time studies were performed by team members using actual bobbins and simulated equipment. During these time trials, the team members were instructed to work at a very comfortable pace which they felt could be sustained for an entire eight hour shift. To ensure that the pace at which the time trials were performed at was reasonable, videos of the operator performing the current process were reviewed. The team found that the pace acted out in the mock time trials was typical of an operator performing repetitive process steps, adding credibility to the results of the time trials for the new process. Fig. 44 shows a comparison of task times between the new and current processes, compiled from data collected by the team.

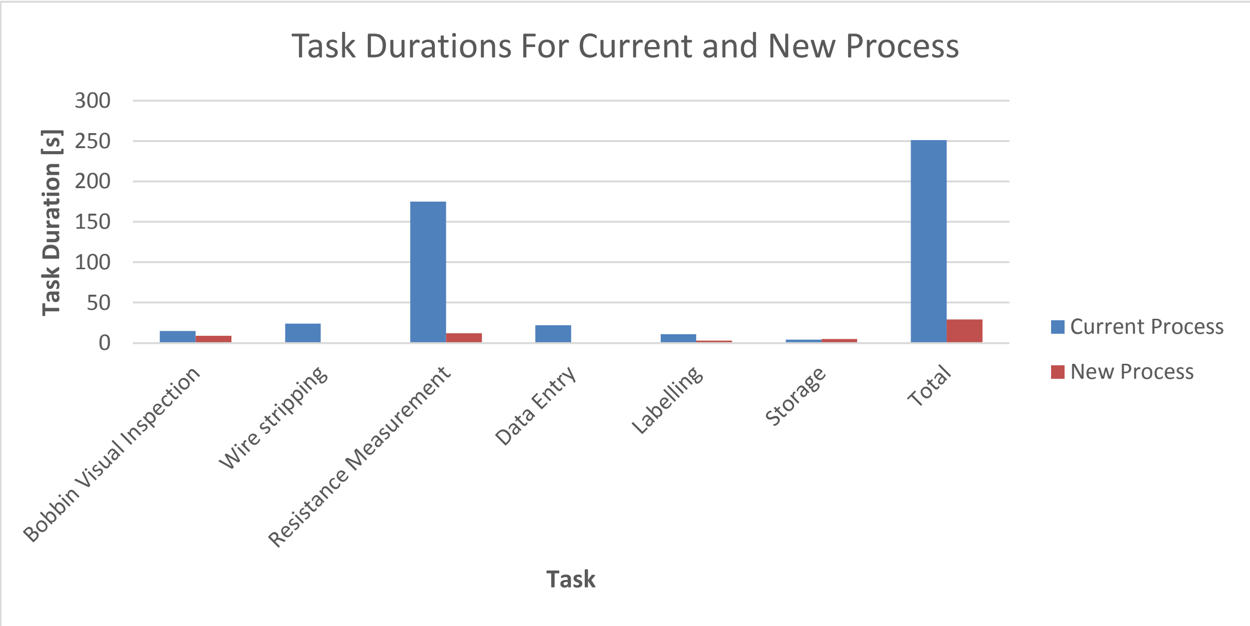

Figure 44: Bar chart comparing task durations of current process to estimated task durations in new process.

The figure clearly shows the reduction in BFC testing time from 251 to 29 seconds per bobbin tested possible with implementation of the new process. As indicated in the figure, the time for storage of the tested BFCs is increased from four to five seconds in the new process when compared to the current process. This storage task duration increase is easily justified by the fact that the organizational tray will reduce the time taken for squib matching in subsequent rocket motor assembly steps by approximately 30 seconds. Therefore, the total rocket motor assembly time is reduced by 29 seconds with the use of the organizational tray. Table I shows a comparison between the task times for the new and current processes, as well as the percent difference showing an increase (+) or decrease (-) in the task times of the new process.

TABLE I: SUMMARY OF INDIVIDUAL TASK TIME COMPARISON BETWEEN CURRENT AND NEW PROCESS FOR A SINGLE BOBBIN

	Process		
Task	**Current Time [s]**	**New Time [s]**	**Percent Difference [%]**
Bobbin Visual Inspection	15	9	-40
Wire stripping	24	0	-100
Resistance Measurement	175	12	-93
Data Entry	22	0	-100
Labelling	11	3	-73
Storage	4	5	25
Total	251	29	-88

Once the bobbin is placed the fixture, the computer program will take nine seconds to ensure that a stable reading is taken. The nine seconds will provide the operator with some idle time, allowing him/her to stretch or just take a quick break, reducing fatigue. Overall, the new process requires 92% less time performing active manual labour when compared to the current process, which indicates that the new process is more user friendly. Table II summarizes the duration of manual operator labour for each task in both the current and new processes.

TABLE II: SUMMARY OF TASK DURATIONS REQUIRING ACTIVE MANUAL LABOUR FOR CURRENT AND NEW PROCESSES

Task	Process		Percent Difference [%]
	Current Time [s]	New Time [s]	
Bobbin Visual Inspection	15	9	-40
Wire stripping	18	0	-100
Resistance Measurement	175	3	-98
Data Entry	22	0	-100
Labelling	11	3	-73
Storage	4	5	25
Total	245	20	-92

7 Cost Analysis

This report section contains a thorough analysis of the costs associated with implementing the new process. Upfront costs for equipment, materials, and manufacturing, maintenance costs for replacement parts, as well as operator labour costs on a batch basis are given. These costs are compared to the costs associated with continuing to use the current system. The point at which the client will begin to benefit from the new process in terms of cost is calculated and discussed. Furthermore, this section of the report includes total costs of each phase which can be implemented according to the aforementioned plan, or progressively at the discretion of the client.

7.1 Upfront Costs

All components of the new process were investigated for item and manufacturing cost. Quotes from various suppliers were used to determine the total cost for each component. As per the client's recommendation, the company McMaster-Carr was used to source parts and materials where applicable. Parts and materials not available from McMaster-Carr were sourced from other companies such as Fastenal, Online Metals, National Control Devices and Enco were chosen due to their reputable customer service and vast product lines. A time estimation guide for machining operations and team member firsthand machining experience were used in conjunction with one another to price out the manufacturing of different fixture parts. It is important to note that the following cost values may not represent the lowest available costs, and the costs may be reduced by searching for competitive prices. Measures taken to reduce costs during the design process are included in Appendix H.

7.1.1 Bill of Materials

Tables III through VI present the required parts and materials costs of every component used in the new process. The totals in each table represent the initial investment for each component in the new process. A detailed bill of materials with a description as well as supplier and part numbers for each item is provided in Appendix F.

TABLE III: MEASUREMENT FIXTURE BILL OF MATERIALS [11], [12], [13], [14]

Item	Purpose	Quantity	Unit Cost	Expense
Compression Spring	Applies pinch force to wires	4	$1.38	$5.52
Track Roller	Cam Follower	4	$11.12	$44.48
Nylon Insert Nut	Lever Pivot	2	$0.13	$0.26
Socket Head Cap Screw	Lever Pivot	2	$0.34	$0.68
Socket Head Cap Screw	Retain Spring	4	$1.04	$4.16
Tool Bit	Pinch Wires	4	$1.54	$6.16
Machine Screw	Fasteners	36	$0.06	$2.16
Machine Screw	Fasten Journal Caps	8	$0.23	$1.84
Garolite	Insulation	1	$29.33	$29.33
Tool Steel Sheet	Tool bit backer	1	$17.97	$17.97
Adjustment Block	Halting slider motion	8	$0.15	$1.16
Bobbin Peg	Constraining bobbin	1	$3.22	$3.22
Cam Plate	Actuating slider motion	1	$18.75	$18.75
Fixture Base	Constraining fixture components	1	$72.14	$72.14
Fixture Quarter Front Right	Housing slider	1	$37.70	$37.70

Fixture Quarter Front Left	Housing slider	1	$37.70	$37.70
Fixture Quarter Rear Right	Housing slider	1	$37.70	$37.70
Fixture Quarter Rear Left	Housing slider	1	$37.70	$37.70
Fixture Top Block	Constrain cam plate, spread wires	2	$0.80	$1.60
Fixture Top Block Mirror	Constrain cam plate, spread wires	2	$0.80	$1.60
Slider Front Right	Provides motion for tool steel bits	1	$26.81	$26.81
Slider Front Left	Provides motion for tool steel bits	1	$26.81	$26.81
Slider Rear Right	Provides motion for tool steel bits	1	$26.81	$26.81
Slider Rear Left	Provides motion for tool steel bits	1	$26.81	$26.81
Spring Washer	Constraining outer end of springs	4	$0.84	$3.35
Tool Bit Fixed Clamp	Clamping tool steel bits	4	$0.66	$2.64
Tool Bit Pivot Clamp	Clamping tool steel bits	4	$0.66	$2.64
Handle	Hand lever	1	$3.75	$3.75
			Total:	$481.45

TABLE IV: ELECTRONIC HARDWARE BILL OF MATERIALS

Item	Purpose	Quantity	Unit Cost	Expense
DPDT Relay	Switching between different bobbin wires	1	$109.00	$109.00
Serial Cable	Interface between computer and ohmmeter	2	$6.00	$12.00
Power Supply	Supplying power	1	$24.00	$24.00
Insulated Wire	Connecting electronics	1	$14.99	$14.99
PC	Performance Upgrade and software compatibility	1	$414.99	$414.99
Push Button Switch	Activating wire measurement sequence	1	$3.08	$3.08
Dual Serial Port Card	Allow PC to interact with two devices via serial connection.	1	$54.99	$54.99
			Total:	$633.05

TABLE V: ORGANIZATIONAL TRAYS BILL OF MATERIALS [13], [12]

Item	Purpose	Quantity	Unit Cost	Expense
Machine Screw	Holds Tray Together	20	$0.14	$2.80
Acorn Nut	Holds Tray Together	20	$0.19	$3.80
Acrylic	Tray Material	1	$76.73	$76.73
Acrylic	Tray Material	1	$137.02	$137.02
Electrical Tape	Number Contrast	1	$1.06	$1.06
			Total:	$221.41

TABLE VI: TOTAL PART AND MATERIAL COSTS FOR ALL NEW PROCESS COMPONENTS

Component	Expense
Measurement Fixture	$481.45
Electrical Components	$633.05
Software	$0.00
Organizational Trays (5)	$221.41
Total:	$1,335.91

7.1.2 Manufacturing and Development Costs

Costs of machining, laser cutting, and assembling the components used in the new process were estimated using several techniques. Machining costs for measurement fixture parts were determined by breaking down each machining operation on each part. Times for each operation were calculated by material removal rates found in "Simplified Time Estimation Booklet for Basic Machining Operations" [15], [16]. Laser cutting costs for the tray and select measurement fixture parts were determined by linear inches of cut in the specified material, and typical laser cutting feed rates [17], [18]. Assembly costs were calculated on an hourly basis. Assembly times were estimated by practice time trials performed by team members for each step. The client's production rate of $160/hr was used when calculating the assembly costs [19].

In order to create a cost breakdown for the development of the automation program, the team developed a list of very specific software requirements which the program must meet. These requirements were organized into a logical hierarchy to form a requirement based design of the software. The requirements design of the software program, together with interactions with professional software developers formed the basis of the estimated production time for such a product. The development costs of the software component of the design are calculated based upon estimates of the number of hours required to complete the program and the number of hours allotted for beta testing.

Since all documentation on the signals which are broadcast by both the serial relay and serial ohmmeter are available to the programmer upon purchase of these components, the program is easily outsourced using a website that connects clients and freelance software developers such as oDesk. The program is estimated to require no more than 16 hours of development in order to be ready for beta testing, and beta testing is expected to require no more than eight more hours of troubleshooting and further development in order to produce a fully functional program which meets all of the application's requirements. These estimates were given by a professional in the software development field at the University of Manitoba [20].

The average hourly rate of a North American professional programmer is $24.50 per hour so the production of the software program would be posted as a $588 contract which is to be completed in no less than one month from the date of acceptance.

The manufacturing costs for the new process components as well as the software development costs are presented in Table VII.

TABLE VII: TOTAL MANUFACTURING AND DEVELOPMENT COSTS FOR MAJOR COMPONENTS [15], [16], [17], [18], [20]

Component	Description	Expense
Measurement Fixture	Machining	$3,766.50
Electrical Components	N/A	$0.00
Software	Development	$588.00
Organizational Tray	Laser Cutting, Assembly	$202.50
	Total:	$4,557.00

7.1.3 Upfront Cost Summary

The measurement fixture requires the largest initial investment ($4,247.95) out of all components, and the cost is justified by the fact that it will hasten the BFC testing process by 163 seconds. The total upfront costs of each component used in the new process are summarized in Table VIII. Table IX provides a breakdown of upfront costs for each of the three implementation phases.

TABLE VIII: TOTAL UPFRONT COST FOR EACH MAJOR COMPONENT

	PARTS	**MANUFACTURING**	**TOTAL**
Component	Expense	Expense	Expense
Measurement Fixture	$481.45	$3,766.50	$4,247.95
Electrical Components	$633.05	$0.00	$633.05
Software	$0.00	$588.00	$588.00
Organizational Tray	$221.41	$202.50	$423.91
Total:	$1,335.91	$4,557.00	$5,892.91

TABLE IX: UPFRONT COST BREAKDOWN FOR EACH PHASE

<table>
<tr><th></th><th>Batches Tested Per Phase</th><th>Item</th><th>Expense</th><th>Total Cost</th></tr>
<tr><td rowspan="2">PHASE 1</td><td rowspan="2">3</td><td>PC</td><td>$414.99</td><td rowspan="2">$838.90</td></tr>
<tr><td>Organizational Tray</td><td>$423.91</td></tr>
<tr><td>PHASE 2</td><td>2</td><td>Software</td><td>$588.00</td><td>$588.00</td></tr>
<tr><td rowspan="2">PHASE 3</td><td rowspan="2">6</td><td>Measurement Fixture</td><td>$4,247.95</td><td rowspan="2">$4,881.00</td></tr>
<tr><td>Remaining Electrical Components</td><td>$633.05</td></tr>
</table>

7.2 Operation Costs

Required operational costs for supplies and maintenance of the new process are kept to a minimum by the features of each component, as previously described in the Detailed Design section of this report. The only required consumables for the new process are the pre-numbered adhesive backed labels used for bobbin identification and the tool bits used in the fixture. The labels are consumed at a rate of one roll per batch. The tool bits must be replaced once the sharp corners begin to wear and lose their ability to form a consistent electrical connection with the bobbin wires. The four tool bits must be replaced at an interval of every 60 batches. Appendix I contains justification of this replacement interval. Table X summarizes the operation costs of the new process on a per batch basis.

TABLE X: OPERATING COSTS OF NEW PROCESS ON A PER BATCH BASIS

Item	Purpose	Quantity/Batch	Unit Cost	Expense
Tool Bit	Pinch Wires	0.0167	$1.54	$0.03
Labels	Bobbin ID	1	$14.97	$14.97
			Total:	$15.00

7.3 Labour Costs

Labour costs associated with performing the BFC testing process are dictated by the time taken to perform the process. Simple time studies were performed using actual bobbins and simulated equipment representative of the new process. The time trials were performed by a team member working at the same comfortable pace as was observed of the current process during a site visit. During the same site visit, a time study was completed on the operator performing the current process. Table XI shows a comparison between the task times for the new and current processes.

TABLE XI: COMPARISON OF TASK TIMES FOR NEW AND CURRENT PROCESSES, ON A PER BOBBIN BASIS

	Process	
Task	**Current Time [s]**	**New Time [s]**
Bobbin Visual Inspection	15	9
Wire stripping	24	0
Resistance Measurement	175	12
Data Entry	22	0
Labelling	11	3
Storage	4	5
Total	251	29

The task times were then scaled to a per batch basis, and the labour costs were calculated. The client's production rate of $160/hr was used when calculating the labour costs [19]. Table XII summarizes the labour costs for each batch of bobbins tested, for both the current and new processes.

TABLE XII: TIME AND LABOUR COSTS FOR NEW AND CURRENT PROCESSES

Task	Process			
	Current Time [hr]	**New Time [hr]**	**Current Cost [$]**	**New Cost [$]**
Bobbin Visual Inspection	2.1	1.3	333.33	200.00
Wire stripping	3.3	0.0	533.33	0.00
Resistance Measurement	24.3	1.7	3888.89	266.67
Data Entry	3.1	0.0	488.89	0.00
Labelling	1.5	0.4	244.44	66.67
Storage	0.6	0.7	88.89	111.11
Total	34.9	4.0	5577.78	644.44

7.4 Payback Period

To evaluate the economic feasibility of the new process, the point at which the client will spend less money on the BFC testing process by using the new process in place of the current process has been calculated. This will be referred to as the payback period of the new process in subsequent sections of this report. To determine the payback period, the team had to analyze costs associated with the current and new processes.

Some of the costs associated with the current process must not be included in the analysis. The equipment and manufacturing costs are both sunk costs, so they are omitted. Operating and labour costs are therefore the only costs relevant to this analysis for the current process. The only operating costs are replacement wire stripper blades and masking tape. The wire stripper blades must be replaced after testing ten batches of BFCs, at a cost of $180 [21]. The cost of the masking tape used for labels is assumed to be negligible. As discussed in the Upfront Costs section of this report, the current process has a labour cost of $5,577.78 per batch. Adding up the operating and labour costs gives a cost of $5,595.78 per batch of BFCs tested using the current process.

Unlike for the current process, the equipment and manufacturing costs (upfront costs) of the new process must be incorporated into the payback period analysis. As discussed in the Upfront Cost Summary section of this report, the total upfront cost for the new process is $5,892.91. As discussed in the Operation Costs section of this report, labour costs are $644.44 per batch for the new process.

With the costs for the new and current processes fully defined, a graph showing money spent vs. number of batches tested for each process was created. Fig. 45 shows the payback period graph.

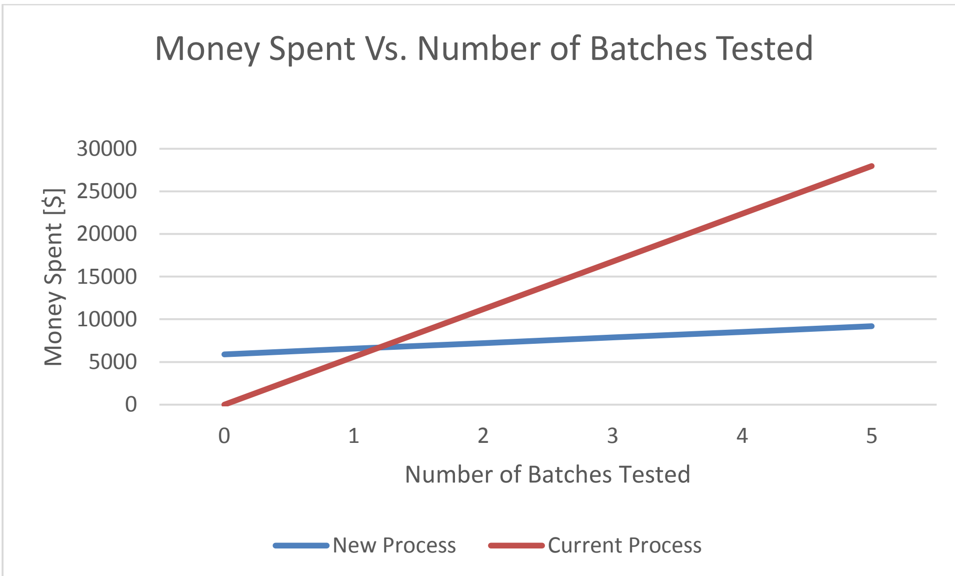

Figure 45: Payback period chart comparing new process to the current process.

The payback period of the new process is between the first and second batches, as indicated by the intersection of the lines shown in Fig. 45. Based on the client's forecast of production levels requiring 20 batches per year, the new process will result in a cost saving of $92,833 every year when compared to the current process (shown in Fig. 46).

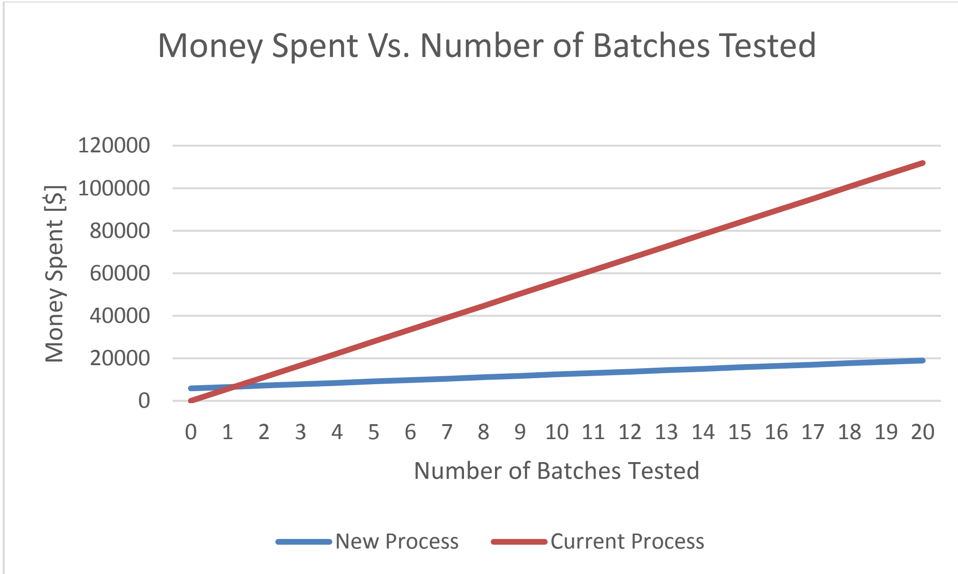

Figure 46: Chart showing annual cost savings provided by the new process.

A payback period analysis for the phased in implementation of the new process was omitted since the determining the labour costs in each phase would involve making many assumptions, invalidating the analysis results.

8 Conclusion

The team performed a thorough engineering design process for an improved method of measuring, recording, and accepting resistance values of BFCs. The design of the new process meets the client's needs of a process that is 88% faster and 92% less labour intensive than the current process.

Results of the engineering design process performed over the course of this project show that a semi-automated BFC test system utilizing a measurement fixture, software, electronic hardware, and an organizational tray will meet the client's needs. The measurement fixture eliminates the need for wire stripping and manual attachment of resistance test leads. This is accomplished by the tool bit pinching mechanism that electrically connects all bobbin wires to the ohm meter by having the operator pull on a single lever. Once the bobbin wires are all connected, there is no need to read resistance values off of the display and retype them into the spreadsheet, as these actions are performed automatically by the software program. Bobbins which fall outside the tolerable resistance range are flagged by the software program, and are separated from the other bobbins. Bobbins which have acceptable resistance values are then assigned a sequential serial number through the use of adhesive backed pre-numbered labels, eliminating the need to write numbers on masking tape. The serial numbers are in series of 500, with each series covering an entire batch of bobbins. After testing, the bobbin is stored in a specific compartment of a 100 bobbin capacity tray corresponding to the serial number, instead of being placed in a bag along with other tested bobbins. The tray allows for quick retrieval of bobbins with specific resistance values during the squib matching process. Through elimination of several steps in the current process procedure and improving organization, the new process meets the basic needs of the client.

Simple time studies were performed by the group using actual bobbins and simulated equipment to compare task durations of the new process to those of the current process obtained from observing the operator during a site visit. Results of these time studies showed a reduction in BFC testing time from 251 to 29 seconds per bobbin tested possible with implementation of the new process. In addition to significantly reducing BFC testing time, the new process will reduce the time taken for squib matching in subsequent rocket motor assembly steps by approximately 30 seconds. Therefore, the new process exceeds the client's need of a faster BFC testing process.

The new process incorporates many features that resolve reliability issues with the current process. Many of these features either reduce the chance for mistakes to be made by the operator or introduce redundancy into the system. Table XIII summarizes all reliability issues with the current process and the corresponding solutions provided by the features of the new process.

TABLE XIII: KEY RELIABILITY ISSUES WITH THE CURRENT PROCESS AND THE CORRESPONDING SOLUTION PROVIDED BY THE NEW PROCESS

Issue With Current Process	**Solution Provided by New Process**
Operator data entry typo	Data entry requires no operator input
Improper electrical connection of test leads	Connections formed by repeatable mechanical device
Label hard to read	Labels are preprinted and high contrast
Label is peels off after application	Tray location serves as secondary label/identification
Bobbin susceptible to damage when in storage	Storage tray is hard sided and enclosed

The project objectives of producing an economical, easy to use, and easy to implement solution to the current BFC testing process were met by carefully considering them throughout the entire design process. The new process is economical with respect to the fact that the payback period occurs before two batches have been tested and after this period the client will save $92,833 dollars each year by implementing the new process. The total upfront costs of the new process is

$5,892.91 and the operating cost, including labour, is $659.44 per batch of bobbins tested. All aspects of the new process were built with the operator in mind, ensuring that they are easy and ergonomic to use. The new process requires 92% less time performing active manual labour when compared to the current process, which indicates that the new process is more user friendly. Lastly, all major components used in the new process can be implemented progressively in phases, decreasing the risks associated with solely relying on a brand new design.

Having completed a thorough engineering design procedure, the team has noted several recommendations that will further improve the final design. The first is to purchase an adjustable office chair and work bench in which the height can be altered. These two items will increase operator ergonomics, especially if there will be more than one operator working at the BFC testing station (at separate times). The second recommendation is to add an Ethernet network connection to building 117 (Rockwood building where BFC testing process is performed). The connection will increase accessibility to the test data for the Engineers working out of an office located in a separate building. Additionally, local suppliers should be looked at when purchasing items listed in the bill of materials, which will reduce shipping costs and lead times for the parts and materials. Lastly, the team recommends that the same principles of the new process such as organization be applied to the subsequent squib matching assembly process.

To assist Magellan Aerospace, Winnipeg with moving forward with the fabrication and implementation of the new process, technical drawings of all parts are provided in Appendix C. By incorporating concept exploration, physical testing, material selection, manufacturing principles and economic analysis into the engineering design process, the team is confident that the proposed design will meet the client requirements of a faster and less labour intensive BFC testing process.

9 REFERENCES

[1] Magellan Aerospace, Winnipeg. (2009, Mar.). "*CRV7 Rocket Weapon System*" [PDF]. Available: http://forum.valka.cz/attachments/5029/CRV7_rotary_wing.pdf [Sept. 21, 2013].

[2] C. Hnatiuk. "BFC circuit diagram." Winnipeg: Design ENG.. Univ Manitoba, Winnipeg, MB, 2013, Sept. 24.

[3] Magellan Aerospace, Winnipeg, "CRV7 Bobbin Preparation MB, OS027442," unpublished.

[4] J. Hewson. (2013, Sept. 24). "Eng Design Project BFC Resistance Measurement: Info Request." Personal e-mail.

[5] National Control Devices. (2013). [Online]. Available: http://www.controlanything.com/Relay/Device/R41DPDTCNRS [Dec 1, 2013].

[6] The Source. (2013). [Online]. Available: http://www.thesource.ca/estore/product.aspx?language=en-CA&catalog=Online&category=Hook+Up+Wire&product=2781305 [Dec 1, 2013].

[7] Memory Express. (2013). [Online]. Available: http://www.memoryexpress.com/Products/MX47699 [Dec 1, 2013].

[8] StarTech. (2013) [Online]. Available: http://ca.startech.com/Cards-Adapters/Serial-Cards-Adapters/2S1P-Port-PCI-Express-Parallel-Serial-Combo-Card-16550-UART~PEX2S5531P [Dec 1, 2013].

[9] United States Environmental Protection Agency. (2011, Nov. 10) *Lean Thinking and Methods* [Online]. Available: http://www.epa.gov/lean/environment/methods/fives.htm [Nov. 2, 2013].

[10] WorkSafe NB. (2010). *Ergonomics Guidelines for Manual Handling* [PDF]. Available: http://www.worksafenb.ca/docs/manualedist.pdf [Nov. 6, 2013].

[11] *Item Details.* (2013). [Online]. Available: http://www.use-enco.com/CGI/INSRIT?PMAKA=383-5316&PMPXNO=939967&PARTPG=INLMK32 [Nov. 10, 2013].

[12] *Fastening & Joining.* (2013). [Online]. Available: http://www.mcmaster.com [Nov. 8, 2013].

[13] *Fasteners.* (2013). [Online]. Available: http://www.fastenal.com/web/products/fasteners/_/Navigation?r=~|categoryl1:%22600000%20Fasteners%22|~ [Nov. 10, 2013].

[14] *Metals Shopping for Orders of Every Size and Shape* (2013). [Online]. Available: http://www.onlinemetals.com/index.cfm [Nov. 28, 2013].

[15] K.C. Polgar, "Simplified Time Estimation Booklet for Basic Machining Operations" [PDF], M.S. Thesis, Mech Eng., MIT, Cambridge, MA, 1996. Available: http://web.mit.edu/2.810/www/readings/Polgar_Time_Est.pdf [Nov. 28, 2013].

[16] *Machine Shop*. (2013). [n.d.]. Available: http://www.science.uottawa.ca/services/machine-shop.html [Nov. 10, 2013].

[17] V. Sumaling. (2013, Nov. 22). "Laser Cutting." Personal e-mail.

[18] Tim Christopherson. (2002). *Laser Processing of Plastic Sheet* [PDF]. Available: http://www.precoinc.com/PDF/PlasticsPaper.pdf [Nov. 19, 2013].

[19] J. Hewson. (2013, Sept. 24). "Eng Design Project BFC Resistance Measurement: Info Request." Personal e-mail.

[20] Michael Zapp (private communication), Nov. 12, 2013.

[21] Grip Technologies. (2013). *Spare Parts for Schleuniger UniStrip 2500* [Online]. Available: http://www.griptech.com/c/schleuniger-unistrip-2500-spare-parts/ [Nov. 12, 2013].

10 APPENDICES

Table Of Contents:

Appendix A: Project Definition

TABLE OF CONTENTS

LIST OF FIGURES

11 LIST OF TABLES

12 DESIGN CONSTRAINTS

Supplementary to the needs expressed by our client, the team identified some boundaries which govern the scope of our design. These boundaries are primarily a result of the inherent risks associated with the production of a weapon component, but are also attributed to existing certifications and contracts which the client is bound to uphold.

The client employs members of a union to manufacture, test, and assemble its rockets. This means that any in-house process which requires a worker in order to be performed must be done by a unionized worker. Tasks requiring a skill set beyond that of the labor force's capabilities are prohibited.

The manufacture of munitions, especially those which are self-propelled and those which use highly explosive material, is a strictly regulated industry. The risks associated with a malfunctioning BFC are extremely high. Due to the danger to human life it is imperative that quality assurance is performed reliably and securely, in the currently available Magellan-controlled facility. Any process design requiring tasks to be performed external to the client's organization are not considered feasible solutions.

When a munitions rocket is undergoing certification for use in military application, costly testing is carried out to determine its safety and reliability in the field. The design for the process of quality assurance may not make any change to the design of the rocket, or the test facility that would compromise the existing certifications of the CRV7 rocket motor. Changes of this nature include, but are not limited to, modification or change of the BFC itself, modifications of the squib, and changes to the assembly of the rocket motor.

The facilities available for the testing of the BFC are located in the client's rocket assembly facility, in Building 117, Propellant Plant Road, Rockwood, Manitoba. The manufacturing facility is EM emission, Spark, and electrostatic discharge controlled to prevent inadvertent detonation of rocket components. The equipment used in the BFC resistance measurement and acceptance must occupy the currently available space within that facility and must not create a risk of inadvertent detonation.

Finally, although no specific budget has been laid out for the BFC resistance measurement upgrade, it is important to constrain the costs associated with this project so that it can be competitive with the client's existing implementation. In order for our design to acceptable, the client must begin to recognize capital returns on investment no more than three years after its date of implementation. The value of the start-up capital is taken into account and estimated annual production quantities must be used to create this assessment. A detailed cost analysis will be completed in the upcoming design phase of this project when we begin specifying components of our design.

13 TARGET SPECIFICATIONS

An extensive examination of our communications with the client was conducted to more fully define the scope of our project. The team distilled this analysis into a list of short and concise target specifications and associated metrics which will be used to guide our design and measure its success. A statement of each of our target specifications are found in this sub-section of this report.

13.1 OPERATOR TIME REQUIRED

The current process is both time consuming and tedious. It is imperative that the new system require less time for a worker to complete. Ideally, each BFC must require fewer than 30 seconds of user input to undergo measurement.

13.2 OPERATOR SKILL REQUIRED

A worker must attach multi-meter leads across each of the BFCs four wires, one at a time. Each wire's resistance is then manually entered into a Microsoft excel spreadsheet. Performing this task quickly, accurately, and repeatedly without error requires a highly skilled worker with a great attention to detail. The ideal process must automate the collection of resistance measurements, requiring only two hours of worker training to be performed.

13.3 LABOUR INTENSITY

The current process requires very precise and controlled hand eye coordination. The ideal solution must automate difficult-to-perform tasks, making all steps which need to be performed by an employee as simple as possible. The total number of steps required to complete the process must be four or less.

13.4 SQUIB MATCHING

Each BFC is matched, based on its resistance, to a corresponding squib in order to maintain tight tolerances for production. The process must organize each BFC so that it may be paired with a squib at a later stage in production. The organization of BFCs after measurement must reduce the time taken to locate any designated BFC. The time required to locate a BFC after it has been verified by testing must be less than 5 seconds.

13.5 RELIABLE PROCESS

The process will utilize redundancies to minimize process failures, and include fail-safe protocols when a systemic measurement failure is detected. The acceptable number of process failures must be 0.

13.6 DAMAGE TO COMPONENTS

Currently, the operator inspects BFC for damaged bobbins. The new process should incorporate post process bobbin inspection and should not damage the bobbin during the process. The ideal process must damage no more than one bobbin per five hundred bobbin batch. The damaged bobbins may not pass inspection.

13.7 Accuracy of Resistance Measurements

The process must accurately read resistance of BFC and ensure pass-fail criteria are met under all circumstances. The resistance measurement device must allow a tolerance of no more than .005 ohms.

13.8 Access to Recorded Data

The current process transfers resistance measurement data from between computers by USB. The time required to access BFC data must be less than 10 seconds.

13.9 Safe Process

The process should in no way harm the operator or generate an unsafe work environment for other employees and visitors within the workspace proximity as per the client's environmental and safety requirements. The number of allowable lost time safety incidents over a span of ten years must be 1.

13.10 Life Cycle of Equipment

The new process must last for several years before being salvaged or replaced. The cost of the apparatus plus salvage value must not exceed the payback period contained within the apparatus life cycle. Ideally this process will last for a period of 25 years before becoming obsolete.

13.11 Equipment Maintenance

There is a need for consistent batch processing times, so that scheduling of orders and operator hours can be performed efficiently. Incorporating equipment that requires minimal maintenance is a way to improve the consistency of batch times. Another way to meet the need is to design the equipment in such a way that it can be maintained on a routine basis, which can be incorporated during scheduling. The two metrics for this need are the associated cost and number of units processed before scheduled maintenance is required. The target is to have minor scheduled maintenance (cleaning, oiling etc) performed after each batch (500 bobbins) is processed. The target cost of maintenance, including supplies and labour, is $20 for each batch processed.

13.12 Ergonomics

Ergonomics are of high importance to the team's design. The proposed process must be designed with operator comfort in mind. This will reduce fatigue as well as repetitive motion injuries, and reduce the amount of human error. To achieve this, the workstation should be arranged so that the amount of walking, bending, twisting, and lifting is minimized. Also, sufficient lighting, comfortable seating, and adjustable table height should be factored into the design. Ergonomics can be measured by the number of expected repetitive motion injuries per year, which will be assigned a value of 0.2.

13.13 AESTHETICS

There is a need for the equipment to be presentable and aesthetically pleasing. Equipment that looks like it was pieced together will decrease the level of confidence that the operator has in his/her work. In addition, the client is much more likely to implement a process if it is visually appealing. The appearance will be evaluated subjectively by team members, using common manufacturing equipment as a benchmark. In general, the process will look acceptable.

13.14 EASE OF ACCESS TO REQUIRED ITEMS

The process shall be designed in such a way that all the tools, parts and equipment that the operator needs are readily accessible and nearby. This will improve process times, reduce human error from fatigue, and improve ergonomics. Ease of access will be quantified by the amount of time spent by the worker retrieving and replacing items required for the process, which must be less than 5 minutes.

13.15 HUMAN ERROR

Part of having a reliable testing process is minimizing the possibility of human errors. Our design will incorporate as many features which eliminate the need for human input as is possible. Ideally, our process will include three or fewer tasks which require human input.

13.16 ENVIRONMENTAL CONCERNS

In order to reduce the impact that our system has on the environment, we will incorporate as many recyclable materials as possible in our design. Our target is to have at least 75% recyclable material used in the new process.

13.17 STANDARD PARTS

Incorporating standard parts in our design will be important both for reducing manufacturing costs and increasing availability of replacement parts. However the usage of some custom parts will likely be unavoidable; therefore we aim to construct our system from at least 50% standard parts.

13.18 PRIORITIZED CLIENT NEEDS

Having completed an in-depth analysis of the information we received from the client, the team compiled a refined list of needs and associated importance levels to ensure that any future solution matches with the expectations set forth during the preliminary design process. Importance level is indicated by a number from one to ten, ten being the highest importance. Our list of prioritized client needs is shown in Table I.

TABLE I: PRIORITIZED TARGET SPECIFICATIONS

#	Target Specification	Imp.
1	The new process reduces the time spent by the operator per unit.	10
2	The process reduces operator skill level required to perform resistance measurement.	6
3	The process is less labor intensive.	6
4	The process facilitates squib matching.	4
5	The process is reliable.	10
6	The process minimizes the number of damaged components.	5
7	The process guarantees that the resistance measurements are within tolerable values.	10
8	The process information is quickly and easily accessible.	7
9	The process is safe for all personnel.	10
10	The process has a long life cycle.	7
11	The process is low maintenance.	3
12	The process is ergonomic for the operator.	8
13	The BFC measuring and sorting equipment is aesthetically pleasing.	4
14	The BFC measuring and sorting equipment is easily accessible.	1
15	The process minimizes the possibility of human error.	9
16	The process is environmentally sound.	2
17	The design uses as many standard parts as possible.	5

Table II shows the metrics, with appropriate units and their assigned target values, corresponding to each target specification.

TABLE II: METRICS AND UNITS

Metric #	Need #	Metric	Unit	Target Value
1	1	Operator time per BFC processed.	seconds	30
2	2,3	Number of training hours required.	hours	2
3	3	Number of steps required to complete process	number	4
4	4	Amount of time to locate a specific BFC after measurement.	seconds	5
5	5, 7	Number of process failures.	number/ 500 BFC	0
6	5, 6	Damaged components.	number/ 500 BFC	1
7	7	Accuracy of multimeter readings	ohms	±0.005
8	8	Time to access information.	seconds	10
9	9	Number of lost-time safety incidents per year.	number	0.1
10	10	Number of years of service.	years	25
11	10, 11	Cost of scheduled maintenance.	dollars/ batch	20
12	12	Number of repetitive motion/stress injuries.	number/ year	0.2
13	13	Physical appearance.	subjective	acceptable
14	14	Amount of time required to retrieve and replace tools.	minutes/ batch	5
15	15	Number of tasks that depend on human input.	number	3
16	16	Percentage of recyclable the materials.	percent	75
17	17	Percentage of standard parts used.	percent	50

A house of quality has been developed to define all relations between key needs expressed by the client and their corresponding metrics. Each correlating item was compared and given a level or weight of importance. The house of quality sections are as follows:

- The triangular gable on the house of quality relates each engineering metric to one another and gives them a magnitude.
- The columns in the center matrix are engineering metrics with a dedicated direction of improvement. Below each metric column, a target value is prescribed a level of difficulty with respect to the other metrics. The same weighting of each metric in our scoring matrix is again represented in the house of quality document.
- The rows in the center matrix are client needs, which are given magnitude and correlated with the engineering metrics.

The house of quality typically compares competitors in the columns to the right of the central matrix. Since there is no competition with the development of this process, this section was eliminated. We found that there are some negative correlations between client needs and engineering metrics. For example, the correlation between the client's need "the process must be safe for all personnel," is reciprocated in relation to the engineering metric "number of training hours required," because further safety precautions require further knowledge in training. Our team's house of quality portrays all focused relations, and is shown in Fig. 1.

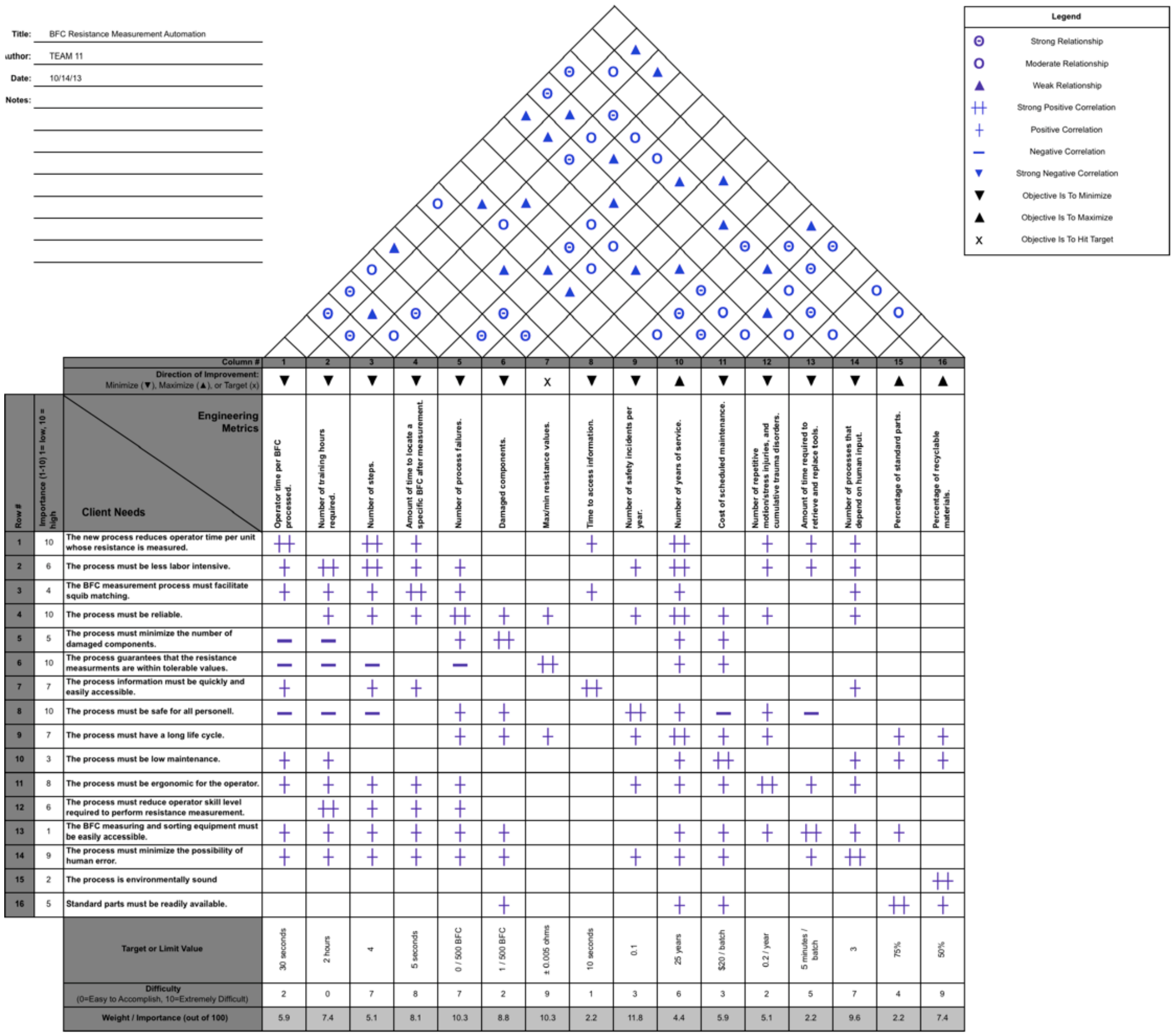

Figure 1: House of quality [1].

14 REFERENCES

[1] C. Matthews. "House of Quality" Winnipeg: Design Eng.,Univ Manitoba, Winnipeg, MB, Oct 13, 2013.

Appendix B: Conceptual Design

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 CONCEPT GENERATION

To further clarify the concept generation phase of our report, we break it down into five unique segments. These five segments are Problem Clarification, External Search, Internal Search, Systematic Exploration, and Reflection on the Process. During the Problem Clarification segment, the team crystallized the problems with the currently used method of BFC resistance measurement into a list of its most basic elements. Using these elements, the team then conducted research into anything related to the basic element that may be beneficial to the project. The team then underwent several brainstorming sessions to generate conceptualizations of how various basic elements could be designed for together.

1.1 PROBLEM CLARIFICATION

In order to ensure that all the important aspects of the BFC quality assurance procedure were thoroughly conceptualized, the team broke the process down into its most basic elements. We could then focus on each element individually for generating a list of concepts. The basic elements of the process were determined to be collecting the bobbins, pairing and preparing the lead wires, measuring resistance, passing/failing bobbins, and bobbin tracking and sequencing.

The first element in the process of performing quality assurance on the bobbins is taking them from their bulk storage state and making them ready for the first task of measurement. Ideas formed pertaining to this element incorporate aspects of physically orienting the bobbins, moving them in any way from their storage location, or organizing them in some way.

Manipulating the lead wires into a position or configuration that facilitates resistance measurement is the next element following the collection and positioning of the bobbins. Concepts related to this element are focussed on orienting, identifying, or otherwise collecting positional data about the wires.

The resistance measurement element is by far the most important component of our design. Ideas grouped here may include different techniques for probing wires, collecting measurements, and interfacing the resistance measurement element with other elements in our projects' scope.

In addition to the measurement process, bobbins must be passed or rejected based on both their conformance to the specific resistance value constraints and their physical condition. Ideas listed in this element may include ways to identify or prevent failures, notification systems for failed BFC's, ways to mitigate a measurement failure and bobbins' physical rejection from the Q/A process.

The final basic element of the process is tracking and sequencing BFC's. Although only the portion of matching BFCs and squibs together is within the scope of our project, the team decided to brainstorm ideas which may involve the integration of both components in our process. In this element, ideas are listed which may facilitate the process of bobbin and squib matching or otherwise organize bobbins for post-processing.

Through communication with our client, the team realized that there was a mistake in understanding for one of the process requirements. Initially it was understood that the eight wires had to be orientated by the operator, into the grooves at the top of the bobbin. However, this is not the case, as the operator only has to perform a visual inspection to make sure that the wires are in the correct grooves as received from the supplier. Additionally, the client informed the team that the current process takes approximately 10 seconds to remove the bobbin from the supplier bag and inspect it prior to measurement. This was a piece of data that was unknown to the team after the Project Definition Report was complete. Since our original brainstorming was based on the perception that the lead wires had to be correctly arranged into the bobbin slots during the process, our concepts had to be slightly modified according to this information. With the basic elements clearly established, the team could ensure that all the important features of the system were included and fully developed into effective concepts.

1.2 External Search

Part of the brainstorming process involves searching for concept ideas that have already been implemented by other companies or individuals. By searching externally for ideas, concept generation is not limited to an individual's or group's creativity. To ensure that the search was thorough and included all relevant elements of the bobbin testing process, each team member was responsible for performing a brief external search for items related to basic elements of the process. Included in this search was a review of documents received from the client. Additional sources of information included lead users, experts, patents, company product websites, and literature.

The following section includes all information collected from our external search, grouped and organized by basic elements of the bobbin testing process.

1.2.1 Lead Users

During the team's site visit to the Magellan Rockwood Propellant Plant, there was an opportunity to speak directly with an operator who performs the current process. The key points of the discussion with the operator are as follows:

- Tedious repetition of the current process is very undesirable
- New process will be well received if it is faster and less labour intensive
- Loading a buffer with bobbins for measurement would be beneficial

1.2.2 Magellan Documents

Documents and technical drawings received from the client were reviewed during the external search to refresh the teams understanding of technical specifications of the bobbin parts. The bobbin consists of a cable containing a total of four conductors spooled around a thermoplastic polyester holder. Two of these conductors are solid stainless steel and the other two have a stainless steel outer casing with an inner copper core. Each of the four conductors has a different color code; red, black, yellow, and green. Specifications for the bobbin are as follows:

- Copper core and solid conductor must be made from the same batch of 446 Stainless Steel
- Conductor final diameter: 0.013 +-0.0003 inch
- Steel Conductor: 2.364 +-0.236 ohms/ft
- Copper Cored Conductor: 0.298 +-0.030 ohms/ft
- Red and black conductors shall each have a resistance of 11.5+-2 ohms per five foot length
- Yellow and green conductors shall each have resistance of 1.5 +-1 ohms per five foot length
- Insulation resistance from any conductor to ground through sheath shall be 10 ohms
- Cable twist 7/8 +- 1/8 inches per twist

[1], [2]

1.2.3 Wire Stripping

The Canadian Intellectual Property Office was used as a source for patents during the team's external search for wire stripping devices. Fig. 2 shows a simple wire stripper that relies on a piece of spring steel and an aperture to strip insulation off the wire [3].

Figure 1: Patent for a simple wire stripping tool [4].

Another patent for a hand held wire stripper was discovered. The patent was for a design that featured a small knife blade that was twirled around the wire to completely cut the circumference of the insulation [5].

1.2.4 Resistance Measurement

There are various types of resistance measuring equipment available for purchase, all with different features and capabilities. The need for the creation of a database of resistance measurements caused the team to focus our search on measuring equipment that had the capability to interface with a computer to store data. Two varieties of computer interface were found to be commercially available, and those were USB and RS-232 serial port (hereinafter "serial port"). While a USB interface offers the advantage of using software supplied by the manufacturer for data acquisition, a serial port interface allows for easier user controlled manipulation of the data outputted from the measurement device.

Since each bobbin requires the resistance of four wires to be measured, multi-channel measurement devices were researched. The number of measurement channels vary with manufacturer, ranging from 2 to 200. This will allow for a device that is capable of testing multiple bobbins arranged in a fixture at once.

Another important specification for measurement devices is accuracy. Through research of commercially available products the team determined that there are numerous options for measurement devices which exceed the accuracy required for testing the bobbins. In addition, one feature available on certain measurement devices is a relay that is triggered when an unacceptable resistance is measured. This relay can be easily wired to set off an alarm or a sorting mechanism that separates the bobbin from the accepted units. Another feature available on some units is the capability to store readings internally, potentially eliminating the need for a permanent computer connection.

Information gathered from the external search on resistance measurement confirmed that measurement devices that fit all of the project needs are readily available commercially, although this doesn't not rule out possibly creating a measurement device of our own. Further external research into the matter shall be performed in the design phase of the project, when a measurement device will either be selected or designed for implementation into the final design.

1.2.5 Bobbin Tracking

An external search was done by the team to look into readily available options for labelling or assigning parts with a number for tracking purposes. A consecutively numbered roll of 500 adhesive backed labels can be purchased from McMaster-Carr for $14.97 (USD). These labels can be peeled off their liner and automatically applied by the Automatic Label Dispenser available from Uline Canada. This unit (Model H-1276), shown in Fig. 3 is powered by an electric motor and has a cost of $629 (CAD).

[redacted]

Figure 2: Uline automatic label dispenser that peels liner off of adhesive backed labels, and cuts label to length [6].

An alternative to stick on labels is printing the number directly onto the bobbin using a dot matrix printer. Printers used for expiry dates on plastic food containers were researched to gain familiarity with the process and equipment. Through this search hand held and contactless ink jet printers were discovered. These printers have the capability to print on cardboard, metal, glass and ceramics without directly contacting the print surface [7]. Sun Packaging Technologies, Inc. produces an inkjet printer with options for sequential numbering and RS-485 cable networking capability (shown in Fig. 4) [8]. Printed character height can be varied from 3/32” to 1/2” with this unit.

[redacted]

Figure 3: Evolution II contactless inkjet printer that could be used to apply tracking numbers to bobbins [9].

1.2.6 Automated Visual Inspection

The team came to a quick conclusion that all members had a general background pertaining to robotics and sensors used for quality control, yet the knowledge required to determine the feasibility of automating visual inspections of wires was lacking. Realizing this, the team turned to an expert on robotics and computer integrated manufacturing at the University of Manitoba, Dr. Subramaniam Balakrishnan, P. Eng. After discussing the problem of verifying wire position and re-orientating them if needed, Dr. Balakrishnan determined that a six degree of freedom robotic arm was required to perform the process. An estimated cost of $15,000 to $20,000 for the robotic arm and associated programming was provided by Dr. Balakrishnan [10]. From this discussion with an expert on the topic, the team concluded that automating the visual inspection for the test process may be cost prohibitive.

1.3 Internal Search

A vital part of the concept generation phase was brainstorming, performed both individually by team members and as a group. The goal of the brainstorming sessions was to generate as many ideas for ways to go about performing each basic element of the bobbin testing process. To promote creativity, judgement of concept ideas was reserved for the future steps in the concept phase of the project. The first session was performed as a group, followed by an individual session, and a final additional group session. Theory of Inventive Problem Solving (TRIZ) was used to aid in creative thinking during each session. The following sections of the report contain brainstormed ideas for each basic element of the process.

During our first group brainstorming session, each member of the team took turns offering suggestions for the process as a complete unit. The purpose of this discussion was to allow all members of the team to introduce their perspectives on how the process can be changed to facilitate the customer's needs. While many legitimate concepts were developed during our first meeting, the greatest advantage each member gained was an equal understanding of the customers' priorities for a successful solution. Each team member then agreed to engage in individual brainstorming.

During individual brainstorming, members of the team were tasked with breaking down the BFC Quality Assurance process into what they believed were its most basic elements. Using their list of the most basic elements, each member of the team then read through the 40 principles of TRIZ and documented the concepts they thought of during the process. Two examples of concepts that were brought up from the TRIZ principles were changing colour – using transparent panels to view the bobbin when it's in the fixture or any other moving parts to make inspection easier, and inversion – changing how the motion of the process happens, such as the operator remaining in one spot and the process moving around him/her. We then shared our lists with the other team members for reflection before our next group brainstorming session.

In our second group brainstorming session, the team's lists were compiled, sparking an in-depth exploration of each individual's alternatives. Through group collaboration, each concept was allowed to be adopted by other compatible concepts, and lone concepts were elaborated upon. The results of our groups brainstorming session are compiled in bulleted lists below. It is important to note that although we have grouped individual ideas below a most basic element, some ideas are not exclusive to a single basic element.

1.3.1 Collecting the Bobbins

Various methods were discussed for transferring the bobbins from the bag they are received in to a configuration or intermediary storage device that facilitates the subsequent resistance measurement procedures. These ideas are summarized as follows:

- Bobbins are collected individually one at a time manually
- Load a buffer device by hand that automatically dispenses bobbin to measurement device
- A conveyor belt is used to deliver bobbins to the workstation
- A hopper is used to feed a gravity chute or sloped trough
- Tray with divots for individual bobbins, used as a transport package from supplier. I.e. the organization and orientation are done by the supplier.
- Spread bobbins out on table, feed machine by hand
- Keep bobbins in original supplier bag
- Grab several bobbins from bag at a time
- An automated claw dispenses bobbins
- A vertical tube holds stacked bobbins and is loaded
- A spring loaded buffer which can be carried or stationary dispenses bobbins
- Use vibratory action to orientate bobbins in buffer after being dumped from supplier bag into hopper
- Use a pallet system with built in multiplexing capabilities
- Use pneumatics, hydraulics, gears, and rotary components to handle bobbins
- A color coded bin organizes bobbins
- Intermediary small bread board type holder that holds and connects wires for measurement
- Interlocking small trays as a carrier and test platform, to reduce chance of overwhelming the operator with lots of bobbins in front of them to test

1.3.2 Pairing and Preparing Wire Ends

There are numerous options for preparing the lead wires for resistance measurement since there are four separate wires that need to be distinguished and measured. In addition, the measurement may be performed after stripping the insulation off the wires or simply by probing through. The following points summarize the possible variations that we brainstormed:

- Wires are identified in one of the following ways
    - Human eye
    - Camera
    - Infrared sensor
    - RGB sensor
    - Contrast sensor
    - Capacitance sensor
    - Inductive sensor
- Hook up all 8 wires at once, run program to test all possible connections, pair wire ends through continuity tests
- Have supplier shape (crimp or bend) wire ends to correspond to each color, allowing for simple identification without need for visual observation
- Different wire coatings are used on each wire that can easily be identified by a machine that detects the following
    - Chemical composition
    - Surface finish
    - Thickness
    - Luminescent paint
    - Paint pattern (stripes, dots, solid etc)
- Have an operator arrange each wire into color coded slots
- Instruct bobbin supplier to have each wire cut to a different set length, allowing for easier mechanical identification of wire ends
- A fixture accepts wires pushed into several holes that align wires for next step in process
- A Specialized hand held tool is used to aid in separating wire ends (comb like device)
- Wires are stripped in one of the following ways
    - Guillotine type device that scrapes insulation of one side of all 8 wire ends at once
    - Heat (flame or soldering iron type device) to burn insulation off

    - Abrasives such as grinders or sand paper
    - Chemical removal of insulation in a bath which the wires get dipped into
    - Wire stripping device used in current process
    - Quickly straighten out bent wires through a comb
- Don’t strip wires, use sharp test probes instead
- Don’t strip wires, use probes that make contact with the cut ends of the wires
- Use fixture that straightens and strips wires when bobbin is inserted

1.3.3 Resistance Measurement

In conjunction with the abundance of different possibilities for wire preparation, the team also came up with a wide variety of methods for measuring the wire resistance, listed below:

- Alligator clamps or pointed probe test leads
- Grouped test leads to measure each set of the wire ends
- Wireless test leads are used
- Data acquisition system to record measurements in Microsoft Excel
- Use multiplexer with integrated circuits if limited by number of measurement channels
- Test leads that clamp tightly through wire insulation to take reading
- Connector that receives all eight wires
- Use a Wheatstone bridge circuit
- Determine resistance based on length of each wire wrapped around spool
- Prototyping platform (Arduino or Raspberry Pi) to interface measurement device to computer
- Open loop vs. closed loop measurement
- Store resistance values
    - Computer memory
    - Spreadsheet
    - Custom program
    - USB flash drive
    - Multi-meter internal memory
    - Pencil and paper
    - Laser engraving onto bobbins
    - Punch tape
    - Audio recording of values
    - Photograph multi-meter display
    - Don’t store actual resistance values, just match squib to bobbin with same serial number
- Test leads on a powered linear axis or axes that moves from wire to wire
- Female connector that accepts all 8 wire ends, connector will have built in crimper and cutter to eliminate future steps in the process

1.3.4 Pass/Fail Bobbin

Intuitively, the main consideration for passing or failing a bobbin is checking that it is in good physical condition and that it falls within the prescribed resistance values. However, we discovered that there many possibilities related to this process, as well as what actions to take when a failed bobbin is found:

- Weigh bobbins to check for damaged or improperly wound bobbins
- When a failed bobbin is detected create an alert that requires operator intervention before the process can continue
- First read checks wire configuration, another checks resistance
- Alarm types
    - Buzzer
    - Light
    - Automatic email
    - Mechanical counter
    - Ejection into fail bin
    - Shutdown process until issue is solved
    - Automatically destroy failed bobbin
- Discharge failed bobbins into a separate pile
- Flag failed bobbins by serial number
- Camera to inspect for damaged bobbins
- Laser scan to inspect for damaged bobbins
- Perform bobbin inspection on an individual or batch basis
- Fit bobbin into shaped hole to check for abnormalities
- Test the tape that is wrapped around coil
- Check wire end length-short or long may indicate error in coil wrapping
- Test fit top connector into steel die, measure force required to connect
- Fixture verifies part condition by fit

1.3.5 Bobbin Tracking and Squib Pairing

Finally, the concepts relating to ensuring that the bobbins are correctly identified and matched with an appropriate squib are listed below. The main trends that emerged in the development of these concepts were labelling the bobbins themselves or making labelled storage devices.

- Separate bobbins into pass or fail groups
- Mark bobbins for future processing
    - Stamp
    - Pre numbered stick on labels
    - Label maker with automatic applicator
    - Automated label dispenser
    - Tape with different colors
    - Stencil ID number
    - Laser etch number
    - Egg best before date printing process
    - Bar codes
    - Laser etching
    - Ink printing
    - ID that wraps around bobbin: zip-tie, twist tie, barcode
    - UPC codes
    - QR codes
    - Stamp that melts ID into bobbin body
    - Large tag tied to bobbin
- Tray with serial numbers based on coordinate system, no ID applied directly to bobbin
- Instead of pairing squibs to bobbins, create groups of compatible squibs and bobbins
- Magazine/tube that holds everything in order (consecutive numbers), allowing individual bobbins to be readily accessible at next assembly station
- Match bobbin and squib numbers
- Pair through spreadsheet or software that pairs serial numbers
- Human pairing
- Use tray system (squib tray, bobbin tray, or bobbin and squib tray)
- Pair one at a time
- Pair based on general value range. Fine tune pairs after

- Use identifiers that can be run through a physical sorting machine
- Pair with magnets
- Sorting machine that arranges serial numbers in a row
- RFID tags-squib tray and bobbin tray scanned, computer matches units, claw transfers units into one tray that now has pairs

1.3.6 Internal Search Conclusion

Through individual and group brainstorming, the team developed a thorough list of concepts for each of the basic elements of the BFC quality assurance process. To aid in generating concepts creatively, we used TRIZ to aid in finding methods of performing the process that we may not have thought of otherwise. With this complete set of concepts the team could then move forward into systematically organizing these ideas in a way that would assist in compiling them into conceptual designs for the entire process.

1.4 Systematic Exploration

1.4.1 Concept Classification Trees

To create a well-structured method of organization for our concepts, our team created classification trees. We originally started by using the basic elements as the base of each tree; however, we discovered that, for this section, it would be more effective to split the process into the following components: positioning the bobbins, distinguishing the lead wires, arranging the lead wires, conditioning the lead wires, attaching resistance measurement equipment, measuring resistance, recording resistance values, pass/fail bobbins, deal with failed bobbins, store for further processing. This breakdown lent itself better to organizing the concepts into classification trees, which are found in Fig. 5 – 9. Each element is its own tree which branches into the methodology that can be used to perform it, and each methodology is split into concepts and sub-concepts as applicable.

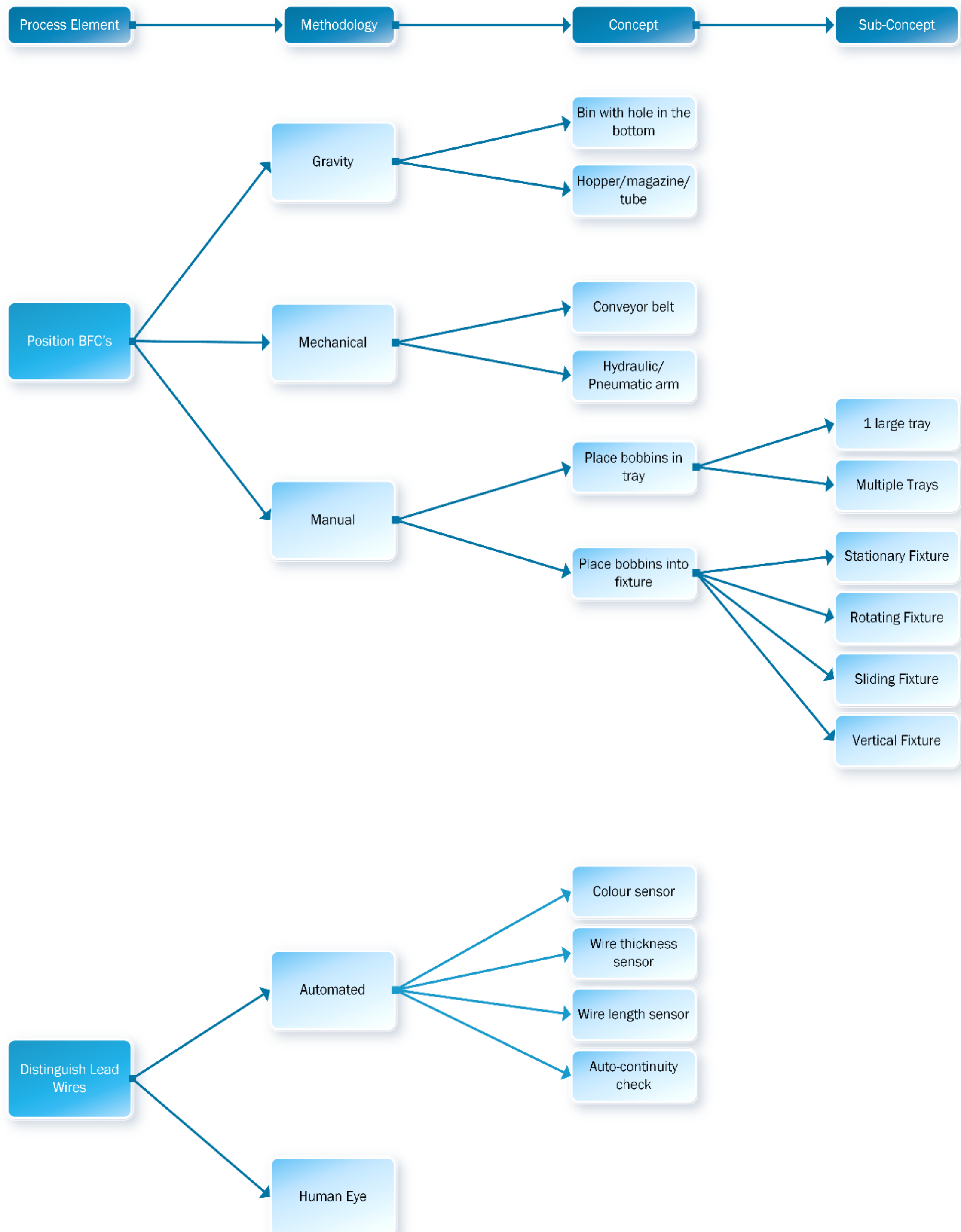

Figure 4: Classification trees 1 and 2 [11].

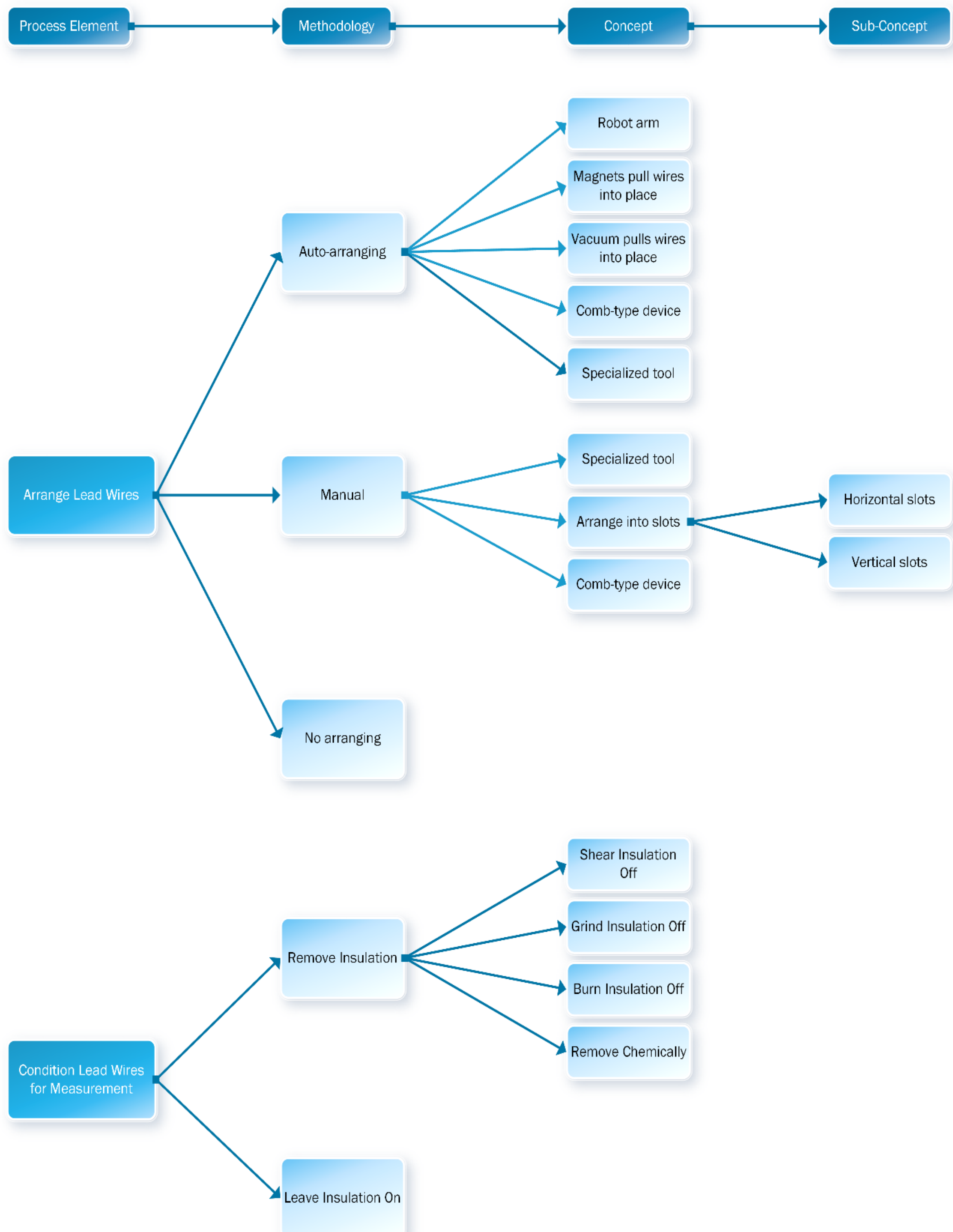

Figure 5: Classification trees 3 and 4 [12].

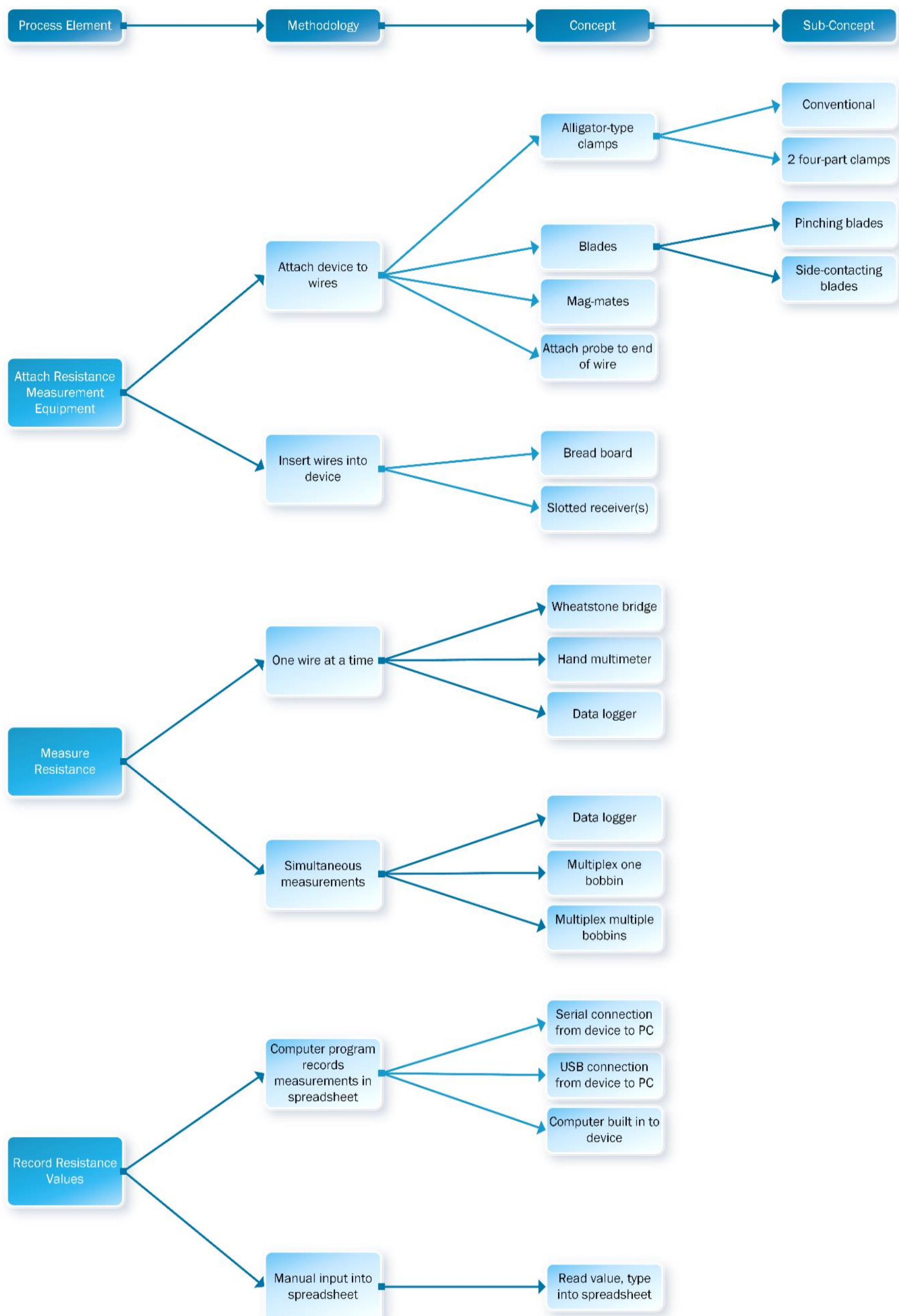

Figure 6: Classification trees 6, 7, and 8 [11].

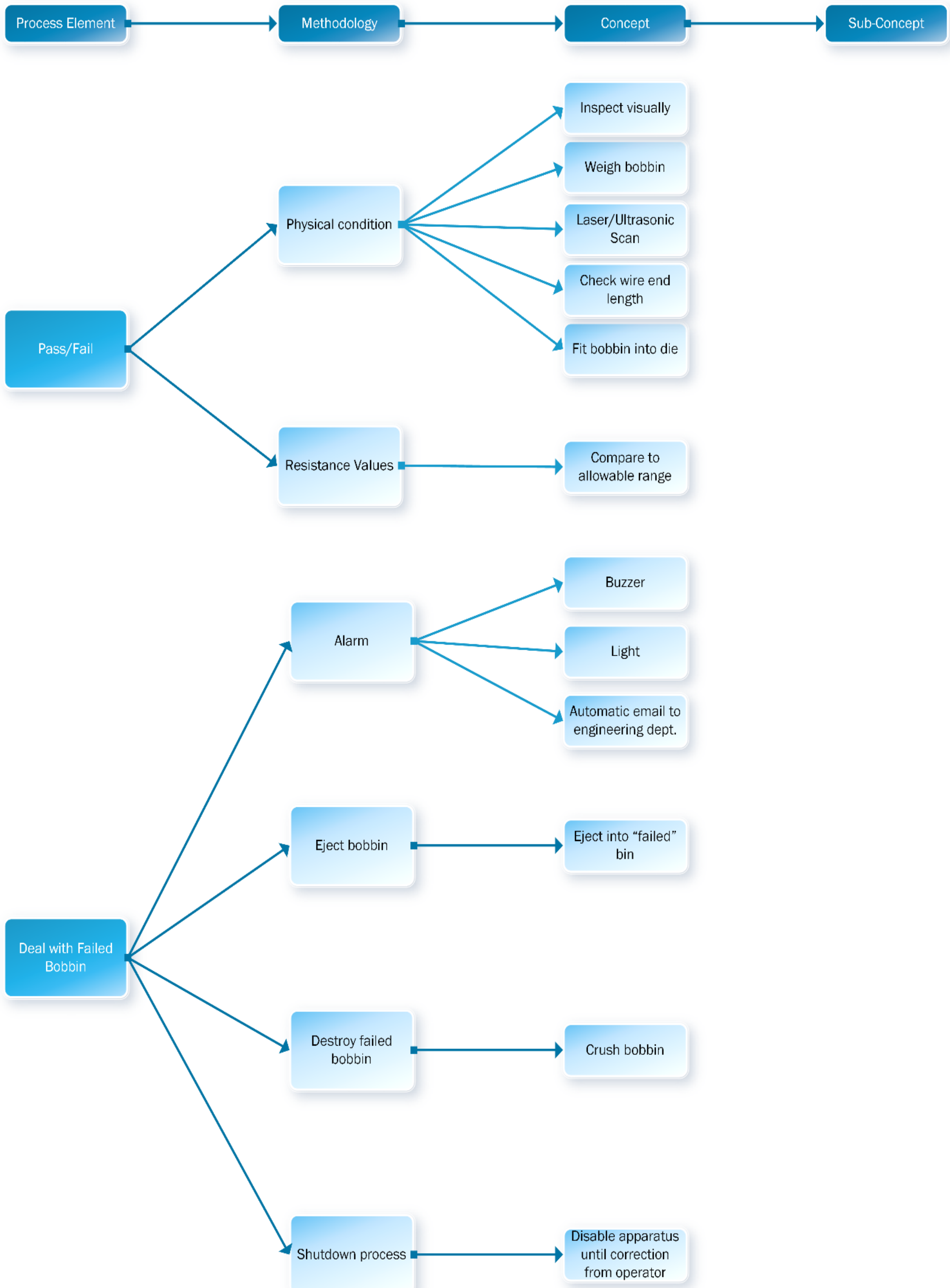

Figure 7: Classification trees 9 and 10 [11].

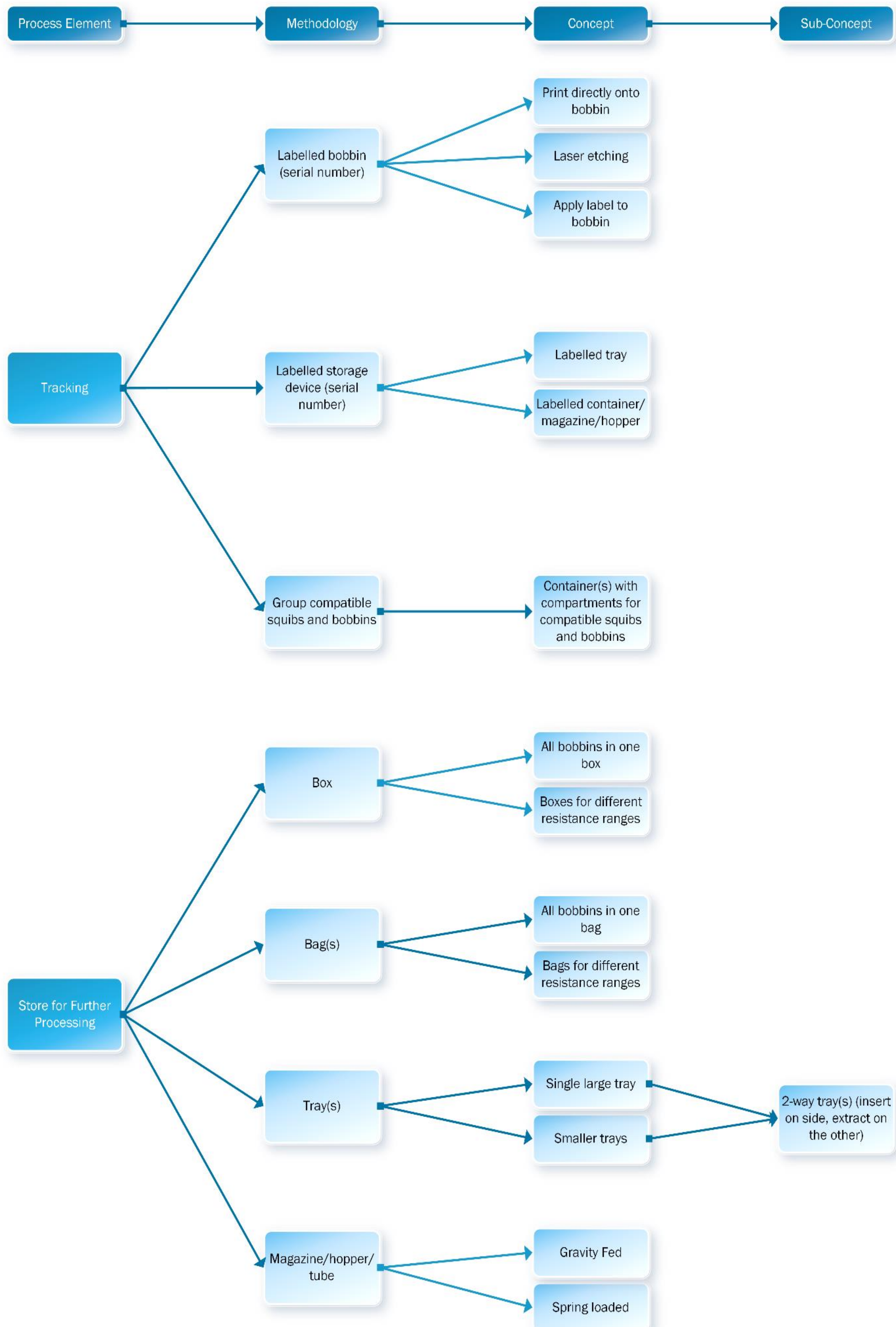

Figure 8: Classification trees 11 and 12 [11].

1.4.2 Concept Combination Table

Having completed the classification trees, we then compiled the concepts into a concept combination table, shown in Fig. 10. We arranged the process elements from the classification trees across the top of the table, with their concepts and sub-concepts listed underneath. This enables arrows to be drawn from one concept to another, showing how all the elements of each overall conceptual design are linked together.

Position BFCs	Distinguish Lead Wires	Arrange Lead Wires	Condition Lead Wires for Measurement	Attach Measurement Equipment	Measure Resistance	Record Values	Pass/Fail	Deal with Fail	Tracking	Store for Further Processing
Bin with hole in the bottom	Colour sensor	Robot arm	Shear Insulation Off	Alligator-type clamps	Wheatstone bridge	Serial connection	Inspect visually	Buzzer	Print directly onto bobbin	All bobbins in one box
Hopper/ magazine/tube	Wire thickness sensor	Magnets pull wires into place	Grind Insulation Off	Pinching blades	Hand multimeter	USB connection	Weigh bobbin	Light	Laser etching	Boxes for different ranges
Conveyor belt	Wire length sensor	Vacuum pulls wires into place	Burn Insulation Off	Side-contacting blades	Data logger	Computer built in	Laser/ Ultrasonic Scan	Auto-email to engineering dept.	Apply label to bobbin	All bobbins in one bag
Hydraulic/ Pneumatic arm	Auto-continuity check	Comb-type device	Remove Chemically	Mag-mates	Multiplex one bobbin	Read value, type into spreadsheet	Check wire end length	Eject into “failed” bin	Labelled tray	Bags for different ranges
1 large tray	Human Eye	Specialized tool	Leave insulation on	Attach probe to end of wire	Mulitplex multiple bobbins		Fit bobbin into die	Crush bobbin	Labelled container	Single large tray
Multiple interlocking trays		Horizontal slots		Bread board			Compare to allowable range	Disable until correction from operator	Container(s) for compatible squibs and bobbins	Smaller interlocking trays
Stationary Fixture		Vertical slots		Slotted receiver(s)						Gravity Fed
Rotating Fixture		No arranging								Spring loaded
Sliding Fixture										

Figure 9: Concept combination table [13

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1.5 Reflection on the Concept Generation Process

After creating and reviewing our Combination Tables and Classification Trees, the Team decided to perform the Concept generation Process once more to allow each concept an opportunity to develop into a more comprehensive solution. Through our second iteration of concept generation, we were able to identify two additional elements in our design which were not directly considered beforehand. The team went on to develop these elements using both an external search and internal search. Below are the two additional elements, and corresponding brainstormed ideas.

1.5.1 Organization

The organization element applies to all physical components and electronic information associated with the process of measuring BFC resistance. As one of our criteria is conformance to the 5S production methodology, this key element is understandably an important feature in our design. Ideas grouped here may include physical configuration management, human interface configuration, and ergonomic developments.

- Refine spreadsheet to only show what is necessary for work to be completed
- Bins to hold tools
- Re-route wires so that workspace is not cluttered
- Improve visual appeal of workspace
- Label every piece of equipment and tool used in process
- Create client process instructions for new process
- Arrange training of operator
- Two schools of thought: design all equipment and parts such that they are easily packed away to utilize workspace when no testing is performed, or keep all equipment in permanent locations at all times
- Cart with tools and equipment
- Designate boxes for each stored item(s)
- Use shadow board outline of tools to prevent loss
- Pull out drawer or rolling cabinet under table containing supplies
- Minimize wires by bundling or boxing electronics
- Single unit computer and multimeter
- Make test equipment pop up out of worktable as needed
- Keep all equipment and tools in place all the time, eliminating need for carrying and excessive handling

- Switch-board style workspace configuration – operator seated in front of a vertical board containing all equipment

1.5.2 Reliability

The single most important component of the BFC resistance measurement process is its reliability. For this reason the team chose to create and all-encompassing basic element for the process's ideas on how to improve reliability. Ideas included here may perform any of the most basic elements of our design with specific regard to reliability. This list was developed after having run through the concept generation phase a second time.

- Rescan every bobbin to check for inconsistency in measurement
- Calibrate tools every batch
- Measure calibrated test standards positioned in corner of tray
- Reintroduce tested bobbins back into new batch and verify readings from both batches
- Perform audits on a periodic schedule
- Test and account for contact resistance, test leads wire resistance
- Induce alternating current into BFC assembly, check for voltage difference across circuit bridge
- Random verification performed by a human with a separate set of testing tools
- Internal check on tools by measuring a standard set of resistances with each testing run
- Incorporate backup systems
- Measure every bobbin with two different meters
- Enable every aspect of the process to be monitored while it is running
- Create statistics of values automatically, get engineer to review stats for trends that may indicate supplier issues
- Create troubleshooting guide
- Balance lightweight vs. stability in the final design
- Vibration dampers to reduce wear and fatigue on system components

2 Concept Selection

During the divergent concept generation phase of the design process, judgement was withheld on all concepts. This was important to ensure that all ideas were treated without prejudice and to allow them to be explored fully without having the creative process stunted by illegitimate concerns about their viability. It is the role of the concept selection phase to whittle these concepts down, forming a set of fully thought out convergent concepts. We begin this process by screening individual concepts against our original list of customer needs and design constraints, moving naturally into our first fully formed convergent concepts. Using our list of customer needs we then develop a scoring matrix, and pit convergent concepts against one-another to determine how strongly each one meets our customer's needs. Finally, through the process of trystorming and testing components of each champion concept, we identify a list of their components which can amalgamate to form our final conceptual design. It is important to note that throughout this selection process, we employed aspects of the concept generation phase such as the external search, brainstorming components to further develop each champion concept as needed.

2.1 Screening

Although the list of considered concept ideas shown in the Concept Generation section of this report are a testament to the teams thorough examination of the problem at hand, In order to maintain the integrity of the generation phase, tedious and careful screening was performed to weed out those concepts which do not inherently satisfy our customer's needs or fall within the project's constraints. In addition to the needs of our client, our team has established internal goals which meet with each team member's core principles. The team agrees that there needs be a good probability that our design will be put into operation, and that the simplest design is often the most effective. To this end, our selection of concepts will focus on choosing the design that is easiest to implement rather than one that is very intricate and expensive. This will help to ensure that our client will be able to actually use the new design, and that our design remains effective over the longest duration.

To a large degree, the constraints imposed on our project's cost determined which concepts were eliminated by the screening process. Through extensive research, the team determined that robotic or electronically controlled automation will cause potential solutions to be infinitively expensive. When this effect was considered alongside our customer's needs for a reliable solution which requires as many standardized parts as possible, it created a great hurdle for any electronic automation process to overcome. This, in fact, may be the very reason why the existing process has been done by hand for over 30 years.

While many of the proposed concepts both eliminate the need for manual input and accommodate our budgetary constraints, they can create additional work, amounting to almost no net time savings. This additional work may branch outside the scope of our project and make individual solutions seem more viable than they are. In order to avoid simply shifting the burden of work to other parts of what would be Magellan's manufacturing domain, the team chose to focus on bundling concepts which keep the integrity and scope of the current process intact.

Finally, what remained of the generated concepts were considered for their safety. In any workplace, safety is paramount, and the team chose to err on the side of caution, eliminating any idea which poses a risk of injury which cannot be easily mitigated. Concepts such as using an acid bath to remove the wire coating were eliminated so as to avoid the regulatory requirements of incorporating such an element into our design.

2.2 Converging Concepts I

From those ideas which remained after concept scoring, individual members of the team were tasked to create fully defined concepts which would undergo the scoring process. Emphasis was placed on making each scored concept as fully defined as possible, while incorporating implementation details which would demonstrate the viability of a concept. The use of implementation details such as the location of individual components were used not as limitations in concept convergence, but as tools to identify bad assumptions about how an individual concept may be implemented. Again, concepts were allowed to diverge through individual brainstorming and research and then were re-integrated in the form of one or more fully defined concepts.

All concepts utilize the same method for measuring and accepting wire resistance values. Four test probes are connected to a device capable of measuring resistance between every paired combination of the test probes. The device is controlled through a serial port by a personal computer running a custom program. Each test probe is electrically connected to a pair of wires leaving the grooves in the bobbin. To take a measurement two test probes must be read. When the first test probe bridges both wires in the pair, it is possible to distinguish which wire is being measured by looking at which wire color is common to the second probe. Since the other wire in the pair does not have a probe connected to both ends it has no effect on the measurement. The computer program tells the device to try and measure every possible pairing of the four probes. Measured values are then automatically uploaded to a spread sheet that matches the bobbin to a squib based on resistance values.

The team's six fully defined concepts are described in the following sections.

2.2.1 Switchboard Concept

The switchboard concept utilizes a user-friendly assembly line-like method of processing all bobbins at a single station. This concept is named for the reason that it will require similar operator movements that a switchboard operator would normally do.

This process requires the operator to do every task by hand. The process is similar to the original setup but utilizes helpful techniques in close proximity to complete the process for each bobbin in reduced time. The backboard of the operator's station holds the following substations that would be ordered from left to right for a unidirectional process:

1. A mounted PD2S ERASER wire stripper with on/off switch.
    - Wires are first stripped by the operator turning the wire stripper on and inserting all wires into the device.
2. A TOWA- AP65-30 handheld label applicator is mounted to the backboard and is always set in the on position.

- The operator simply rubs the side of the bobbin against the dispensing section of the label applicator, and a label sticks to the side of the bobbin.

3. A multiplexer for all wires in a single bobbin is mounted.

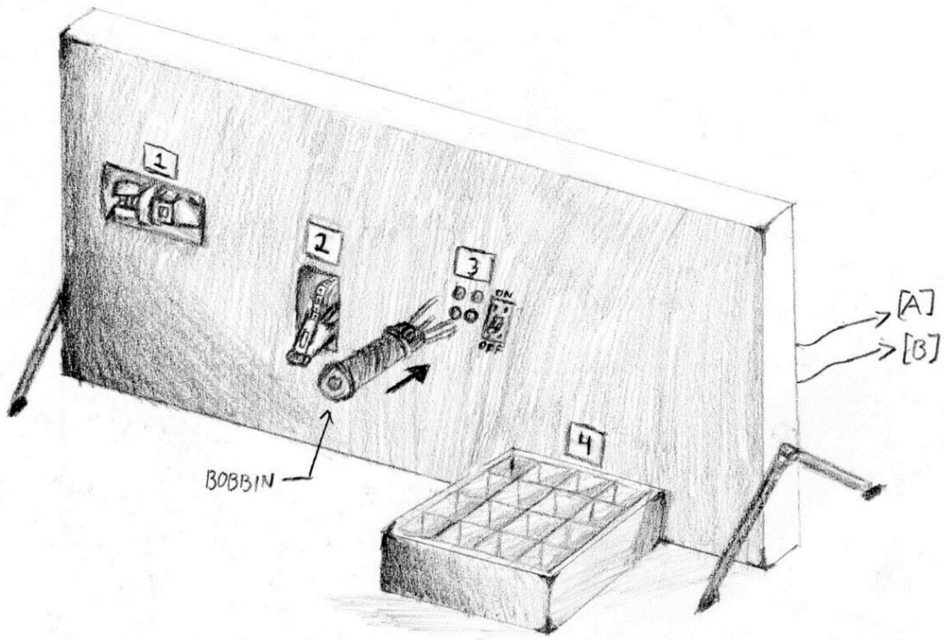
- Wires must be paired by the operator as per Magellan's standard. The wires are then funneled into four separate holes with conductive contacts embedded inside. The contacts are multiplexed by a microcontroller and measured by using a combination of algorithmic software and transistors hooked up to an ohmmeter. Both the microcontroller and ohmmeter are hooked up to a PC interface where resistance measurement data is entered into an excel spreadsheet in real time, and the measurement process is initiated by a button next to this substation on the backboard.

4. A tray at the base of the backboard holds measured bobbins.

- Bobbins are placed into a tray after all other tasks are completed for organization and accessibility.

This process is less labor intensive than the original process but is still fully dependent on an operator. Materials are expensive due to the off the shelf products that must be mounted to the backboard. A sketch of this concept with a brief description is shown in Fig. 11.

SWITCHBOARD CONCEPT



[1] WIRE STRIPPING STATION

[2] LABEL APPLICATION STATION

[3] RESISTANCE MEASURING STATION

[4] BOBBIN STORAGE TRAY

[A] MICROCONTROLLER IS MOUNTED BEHIND WIRE INSERTION HOLES AT STATION THREE AND CONNECTS TO PC INTERFACE.

[B] SERIAL PORT FROM OHMMETER LOCATED BEHIND BOARD AND CONNECTS TO PC INTERFACE.

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Figure 10: Switchboard concept.

2.2.2 Multiplex Matrix Concept

This design has a goal of measuring several bobbins at a time. An arrangement of wires underneath a board that connect to several conducting nodes along rows and columns are its key feature. By connecting wires to conducting nodes along the columns and rows, a shared medium is created, and thus the board is multiplexed. By sharing mediums, the hardware is reduced, but a coded algorithm is required to measure specific wires in the matrix. The wires are then hooked up through an integrated circuit, which is actuated by a microcontroller, and measured by an ohmmeter. The ohmmeter and microcontroller are then integrated with a PC interface which displays the resistance measurements on an excel spreadsheet, and prompts the user for a request for measurement process.

The Multiplex Matrix concept reduces the possibility for process failure by having few moving parts, however there is still a need for extensive operator interaction. The Multiplex matrix concept is also considerably more expensive than other concepts, but has more standard parts.

The operator must follow a specific process, which starts with stripping the bobbin wires, while the bobbins are placed horizontally one by one in a trough jig. A handheld wire stripper strips the wires. e.g. PD2S Eraser [14]. The bobbin is then labeled by a handheld TOWA AP65-30 handheld label applicator. [15]. The bobbin wires must be checked for proper pairing as per the Magellan standard. Each pair of bobbin wires for several bobbins are then placed upside down into color-coded designated holes where the conducting nodes are embedded. When the measuring process is complete, each bobbin is placed into a tray. A sketch of this concept with a brief description is shown in Fig. 12.

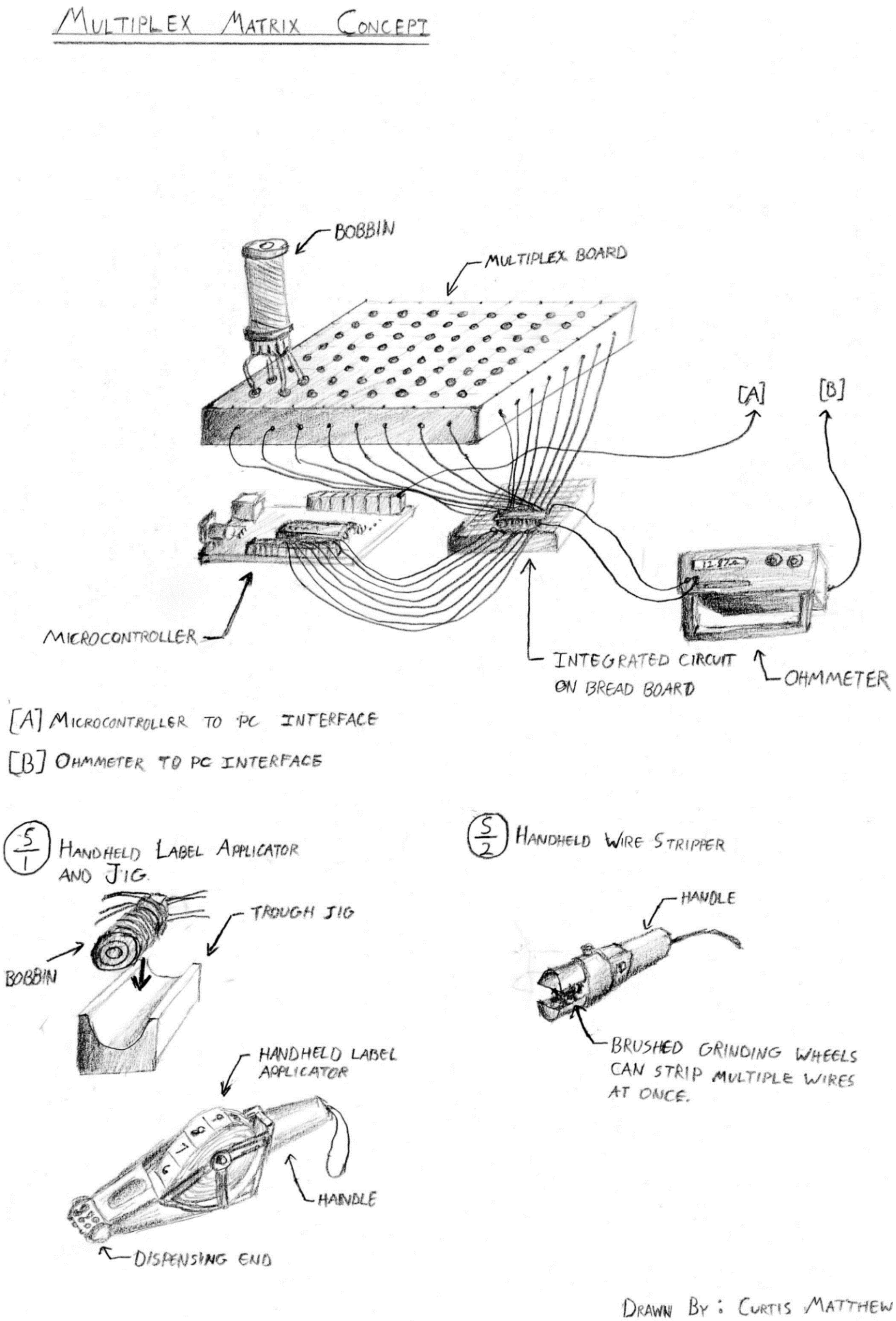


Figure 11: Multiplex matrix concept.

2.2.3 Mag-mate Wire Probing

This concept involves removing a bobbin from the storage container and inserting it vertically into a designated slot in the apparatus, with the lead wires at the top.

The bobbin is physically constrained by the following features:

- A square pin dimensioned according to the gap running up the centre of the bobbin
- A recess at the bottom of the apparatus, which the base of the bobbin fits into
- The hole at the top of the fixture, which the bobbin was inserted into.

The lead wires are arranged into the bobbin slots and the fixture slots simultaneously according to the designated colour scheme.

The Mag-mate fixture is lowered and locked into place. The Mag-mate s are the same as those used in the actual rocket, except split in half. They slide into the slots on either side of the bobbin, and cut through the wire insulation.

The Mag-mate s are wired up to a resistance measurement device. The operator is prompted to measure the resistance, the operator will click OK, and the resistance will be measured via a program that will record each measurement into the excel spreadsheet.

If the bobbin passes, the operator is prompted to attach the appropriate numbered label o the bobbin. If the bobbin fails, the operator is prompted to attach a reject label. These labels are on spools attached to the apparatus.

The operator then clicks OK and the Mag-mate fixture is raised and the operator can take the bobbin out and place it into a compartmentalized container. This container has a lid on the top and bottom. The bobbins are inserted lead wire end first. When the container is full, the lid is put on and the container flipped over. The bobbins can then also be taken out lead wire end first so that the wires will not come out of their slots. A sketch of this concept with a brief description is shown in Fig. 13.

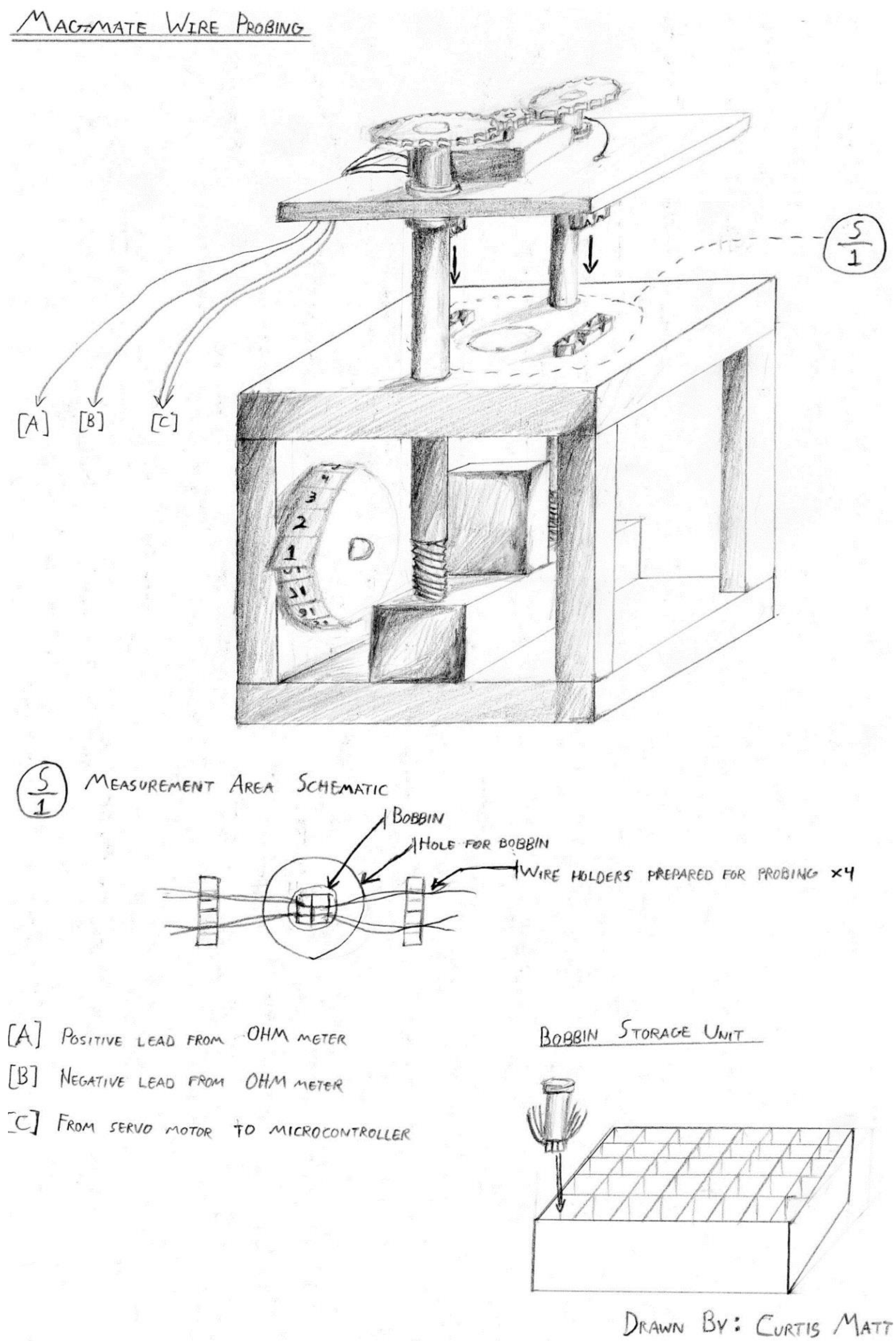


Figure 12: Mag-mate wire probing concept.

2.2.4 Bobbin Measurement Console

The concept behind a Bobbin Measurement Console is that each bobbin treated from start to completion of this process one at a time. The bobbins are retrieved directly from a storage bin in their as-received condition. Then, an operator is responsible to orient each of the four wire colours into the appropriate slot on the bottom of the bobbin. The bobbin is then placed onto a measurement console.

The role of the measurement console is to first probe each pair of wires with a pinching interface. This pinching interface slices through the Kapton insulation around each of the four wire sets sufficiently to monitor their DC resistance value. A gathering device is used to ensure that the wires are orientated properly for the pinching to occur, and a bobbin-shaped-slot holds the bobbin firmly on the console.

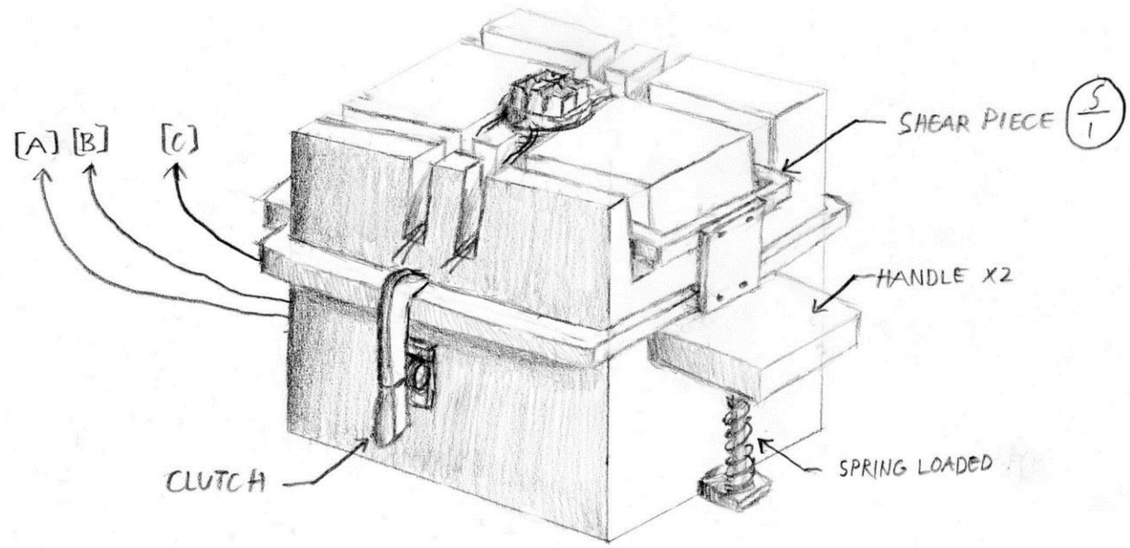
Once the bobbin is probed, a check for continuity is performed to ensure both that an adequate connection has been made, and that the operator has installed each wire in its appropriate place. If a bobbin fails the continuity check, the wires are adjusted automatically by the console and the check is performed again. If the bobbin fails a second time, an error is flagged and the bobbin is rejected.

When the bobbin passes the continuity check, each wire is probed for its resistance value using a multiplexer to switch between wire ends which are attached to the ohmmeter. If any wire fails its resistance measurement tolerance, the process starts over. If the process still does not collect an appropriate resistance value after its second time reaching the measurement stage, an error is flagged and the bobbin is rejected.

Once the console has collected each of the four resistance measurement values, they are recorded into a spreadsheet along with the serial number of the bobbin, which is applied by the operator manually from a spool of numbered stickers. The console then releases the bobbin, and is ready for the next bobbin to be measured. The operator places the measured bobbin onto a tray which has space for 100 (10x10) bobbins for easy retrieval during the following stage in manufacture of the CRV7. The trays locations correspond to the last three digits of the bobbins serial number.

In the event that ten bobbins out of thirty fail inspection, an error is flagged for all bobbins tested during that production run, and the console is flagged for immediate maintenance. A backup console may be employed to ensure that work does not halt in the event of a console failure. A sketch of this concept with a brief description is shown in Fig. 14.

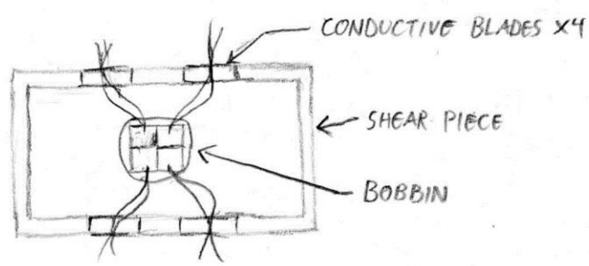
BOBBIN MEASUREMENT CONSOLE



[A] POSITIVE LEAD TO OHMMETER.
[B] NEGATIVE LEAD TO OHMMETER.
[C] MULTIPLEXER TO MICROCONTROLLER TO TURN ON SPECIFIC CONDUCTOR PIECES.

NOTE: AFTER BOBBIN IS IN PLACE, OPERATOR MUST PUSH DOWD ON SPRING LOADED HANDLES UNTIL CLUTCH ENGAGES. AT THIS POINT, THE SHEAR PIECE WILL BE CONNECTED TO THE BOBBIN WIRES AT FOUR CONDUCTIVE POINTS. WHEN BOBBIN IS MEASURED OR REJECTED, THE OPERATOR MUST PRESS CLUTCH TO RELEASE THE BOBBIN.

5/1 SHEAR PIECE TOP VIEW



DRAWN BY: CURTIS MATTHEWS

Figure 13: Bobbin Measurement Console concept.

2.2.5 Shear Stripper and Probe

This concept features a multi bladed shear style wire stripper with built in electrical contacts. A fixture with tapered grooves adjacent to the grooves at the top of the bobbin is used to hold the bobbin upright and position the paired wires for measurement. A shear with two electrically insulated blades travels vertically downwards when a hand lever is pulled. The shear pushes the wires to the bottom of the fixture grooves and bends them against the exterior of the fixture. The distance between the shear and fixture exterior is such that the shear scrapes the insulation off both wires in the pair. After stripping the wires, the shear is held in the down most position momentarily, where the resistance of each wire is measured through contact with the shear blades. Once the resistance measurements are taken the bobbin must be lifted out of the fixture and labelled to complete the process.

A hand lever with a simple "X" linkage can be used to actuate both shears at one time, allowing for simultaneous resistance measurement of all four pairs of wires on the bobbin.

The advantage of this shear design is that the stripping and measuring actions of the process are combined into one step. In addition, the fixture will allow for the wires to be untwisted by the shear if needed prior to measurement.

Disadvantages of this shear design include difficulty of manufacturing the fixture and the requirement of a separate process for labelling the bobbins after measurement. The grooves in the fixture must have a smooth taper and converge to a width of one wire diameter. Another issue is the need for electrically insulated blades and portions of the fixture. For proper function, the design must be structurally rigid and be built to tight tolerances. Producing the required geometry on such a small scale will prove to be challenging using conventional manufacturing methods. A sketch of this concept with a brief description is shown in Fig. 15.

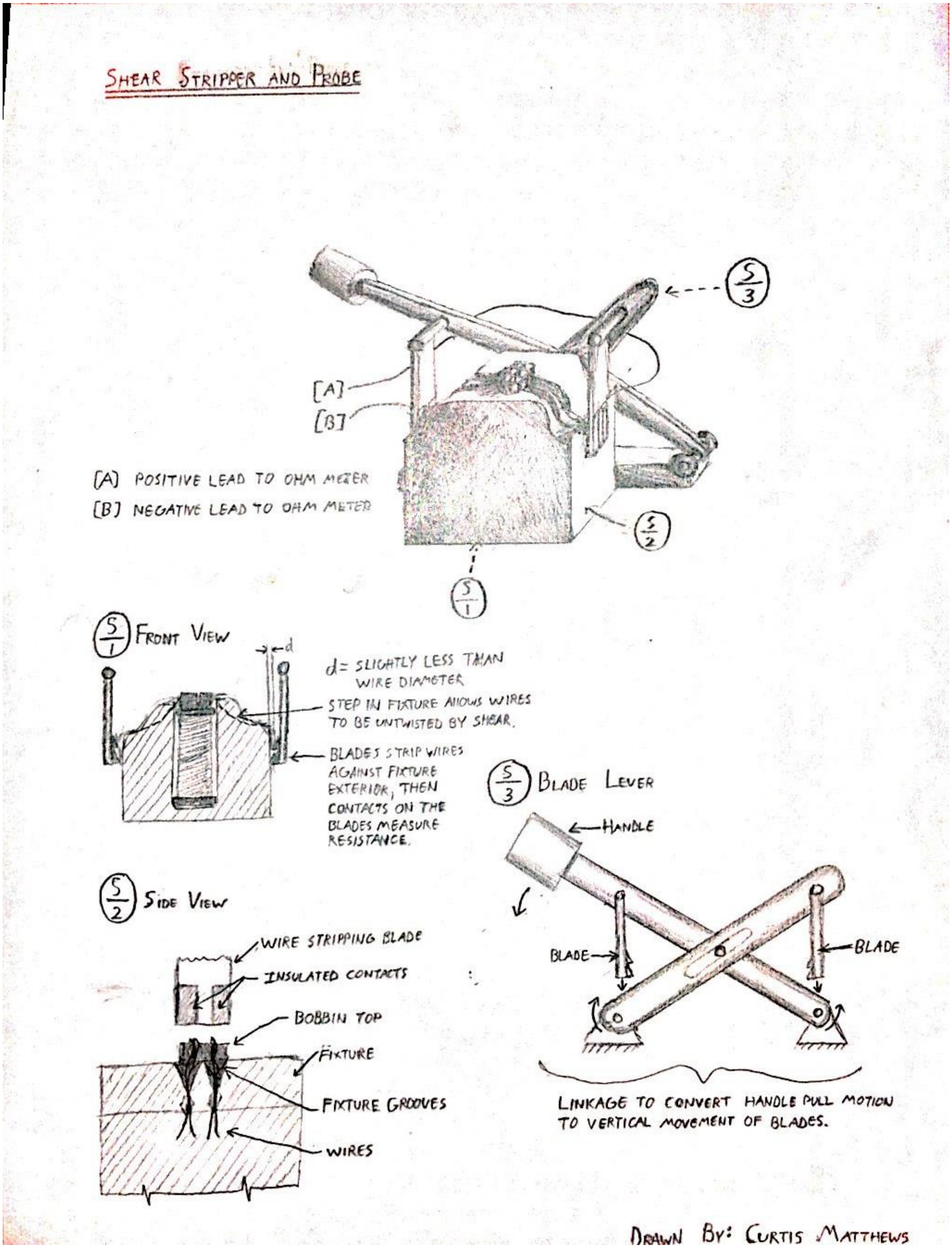


Figure 14: Shear Stripper and Probe concept.

2.2.6 Wheel

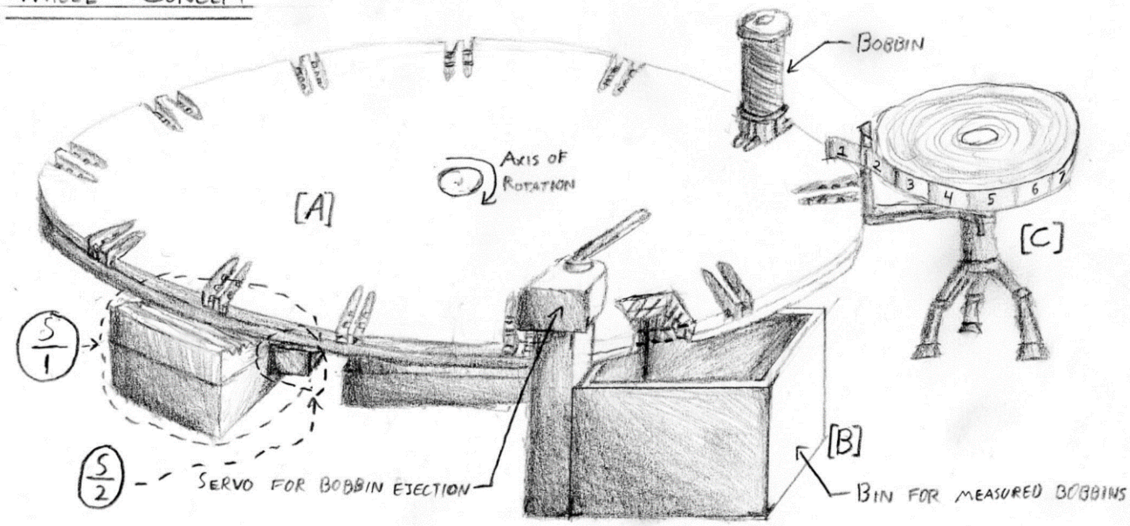
This concept features a wheel that is hand loaded with bobbins around its circumference. Underneath the wheel are several separate units which each perform a different operation on the bobbin. After a bobbin undergoes one complete revolution of the wheel, it will have had its wires stripped, been measured for resistance, have a tracking label applied, and been automatically dispensed into a bin.

There are only two operator actions required to be performed on each bobbin with this concept. The first is to insert the paired wires into four holes in the wheel. The second and final action is to actuate rotation of the wheel such that the next bobbin can be loaded and a completely tested bobbin is automatically dispensed into a collection bin. The wheel may be rotated by hand or by an electric motor.

The advantage of this rotary design is that it reduces the amount of operator bobbin handling between different operations of the testing process. In addition, this concept would improve operator ergonomics since all of the required interaction can occur at one location, eliminating leaning, bending, and reaching.

Disadvantages of this rotary design include structural issues and the potential for parts to jam, preventing the wheel from rotating. In order for the wire stripping process to be reliable, the distance between the wire stripping cutting edge and the bottom edge of the outside of the wheel is critical. To maintain this distance, the wheel will have to be sufficiently rigid and mounted on a set of large bearings to reduce the amount of deflection due to bending. The wheel may be jammed from wire pairs being twisted together as they enter the grooves. The grooves will only be able to straighten and separate wires that are not twisted together. A sketch of this concept with a brief description is shown in Fig. 16.

WHEEL CONCEPT

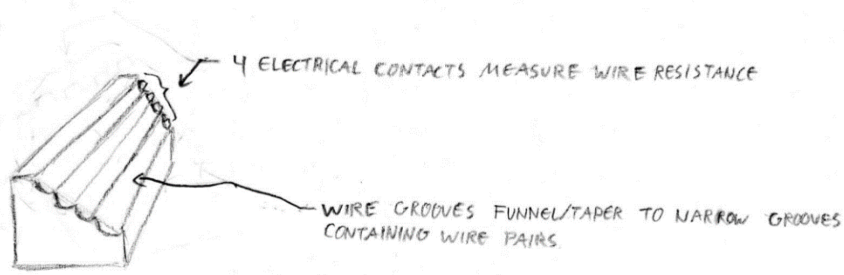


[A] THE SPINNING WHEEL TO WHICH THE BOBBINS ARE MOUNTED VERTICALLY ONTO IS MADE UP OF TWO DISKS. THE BOTTOM DISK HAS TWO TRACKS THAT FOLLOW THE PROFILE OF ITS PERIMETER, WHILE THE TOP DISK HAS MULTIPLE CUTOUTS. BETWEEN THE TRACKS AND THE CUTOUTS, THE BOBBINS PAIRED WIRES ARE SEPARATED FROM EACHOTHER. THE TOP DISK ROTATES WHILE THE BOTTOM DISK REMAINS STATIONARY.

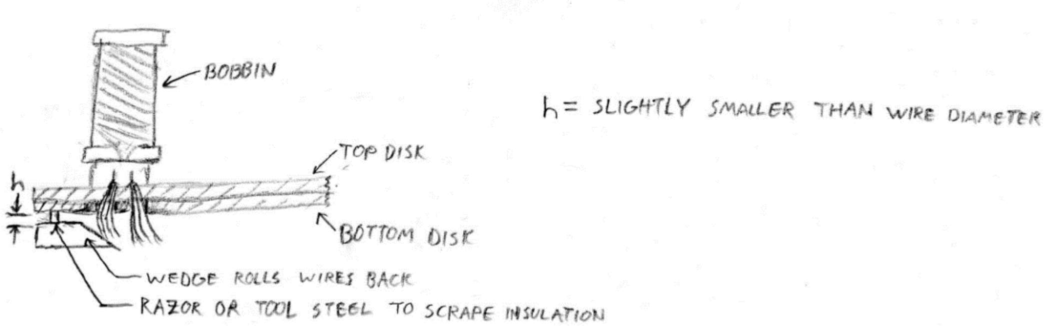
[B] BOBBINS ARE PUSHED OUT OF THE SPINNING WHEEL BY A SERVO ARM AT A CUTOFF POINT IN THE BOTTOM DISK.

[C] ADHESIVE LABEL IS ATTACHED AS BOBBINS PASS BY.

S/1



S/2



DRAWN BY: CURTIS MATTHEW

Figure 15: Wheel concept.

2.2.7 Converged Concept Combination Table

Six concepts in total were submitted for concept scoring, to be conducted as a group. Two fully defined concepts were found to have significantly increased the scope of our project. The team found that this increase in scope made each of those concepts infeasible. This scope creep was due to the incorporation of both outsourced designed components such as custom electronics creation and to the shift of work to other Magellan processes. The team chose to move forward with scoring each of the four remaining fully defined concepts as follows: mag-mate wire probing, Bobbin Measurement Console, Shear Stripper and Probe, and Wheel concepts. The team then used our concept combination table to map out the elements of each of the converged concepts, as shown in Fig. 17.

Figure 16: Concept combination table with arrows [13].

2.3 Scoring

Once the converging concepts phase was complete, the four concepts (Mag-mate Wire Probing, Bobbin Measurement Console, Shear Stripper and Probe, Wheel) underwent a scoring process with the goal of choosing a single concept most likely to lead to product success. The scoring was based on how well the concept fulfilled the customer's needs, measured using a decision matrix as well as a simplified cost analysis. Before completing the decision matrix, the criteria, weighting, and reference design needed to be determined.

2.3.1 Simplified Cost Analysis

For each concept entering the scoring process, the costs of parts, fabrication, implementation and maintenance were investigated. Note that the cost and time for an operator to test one bobbin are directly related to one another. Since the time spent by the operator per unit tested will be accounted for in the decision matrix, costs associated with the operator were left out of the cost investigation. In order to look at the total cost of parts for each concept, materials and approximate quantities had to be determined. Following this, the relative fabrication costs were looked at. Lastly, costs associated with the changeover to the new concept for the process were accounted for. It is important to note that this is a very simplified cost analysis due to the lack of a detailed design to analyze in this phase of the project.

There are no major differences in materials and quantities of parts required for concepts Mag-mate Wire Probing, Bobbin Measurement Console, and the Shear Stripper and Probe concepts. The Wheel concept on the other hand requires a large disk and several bearings for the center axle of the wheel so the approximate parts cost is higher than the others.

Fabrication costs were looked at next, and the team decided that due to the similar level of design complexity between all concepts, the comparative difference in fabrication costs was negligible.

Next, implementation cost was considered. Included in implementation cost was the required amount of training for the operator as well as any necessary changes to the building (e.g. lighting rearrangement and different electrical service). While each concept has a different requirement for operator skill, the training for each concept could take the same amount of time, leaving it up to the operator to practice and become more fluid their own. Additionally, all concepts do not require any changes to be made to the facility. Therefore the implementation costs are the same for all concepts.

One of the largest variations in cost between concepts came down to maintenance costs. While all concepts would require approximately the same amount of time to clean and oil, the costs of consumable wire stripping tools varied when measured on a per bobbin basis. The most expensive concept in this case was the Mag-mate type wire stripping tool found in the Mag-mate Wire Probing concept. Due to the tool geometry, material choice is limited to metals with low hardness. For proper function, the width of the slit in the tool must be maintained. Repeated use of the tool will wear the tool to a point that it must be replaced. On the other hand, the wire strippers on the Bobbin Measurement Console, Shear Stripper and Probe, and Wheel concepts are made out of hardened tool steel, which makes the replacement interval approximately ten times as long as for the Mag-mate Wire Probing concept. The Shear Stripper and Probe and Wheel concepts make use of a readily available rectangular high speed steel metal cutting bit, whereas the Bobbin Measurement Console concept requires a custom ground curved cutting bit. The team estimated that the custom cutting bit would cost four times as much as the rectangular one.

After reviewing the previously mentioned estimates for costs of each concept, the Shear Stripper and Probe concept was determined to have the lowest cost.

2.3.2 Decision Matrix

After completing the cost analysis, a decision matrix was created to mathematically rank each concept in terms of project success. To do this, the needs defined in the team's previous Project Definition Report were used as a basis to form selection criteria. Weightings were assigned to each criteria using an importance weighting matrix. In this matrix, all needs were compared against each other in pairs, and the more important need from each pair was entered into the matrix. After that, the totals for each need in the matrix were used to assign the weighting values. The most important criteria was determined to be personnel safety, while aesthetics of the equipment wasn't found to be more important than any other need. The importance weighting matrix with the determined weighting values is shown in Table III.

TABLE I: IMPORTANCE WEIGHTING MATRIX

		Need ID																
Need ID	**Criteria**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
A	**Reduced operator time per unit**		A	A	D	E	F	G	A	I	A	K	L	A	A	O	A	A
B	**Reduced operator skill level**			C	D	E	F	G	H	I	J	K	L	B	N	O	P	Q
C	**Less labor intensive**				D	E	F	G	C	I	C	C	L	C	C	O	P	C
D	**Ease of squib matching**					E	F	G	D	I	D	D	D	D	D	O	D	D
E	**Process reliability**						E	G	E	I	E	E	E	E	E	E	E	E
F	**Reduced number of damaged components**							F	F	I	F	F	F	F	F	O	P	F
G	**Pass/Fail accuracy**								G	I	G	G	G	G	G	G	G	G
H	**Information is quickly and easily accessible.**									I	J	K	L	H	N	O	P	H
I	**Personnel safety**										I	I	I	I	I	I	I	I
J	**Life cycle durability**											K	J	J	J	O	P	J
K	**Low maintenance**												K	K	K	O	P	K
L	**Operator ergonomics**													L	L	O	P	L
M	**Equipment aesthetics**														N	O	P	Q
N	**Equipment accessibility**															O	P	Q
O	**Reduced chance of human error**																O	O
P	**Environmentally sound**																	P
Q	**Percentage standard parts used**																	
	Total Hits	8	1	7	11	14	12	14	3	16	6	8	7	0	3	13	10	3
	Weighting	5.9	0.7	5.1	8.1	10.3	8.8	10.3	2.2	11.8	4.4	5.9	5.1	0.0	2.2	9.6	7.4	2.2

Once the weighting values were assigned, the current process was used as a reference to score each concept in the decision matrix. All concepts were scored as a group by going through each criteria one at a time. This ensured that all concepts were graded on the same basis. Table IV shows the complete decision matrix.

TABLE II: DECISION MATRIX USED TO SCORE CONCEPTS

		Concepts									
		A: Current Process		B: Mag-mate Wire Probing		C: Bobbin Measurement Console		D: Shear Stripper and Probe		E: Wheel	
Selection Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Reduced operator time per unit	5.88%	2	0.12	6	0.35	8	0.47	8	0.47	9	0.53
Reduced operator skill level	0.74%	2	0.01	7	0.05	8	0.06	9	0.07	6	0.04
Less labor intensive	5.15%	2	0.10	8	0.41	9	0.46	9	0.46	6	0.31
Ease of squib matching	8.09%	2	0.16	7	0.57	7	0.57	7	0.57	2	0.16
Process reliability	10.29%	10	1.03	9	0.93	7	0.72	7	0.72	4	0.41
Reduced number of damaged components	8.82%	9	0.79	8	0.71	8	0.71	5	0.44	4	0.35
Pass/Fail accuracy	10.29%	10	1.03	9	0.93	9	0.93	9	0.93	9	0.93
Information is quickly and easily accessible.	2.21%	2	0.04	10	0.22	10	0.22	10	0.22	10	0.22
Personnel safety	11.76%	10	1.18	7	0.82	8	0.94	7	0.82	9	1.06
Life cycle durability	4.41%	10	0.44	10	0.44	10	0.44	10	0.44	10	0.44
Low maintenance	5.88%	5	0.29	4	0.24	4	0.24	6	0.35	5	0.29
Operator ergonomics	5.15%	2	0.10	7	0.36	10	0.51	10	0.51	6	0.31
Equipment aesthetics	0.00%	2	0.00	8	0.00	8	0.00	8	0.00	9	0.00
Equipment accessibility	2.21%	2	0.04	9	0.20	7	0.15	7	0.15	10	0.22
Reduced chance of human error	9.56%	2	0.19	8	0.76	7	0.67	7	0.67	10	0.96
Environmentally sound	7.35%	10	0.74	10	0.74	10	0.74	10	0.74	10	0.74
Percentage standard parts used	2.21%	10	0.22	4	0.09	7	0.15	8	0.18	2	0.04
	Total Score	6.50		7.81		7.98		7.74		7.01	
	Rank	5		2		1		3		4	
	Continue?	No		Closeness In Total Scores Indicate Concept Convergence Before Development Would Be Beneficial						No	

As Table IV shows, the total score of the current process was 6.50, whereas the total scores of the concepts were 7.01, 7.74, 7.81, and 7.98. This indicates that all concepts offer an improvement over the current process, and the closeness between scores for the top three concepts indicates that there is no clear champion. Therefore converging the designs before development will yield an optimal concept. The decision matrix allowed the team to eliminate the Wheel concept, as it was the lowest scoring concept. In addition, the decision matrix clearly determined the top concept for each individual selection criteria. This information will be used moving along into the converging concepts section of the report.

2.3.3 Sensitivity Analysis of Decision Matrix

In order to test the robustness of the concept rankings, a sensitivity analysis was performed by altering selection criteria weightings. The weightings were changed to reflect an increased focus on the two major requirements requested by the client; reduced operator time per unit and a less labor intensive process. In order to increase the weightings for these criteria, other criteria weightings had to be decreased. One of the criteria, personnel safety was decreased since it was the criteria with the highest weighting. The other criteria changed was life cycle durability. Since all concepts scored the same for this selection, decreasing this criteria weighting will shift more weighting on all other criteria. Table V shows the alterations made to the weightings for specific selection criteria.

TABLE III: SUMMARY OF WEIGHTING ALTERATIONS FOR SELECTION CRITERIA

Selection Criteria	**Change in Weighting (%)**
Reduced operator time per unit	+2
Personnel safety	-2
Less labor intensive	+1
Life cycle durability	-1

The new weightings were then entered into the decision matrix and the total scores for each concept were calculated. These scores for the new weightings were then compared to the scores for the original weightings. The results showed that the ranking of each concept was not affected by the weighting alterations. In fact, four out of the five scored concepts had a decreased total score with altered weightings. The only concept that scored higher (only a 0.1% score increase) was the Shear Stripper and Probe. The following table, Table VI, summarizes the results of the decision matrix for the original scoring and the scoring with the altered weightings.

TABLE IV: SUMMARY OF DECISION MATRIX RESULTS FOR ORIGINAL AND ALTERED WEIGHTINGS

Highlight Indicates Top Score Out of Both Weighting Variations		**Concepts**				
		A: Current Process	**B: Mag-mate Wire Probing**	**C: Bobbin Measurement Console**	**D: Shear Stripper and Probe**	**E: Wheel**
Original Scoring	**Total Score**	6.50	7.81	7.98	7.74	7.01
	Rank	5	2	1	3	4
Scoring With Altered Weighting	**Total Score**	6.26	7.77	7.97	7.75	6.97
	Rank	5	2	1	3	4
	Change in Rank?	NO	NO	NO	NO	NO

From this sensitivity analysis, the team drew the conclusion that the original scoring parameters are not sensitive to realistic changes in the criteria weightings. These realistic changes are ones which would reflect an alternative approach that put more emphasis on the technical capabilities and inabilities of each concept. Having verified the scoring method used, the team moved onto the Testing segment of the Conceptual Design phase.

2.4 TESTING

To ensure that the team did not converge on a solution that is physically impossible or surprisingly complex, testing was completed. Realizing that some ideas look good on paper, yet may not be feasible in real life, the team decided to trystorm different wire stripping and probing ideas to test for feasibility. The various methods of wire stripping and probing that were tested were as follows: knife blade to scrape insulation, side cutter pliers to pinch through insulation, sharp probes to poke through insulation, hand held automatic adjusting wire stripper tool, sandpaper to abrade the insulation off, and high speed steel tool bits to pinch wires. Tests were performed on bobbins supplied to us by the equipment. Results of each test helped the team converge various concepts into one final concept.

Each method of probing was tested by taking one bobbin, measuring all wire resistances, and recording all measurements. A Fluke brand handheld multimeter was used for throughout the test. Following that, the wires were orientated into the bobbin grooves and each pair of wires was stripped and probed using one of the aforementioned methods. The resistance measurement was then compared to the recorded value for the color of wire that was being probed at both ends.

The first test was to scrape away the insulation on the wire with a knife. This was done to determine how much force is required to remove the Kapton insulation. The team then determined that with a sharp blade cutting at an angle of 45 degrees approximately five pounds of force was all that was necessary to scrape away the insulation. Only a small amount of insulation is scraped away with each pass, so rotation of the wire coupled with repeated cuts is needed to remove a majority of the insulation from the wire end.

A pinching mechanism for wire stripping and probing was trystormed next. Side cutter pliers were readily available and could be used to accurately simulate the concept idea of pinching through the insulation to form an electrical connection to the wire. Through trial and error, the team determined that there is a risk of accidentally cutting completely through the wire. A mechanical hard stop to limit the pinching mechanism from closing too much could easily resolve this issue.

Next, pointed multimeter test probes were tested for their ability to poke through the insulation and establish a steady electrical connection. The first issue was guiding the probe to the top center of each wire, which is a very small target. A fixture with one hole for the wire and another perpendicular to it for the probe may resolve this issue. Roughly 30 pounds of force was required to poke through the insulation and create connection to the wire. The small pointed contact surface area proved to make establishing a steady electrical connection difficult.

Following that, a handheld automatic wire stripping tool was used on the bobbin wires, similar to as what is shown in Fig. 18. The tool did a very good job at removing the insulation, but the stripped Kapton insulation began to gum up the blades. Repetitive use of the tool will surely cause issues if there is no periodic cleaning.

Figure 17: Commercially available hand held automatic wire stripper [19].

As an alternative to the previously attempted cutting methods, sandpaper was used to try and abrade the Kapton insulation off. The team found that 80 grit sandpaper removed the Kapton after three to four passes. Issues with using this technique are that the sand paper must be replaced frequently and holding the wire straight as the sand paper is passed over it can prove to be challenging.

At this point in the trystorming process, the pinching mechanism seemed to be the most effective way of simultaneously stripping and probing the wires. While the side cutters worked with a single wire, measuring two wires side by side in the same tool was next to impossible due to the angle formed between both cutting edges. The team then brainstormed ideas for a readily available hard material that can be shaped with a cutting edge. High speed steel tool bits used for machining tools were thought of almost immediately. These bits are readily available in various sized rectangular blocks with a square cross section, and are of sufficient hardness to machine stainless steel. Two bits with a ¼" square cross section were acquired for testing purposes. The bits come precision ground with sharp 90 degree edges, which make for a convenient cutter to pinch through the insulation. Pinching two wires side by side between two of the tool bits positioned as shown in Fig. 19 proved to provide very accurate resistance measurement readings.

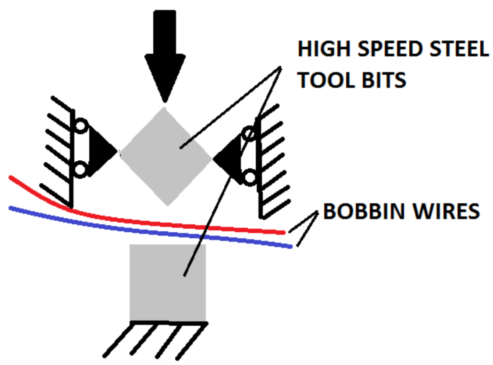


Figure 18: Tool bits arranged to pinch through wire insulation and probe bobbin wires for resistance measurement [17].

The advantages of this concept are numerous. First, the tool bits are readily available, in various sizes ranging from 3/16" to 3/4". Second, the bits have four usable edges if used in the configuration as shown in Fig. 19, allowing for indexing if the edge begins to dull. Lastly, the rectangular geometry would allow for a simple electrically insulated holder to be designed.

To electrically connect a test lead to one of the tool bits, the team trystormed two ideas. The first was to hold the test lead against the bit as a measurement was taken. This produced accurate measurement readings. Next, wires were attempted to be soldered to the tool bits using rosin core solder and a pencil type soldering iron after scuffing the surface with a grinding wheel. The tool bit could not be heated enough with the soldering iron to make a strong solder joint. More heat and the possible use of silver solder may resolve this issue. To make replacing the tool bits easier if they begin to dull, the ideal solution is a set screw that holds the bits in place in the fixture while at the same providing an electrical path for resistance measurement.

Through trystorming the team came up with a solution to strip and probe the bobbin wires for resistance measurement that uses readily available high speed steel tool bits. By actually physically testing the different concepts issues that were not predicted by the team (stripped Kapton building up and gumming the blades) arose and a work around was developed.

3 CONVERGING CONCEPTS II

The scoring process narrowed down the concept selection from four whole concepts to the best aspects of just three. Instead of simply selecting the concept which scored the highest, the team decided to integrate as many of the compatible methods for handling each basic element as possible. We refer to these methods as “key features”. Table VII presents the naming system used for each concept. Table VIII shows the concepts which excelled in meeting each selection criteria. In this table, multiple top concepts indicate a tie in score for the respective selection criteria. Key features of the top concepts related to the respective selection criteria are listed in the table as well.

TABLE V: CONCEPT NAMING SYSTEM

Current Process	A
Mag-mate Wire Probing	B
Bobbin Measurement Console	C
Shear Stripper and Probe	D
Wheel	E

TABLE VI: TOP CONCEPT (AS DETERMINED FROM DECISION MATRIX RESULTS) FOR EACH SELECTION CRITERIA, TAKEN FROM DECISION MATRIX RESULTS

Selection Criteria	Top Concept(s)	Key Features of Top Concept(s)
Reduced operator time per unit	E	Bobbins do not have to be unloaded from device by operator
Reduced operator skill level	D	Wires automatically splay out when entered into fixture
Less labor intensive	C,D	Bobbins only need to be plugged in then removed from device
Ease of squib matching	B,C,D	Tray used to store and recall tested bobbins
Process reliability	B	Mag-mate terminals are proven in the current process
Reduced number of damaged components	B,C	No wire stretching during wire stripping
Pass/Fail accuracy	B,C,D,E	Sufficient measurement device accuracy
Information is quickly and easily accessible.	B,C,D,E	Test results uploaded to network
Personnel safety	E	Wire stripping blade is easily guarded
Life cycle durability	B,C,D,E	All components are serviceable
Low maintenance	D	Wire stripping blades are hardened steel, quick to replace
Operator ergonomics	C,D	No precision individual wire placement
Equipment aesthetics	N/A	Place cover over device
Equipment accessibility	E	One single area of operator action
Reduced chance of human error	E	Minimal number of operator tasks
Environmentally sound	B,C,D,E	Time efficient, minimal waste generation
Percentage standard parts used	D	Wire stripping blades are tool steel

In order to begin integrating the top concepts, the team chose to elaborate on the aspects which made a single design the best at achieving the desired selection criteria. This analysis was done on a case-by-case basis by reviewing the champion concept for each of the selection criteria in order.

3.1 Operator Time Required

While all concepts considered for selection drastically reduce the amount of operator time required to complete the process of bobbin measurement, the Wheel concept was found to be the best in this area.

While all other concepts relied on human interaction to sort bobbins into their respective piles after measurement, this concept incorporates a method to automatically label ad sort bobbins into their respective categories. This advantage presents yet another built in benefit, while other concepts require the operator to wait for each bobbins resistance to be measured by its automated system before they are removed, in this system the operator need only insert each bobbin into the apparatus and this work can be done in parallel, reducing the overall time required even further.

3.2 Operator Skill Required

The Shear concept automatically splays wires out into individual positions so that they can be measured, a property it shares with the pinching tool concepts. The property which makes the shear the clear winner is the orientation of the bobbin when inserted into the measurement console. When the bobbin is received from the manufacturer, all eight wires held to the side of the bobbin with elastics. The wires are rigid, and when the elastic is removed, they remain close to the bobbins side. The Shear concept takes advantage of this property to use the residual position of each wire when sliding the wires into position to be shorn for measurement. The orientation of the bobbin in the final design will use its inherent position to benefit the system of probing each wire.

3.3 Labour Intensity

While all options considered reduce the intensity of the process of measurement, only the Shear and Console options involve only dropping the bobbin into the device and removing it after the process is complete. Each of the other options require precise hand-eye-coordination to be completed. The final design will make use of the simplicity of the Shear and Console options to keep labour intensity to a minimum.

3.4 Squib Matching

The single largest challenge in matching squibs to BFC's is the time required to find each bobbin for the next step in manufacture. Each of the four options have a labeling process which identifies individual bobbins for post processing, and all of these labeling processes represent a significant increase in efficiency when compared to the existing process. That said, the Wheel concept simply sorts failed and passed bobbins into bins. Options the remaining three concepts make use of a small increase in skill for the operator to sort bobbins, based on their label, into a labelled tray for future processing. This tray reduced the time taken to complete the integration process, a benefit which we believe will add to our client's satisfaction in the re-design.

3.5 Reliable Process

The Mag-mate option championed the criteria for reliability when compared to the existing process due to its innovative use of the Mag-mate connectors which are already proven in Magellan's rocket design. For clarification, Mag-mate connectors are disposable components which make the electrical connection between every wire within the rockets ignition system. Using these components in order to compete the measurement process is a truly innovative idea, and the reliability of the Mag-mate connection has already been proven in the current process.

3.6 Damage to Components

The only two concepts which passed this criteria reasonably were the Mag-mate and Console options due to the inherent stresses which other options impose on the bobbins structure. The Wheel and Shear concepts rely on stretching imposing tensile loads on the wire in order to probe each wire. These tensile loads may harm the bobbins fragile structure, making the bobbin platform vulnerable to breakage.

3.7 Accuracy of Resistance Measurements

Through the various testing don't by the team to verify that each method would provide adequate measurement, it was identified that each concept could consistently provide reliable resistance measurements.

3.8 Access to Recorded Data

All four concepts which underwent scoring proved to make use of a networked workstation to share quality assurance data.

3.9 Safe Process

While all proposed concepts achieved high safety scores, the Wheel concept is the clear winner since, by its very design, all components are hidden safely beneath the thick aluminum platform.

3.10 Life Cycle of Equipment

Each concept made unique allowances to achieve a long lasting life cycle. It was found that all of these ideas would be viable for use, as one, in our final concept. The use of commercially available, high grade, standard replacement parts which are easily accessed and easily calibrated in our final concept is a high priority.

3.11 Equipment Maintenance

The lowest maintenance idea was the Shear concept, making use of commercially available, high-strength tool steel. This material consideration will be adapted for use in our final concept.

3.12 Ergonomics

While all concepts significantly reduce the labour required to complete the process, only the Shear and Console measurement options prove to be ergonomic enough for use in our final design. The Wheel and Mag-mate concepts rely on tedious, high accuracy and repetitive finger motions which will result in operator discomfort when performed over a long period of time. The workstation will be orientated in a similar fashion these concepts as-well in our final concept to avoid posture related injuries.

3.13 Aesthetics

Victims to our own vanity, the team chose the Wheel concept as the most visually appealing. This is still a very subjective measurement, and it was decided that the appearance of the final concept will make use of a cover which can be tailored to meet the desired aesthetics of our client.

3.14 Ease of Access to Required Items

Surprising little detail about the accessibility of required items was included in each of the four concepts. While each of the concepts are suitable to be accessed equally, the Wheel concept incorporates every single tool into one completely packaged unit. For this reason, the team chose to combine as many components of each design into one, eliminating clutter, and making equipment easily accessed by the operator.

3.15 Human Error

The trade-off between ease of use and the number of steps which can result in an error is perhaps the most crucial to our design. The Wheel concept won over all others in this area due to its use of only a single step which the operator is required to perform. This step, however, is one of the most complex of any of the considered concepts. Nevertheless, the team will attempt to mitigate human error by incorporating redundancies in the electronic components which check for commonly made mistakes.

3.16 Environmental Concerns

All components of each design are recyclable and in the case of damaged components, easily repaired. This meets perfectly with the team's ethical commitment to the environment.

3.17 Standard Parts

Again, the use of tool steel identifies the Shear concept as the clear decision when considering longevity and reliability of the measurement instrument. Tool steel is a widely manufactured material of precise dimensional tolerance. Its use in our design will assure that replacement parts are available in perpetuity and that the calibration of any of our mechanisms for measuring resistances can be performed with as few steps and time as possible after replacement of the tool.

4 FINAL SPECIFICATION DEFINITION

After many iterative steps in the conceptual design phase, the final concept could be created. At a very basic level, the final concept involves the following steps:

1. The operator obtains a single bobbin from the supplier bag.
2. The operator inserts the bobbin into the fixture with the connector end facing upwards.
3. The fixture guides the paired wires to four test probe locations
4. The operator activates a sequence that brings the test probes into contact with each pair of wires without the need for prior wire stripping.
5. The fixture signals a digital logic process to control the following steps, in order:
    a. A multimeter device checks every combination of pairs of test probes for continuity
    b. Resistance values of all wires are measured and recorded by the multimeter device.
    c. The digital logic process verifies the placement of the high and low resistance wires based on steps a and b.
    d. The digital logic process repeats steps a, b, and c, checking for discrepancies in results from trials.
6. If there are discrepancies, or if any resistance values fall outside of the accepted range, the bobbin is flagged as a rejected part on the tracking label, and placed in a bin for rejects.
7. If there are no discrepancies, the computer program pairs the bobbin to an appropriate squib tracking number, and the operator applies the label with number onto the bobbin.
8. The digital logic process program signals the operator to place the bobbin in a specified spot on the tray.
9. Steps 1 through 8 are repeated for subsequent bobbins

To perform the aforementioned steps, several pieces of equipment must be used. These are a fixture with built-in tooling for electrically probing the bobbin wires, a measurement device capable of RS 232 communication, a personal computer, labelling machine, and a tray divided into grid-like compartments to hold individual bobbins. Fig. 20-22 are renderings showing how the final design may look, based on the final conceptual design developed in this report.

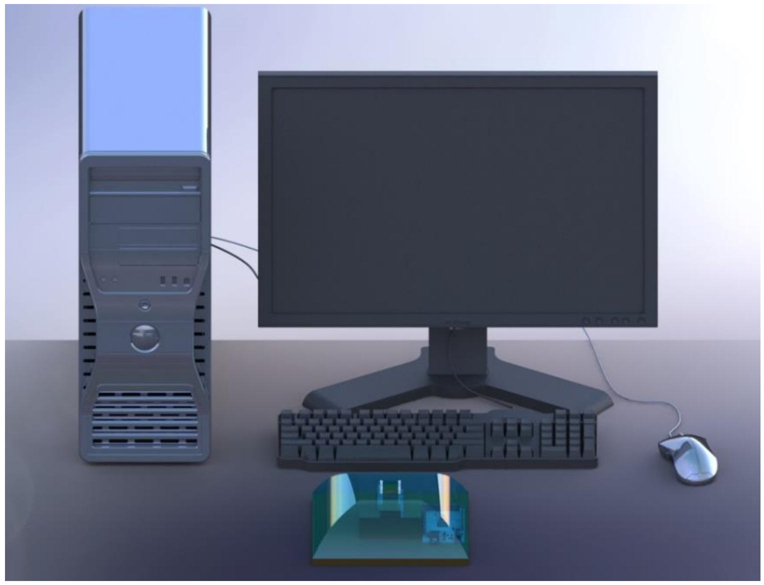


Figure 19: Proposed conceptual equipment for BFC resistance measurement process [18], [19], [20], [21].

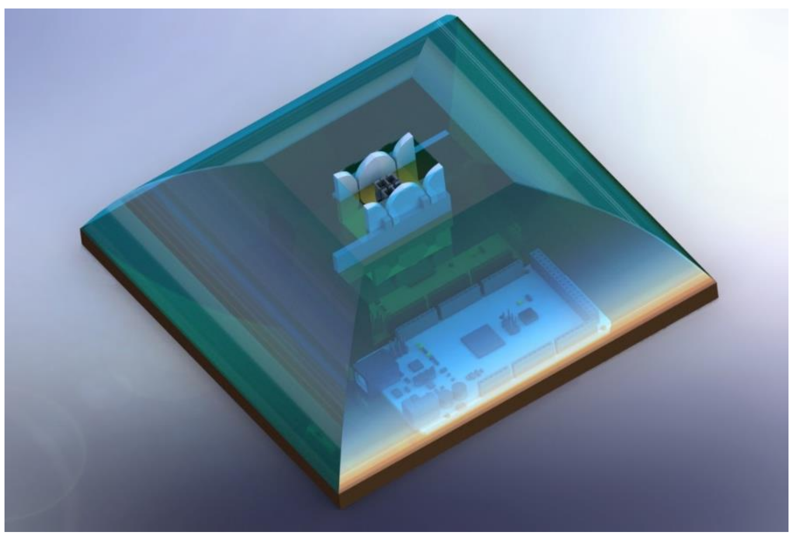


Figure 20: Proposed concept fixture [18], [19], [20], [22].

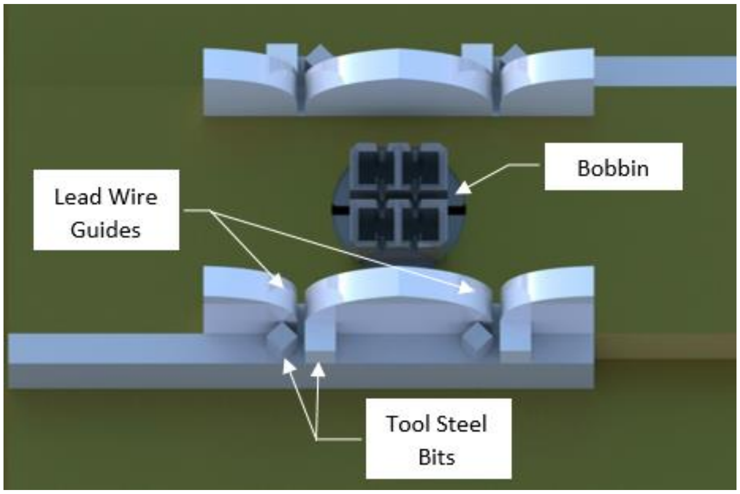


Figure 21: Fixture detail with bobbin holder in middle, wire guides direct wires to pinch and probe mechanism [18], [19], [20], [23].

The fixture serves several purposes in the process, the first is to position and hold the bobbin in an easily repeatable position. This is performed by a vertical post in which the bobbin is slipped over. Rotation of the bobbin is prevented by splines on the post which match those present on the bobbin. Second, the fixture uses mechanical fitment to ensure that the bobbin is not damaged (e.g. Lower base squished into oval shape by damage during transport from supplier). Third, the fixture guides the four sets of paired wires (coming out of the grooves at the top of the bobbin) outwards away from the bobbin body. This is performed by having the paired wires follow four curved troughs that extend outwards away from the bobbin as the bobbin is slipped over the post. The fourth function of the fixture is to connect both wires in each pair to a test lead hooked up to the measurement device. This is performed by having the wires laying flat on a fixed lower die made out of a high speed steel tool bit. The top die is a second high speed steel tool bit which is then precisely lowered, pinching the wires between the 90 degree angle edge of the top die and the flat surface of the bottom die. A mechanical stop between the dies ensures that only the wire insulation is cut through. The fixed lower die is electrically connected to the measurement device. Once measurement is complete, the bobbin is automatically released from the fixture.

The measurement device serves as a sensor, outputting data to the computer for processing and storage. The device has a channel for each one of the four test leads, and communicates with the computer using a RS 232 cable. This piece of equipment will be an off-the-shelf part with the appropriate accuracy and settling time specifications.

The third piece of required equipment for this concept is a personal computer. A Windows operating system, keyboard, mouse, connection to the client's network connection and RS-232 serial port are the only requirements.

For labelling the bobbins with tracking numbers after resistance measurement is complete, there are two concept options. The first is to use or adapt a commercially available automatic adhesive backed label dispenser that works off of sliding contact between the roll of labels and the bobbin. The second option is to use a commercially available inkjet printer capable of printing a tracking number generated by the computer directly onto the bobbin.

The final piece of required equipment is a tray to hold and organize the bobbins after measurement. The tray has a multitude of walled off compartments that hold the bobbins individually. The bobbins are to be placed into the compartments connection side down, causing the loose wires to be pushed back against the bobbin body. For easy bobbin removal, the tray has a hinged lid on the top and bottom, allowing a full tray to be flipped over for bobbins to be pulled out connection side first.

Having gone through an extensive and methodical conceptual design phase, the team is confident that this final concept will lay a solid foundation for starting the upcoming design phase of the project.

5 REFERENCES

[1] Bristol Aerospace Limited, "*Specification For Product Requirements And Manufacturing Processes For Matched Attenuator Conductor 606-11703."* Winnipeg, MB: Bristol Aerospace Limited, 1986.

[2] Bristol Aerospace Limited, "*Specification For Requirements And Manufacturing Process For Attenuator Conductor Cable 609-69040-1."* Winnipeg, MB: Bristol Aerospace Limited, 1994.

[3] Wire Stripping Arrangement, by R. Flot, R. Lionnet, J. Hine. (1987, Sept. 8). *CA 1226422* [Online]. Available: http://brevets-patents.ic.gc.ca/opic-cipo/cpd/eng/patent/1226422/

summary.html?query=wire+stripping&start=1&num=50&type=basic_search [Oct. 16, 2013].

[4] Wire Stripping Arrangement, by R. Flot, R. Lionnet, J. Hine. (1987, Sept. 8). *CA 1226422* [PDF]. Available: http://brevets-patents.ic.gc.ca/opic-cipo/cpd/eng/patent/1226422/page/

1226422_19930803_drawings.pdf [Oct. 16, 2013].

[5] Wire Stripping Tool, by R. Goodrich, R. O'Connor, C. Krumreich. (1986, April 8). *CA 1202767* [Online]. Available: http://brevets-patents.ic.gc.ca/opic-cipo/cpd/eng/patent/1202767/

summary.html?query=1202767&start=1&num=50&type=basic_search [Oct. 20, 2013].

[6] HD_558_L. [Image]. Available: http://www.uline.ca/images/product/Large/HD_558_L.jpg [Oct. 12, 2013].

[7] EBS Ink-Jet Systeme. "*EBS-230"* [Online]. Available: http://www.resservices.ca/EBS-230.pdf [Oct. 19, 2013].

[8] Digital Design Inc. "*Evolution II Ink Jet Printer Series"* [Online]. Available: http://www.sunpkg.com/SunPac_Website/PDF/ev2.pdf [Oct. 19, 2013].

[9] DDWeb-EV-Jewel-Case2-500x500. [Image]. Available:

http://packaging-tools.com/pt/image/cache/data/DDWeb-EV-Jewel-Case2-500x500.jpg [Oct. 12, 2013].

[10] Arizona Machinery. (2013). *Epson Scara LS* [Online]. Available:

http://www.arizonam.com/en/scara_robot_ls.php [Oct 24, 2013].

[11] G. Buist. "Concept Classification Trees." Winnipeg: Design ENG. Univ Manitoba, Winnipeg, MB, 2013, Oct. 23.

[12] G. Buist. "concept combination table." Winnipeg: Design ENG. Univ Manitoba, Winnipeg, MB, 2013, Oct. 23.

[13] G. Buist. "concept combination table with arrows." Winnipeg: Design ENG. Univ Manitoba, Winnipeg, MB, 2013, Oct. 23.

[14] Eraser. (2012). *PD2S handheld wire stripper* [Online]. Available: http://www.eraser.com/products/wire-cable-strippers-product/wheel-strippers/pd2s-hand-held-wire-stripper/ [Oct 24, 2013].

[15] Effective Barcode Solutions. (2010). *Towa APN hand-held label applicators* [Online]. Available: http://www.ers-online.co.uk/p2555/towa-apn-hand-held-label-applicators [Oct 24, 2013].

[16] 38274_3000AT. [Image]. Available: http://www.toolstop.co.uk/components/com_virtuemart/shop_image/product/38274_3000AT.jpg [Oct. 18, 2013].

[17] C. Hnatiuk. "Tool Bit Concept Drawing." Winnipeg: Design ENG. Univ Manitoba, Winnipeg, MB, 2013, Oct. 21.

[18] C. Matthews. "Bobbin Solid Model" Winnipeg: Design Eng.,Univ Manitoba, Winnipeg, MB, Oct 16, 2013.

[19] F. Rezende. (2013, Aug 15). Cadgrab.com [Online]. Available: http://grabcad.com/library/dell-precision [Oct 24, 2013].

[20] A. Aelevoutharo. (2012, Nov 17). Dl today [Online]. Available: http://grabcad.com/library/arduino-mega-2560--1 [Oct 25,2013].

[21] J. Nixon. "Final Concept Assembly 1" Winnipeg: Design Eng.,Univ Manitoba, Winnipeg, MB, Oct 20, 2013.

[22] J. Nixon. "Final Concept Assembly 2" Winnipeg: Design Eng.,Univ Manitoba, Winnipeg, MB, Oct 20, 2013.

[23] J. Nixon. "Final Concept Assembly 3" Winnipeg: Design Eng.,Univ Manitoba, Winnipeg, MB, Oct 20, 2013.

Appendix C: Manufacturing Drawings

LIST OF FIGURES

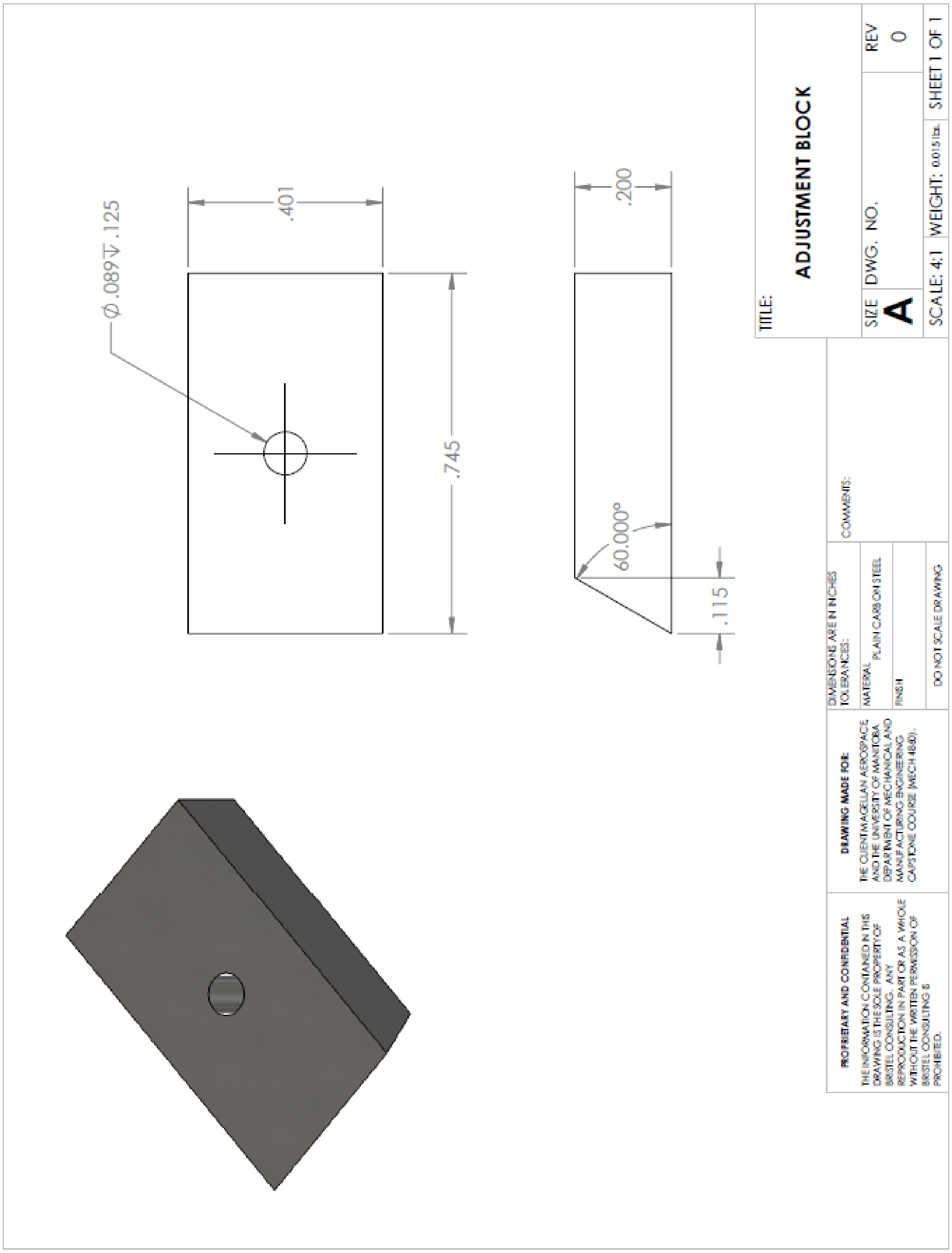


Figure 1: Adjustment Block

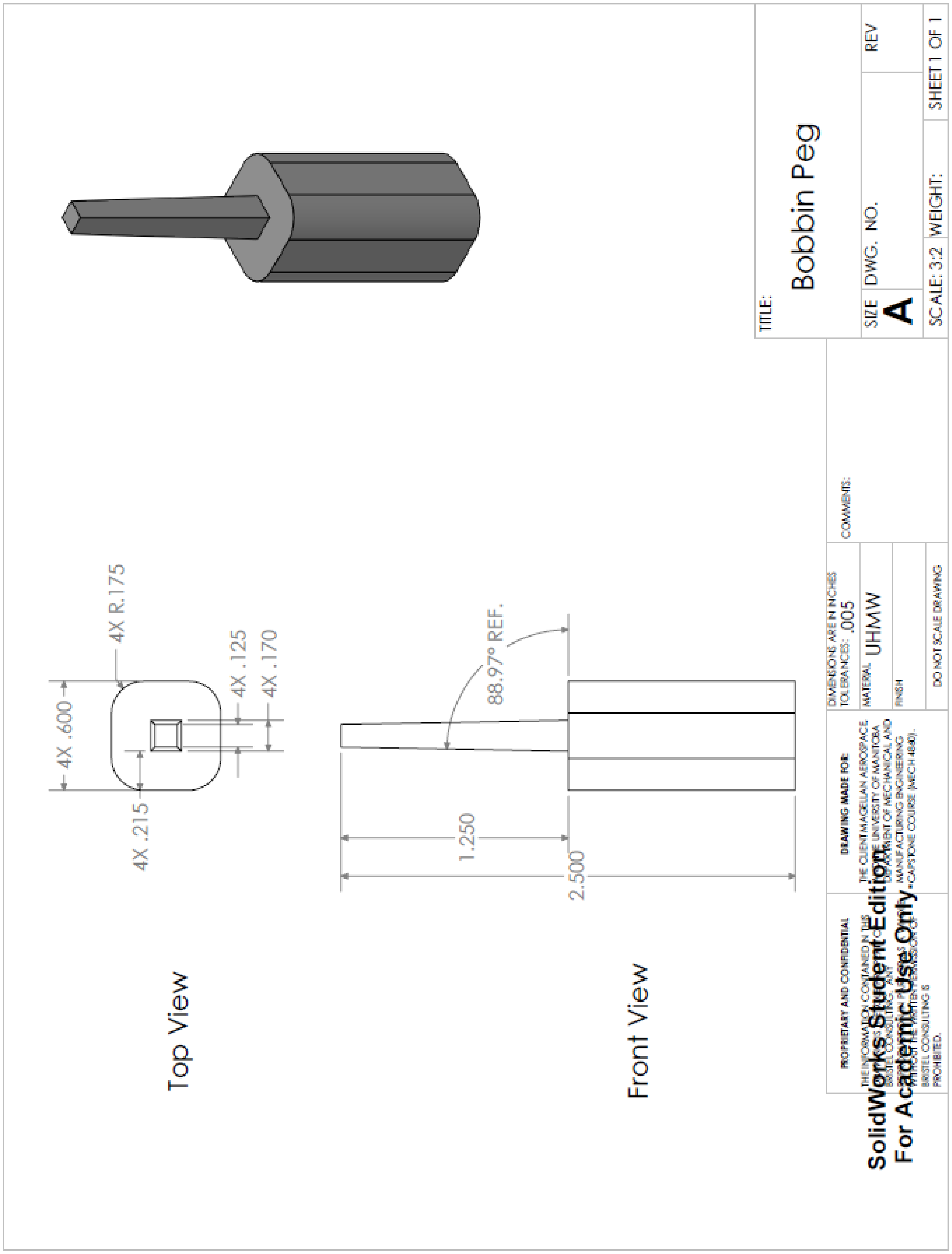


Figure 2: Bobbin Peg

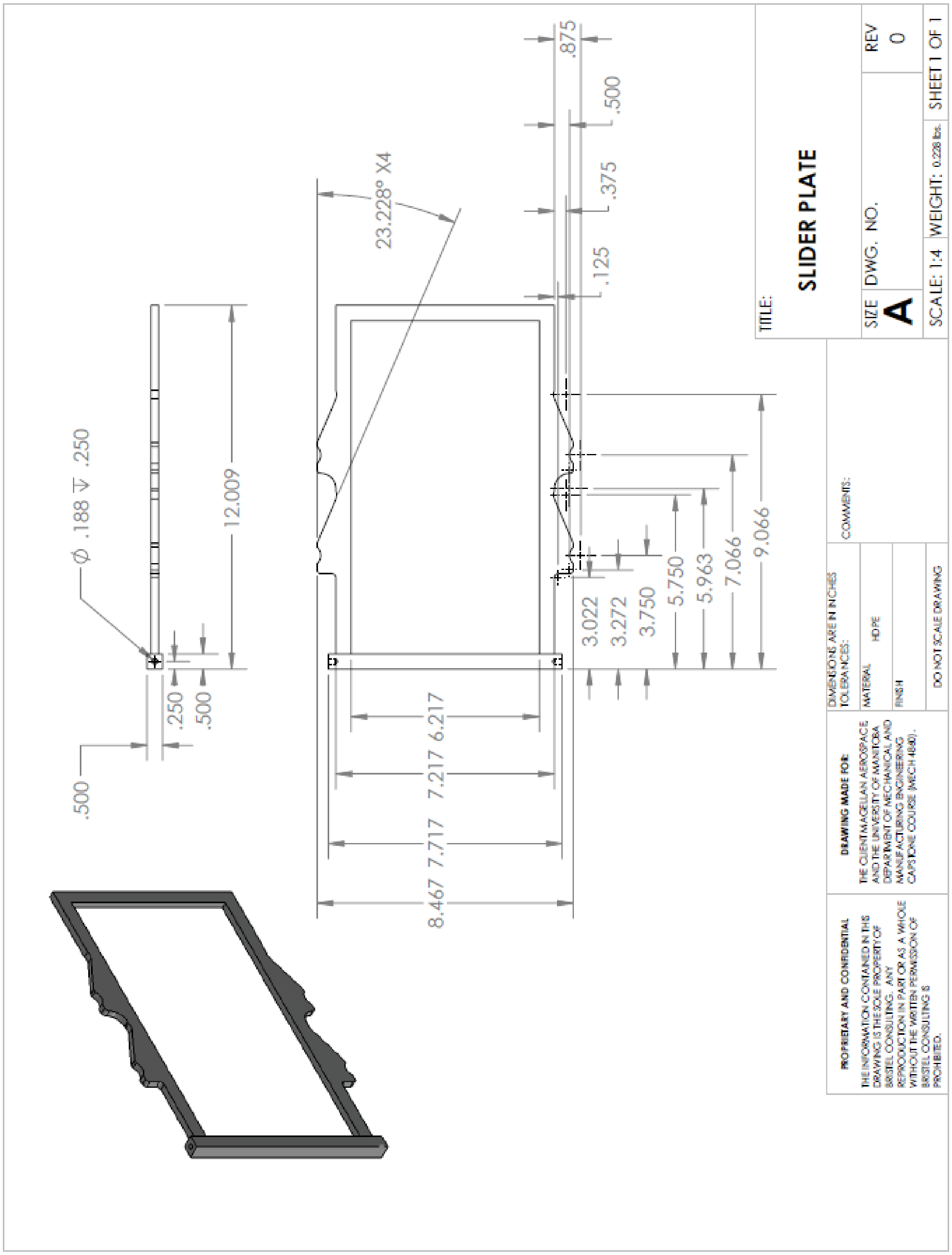


Figure 3: Slider Plate

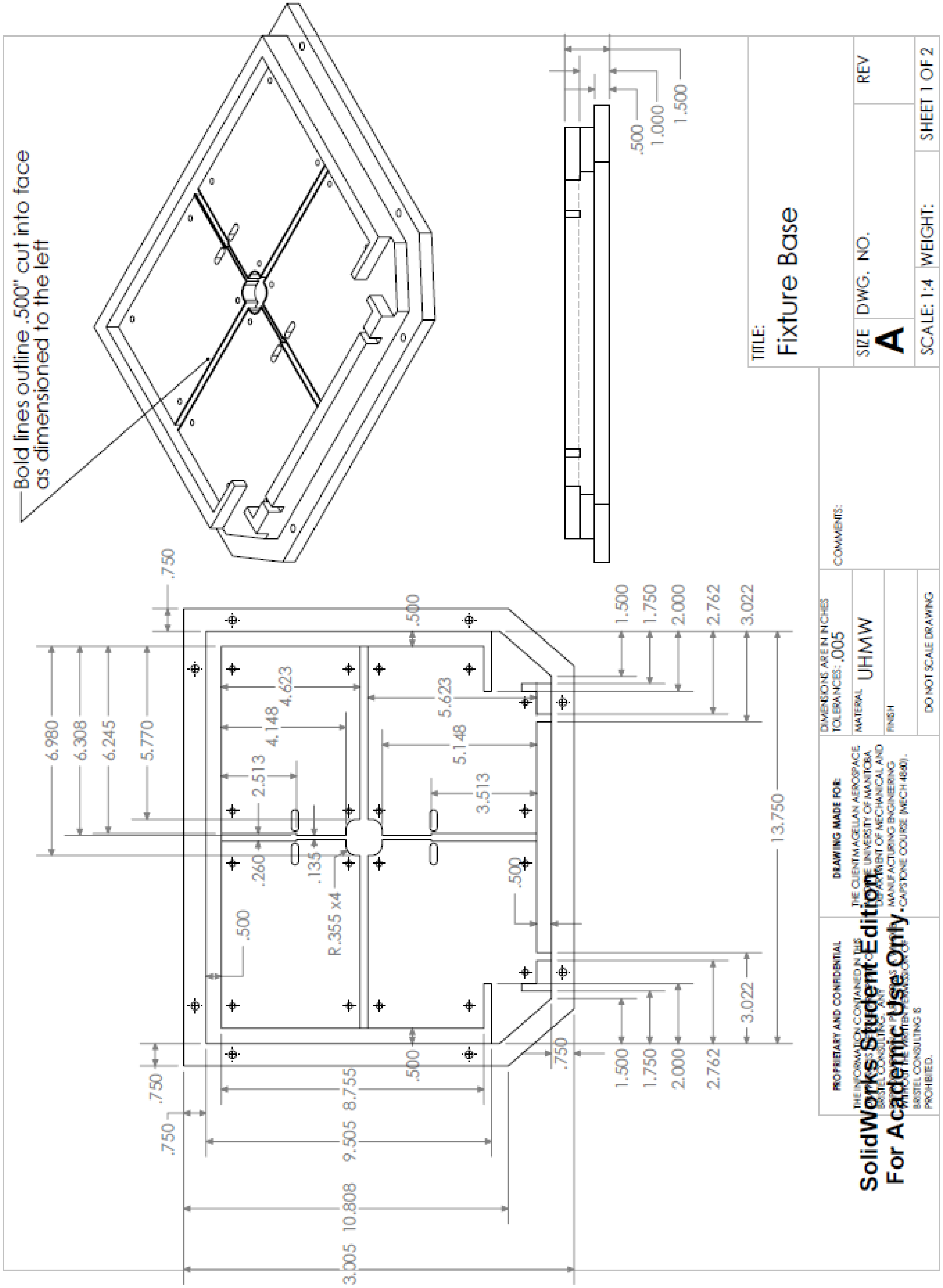


Figure 4: Fixture Base (page 1 of 2)

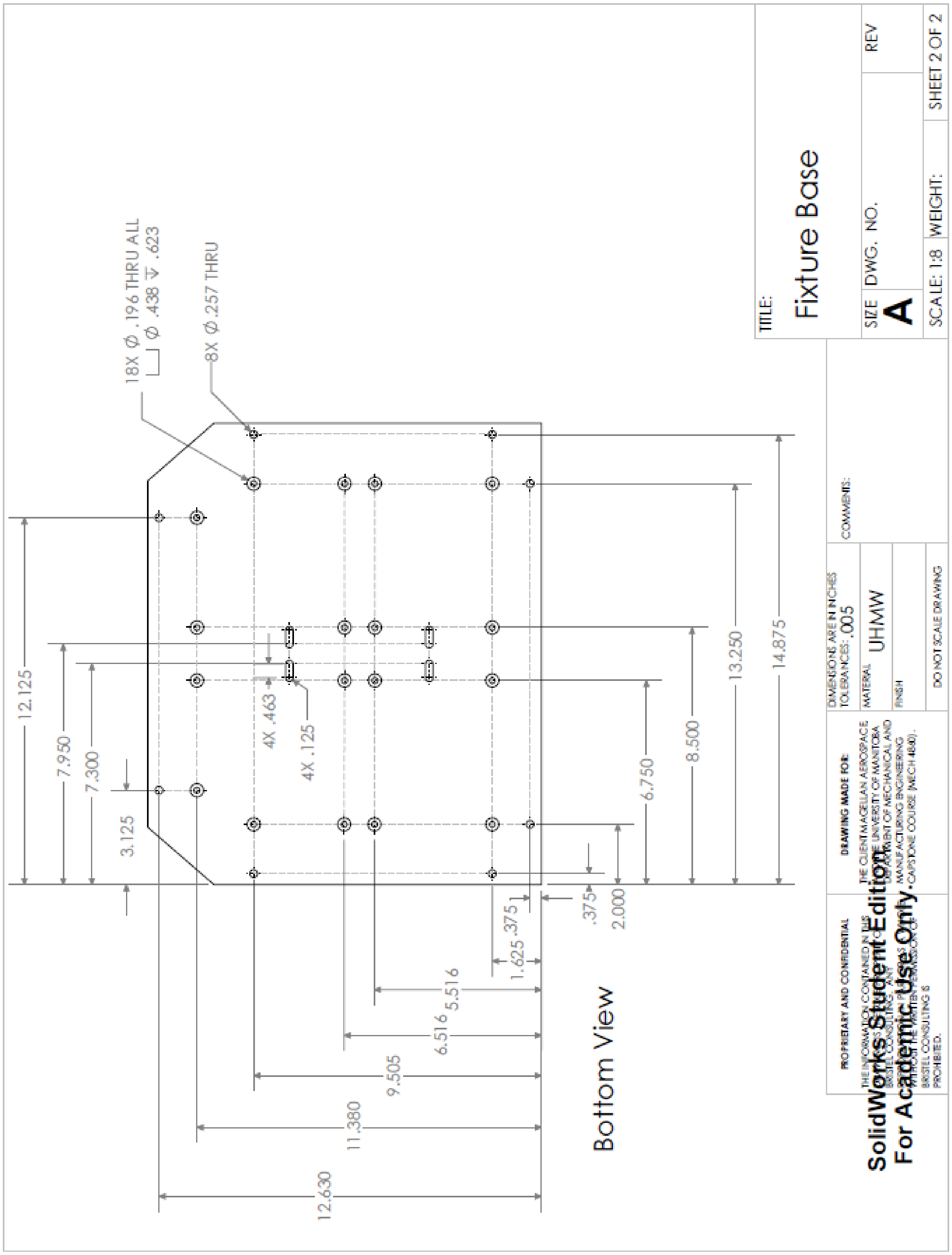


Figure 5: Fixture Base (page 2 of 2)

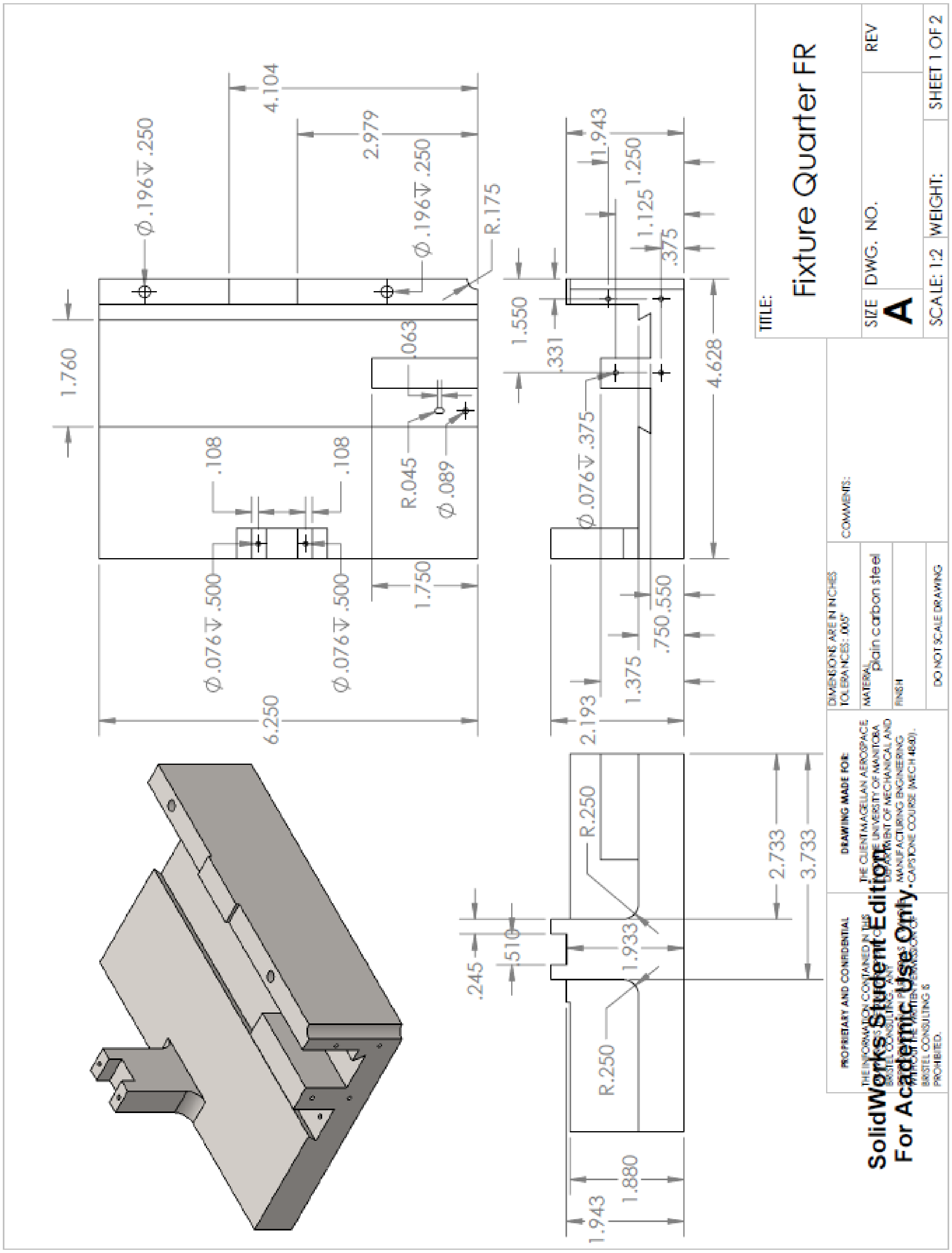


Figure 6: Fixture Quarter FR (page 1 of 2)

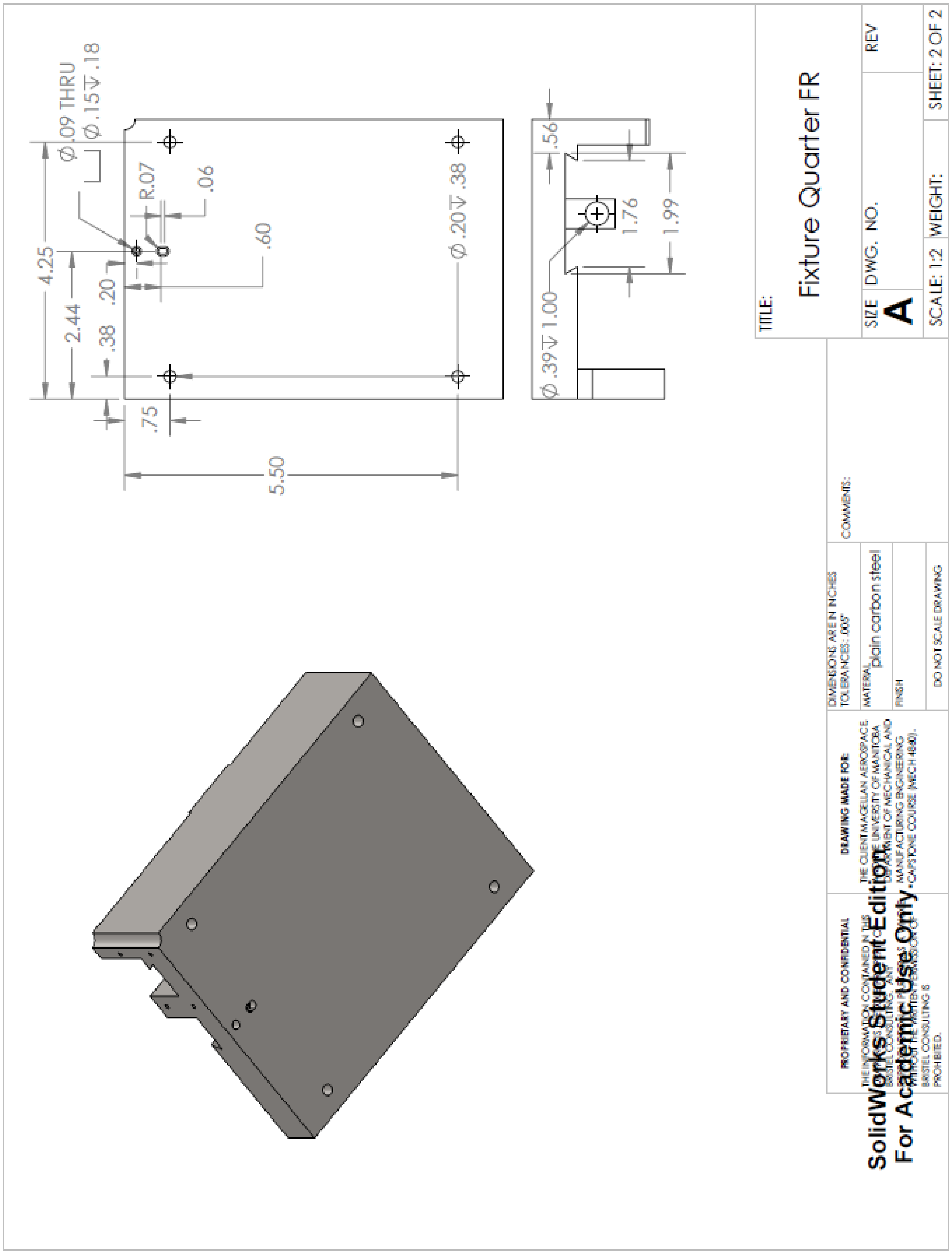


Figure 7: Fixture Quarter FR (page 2 of 2)

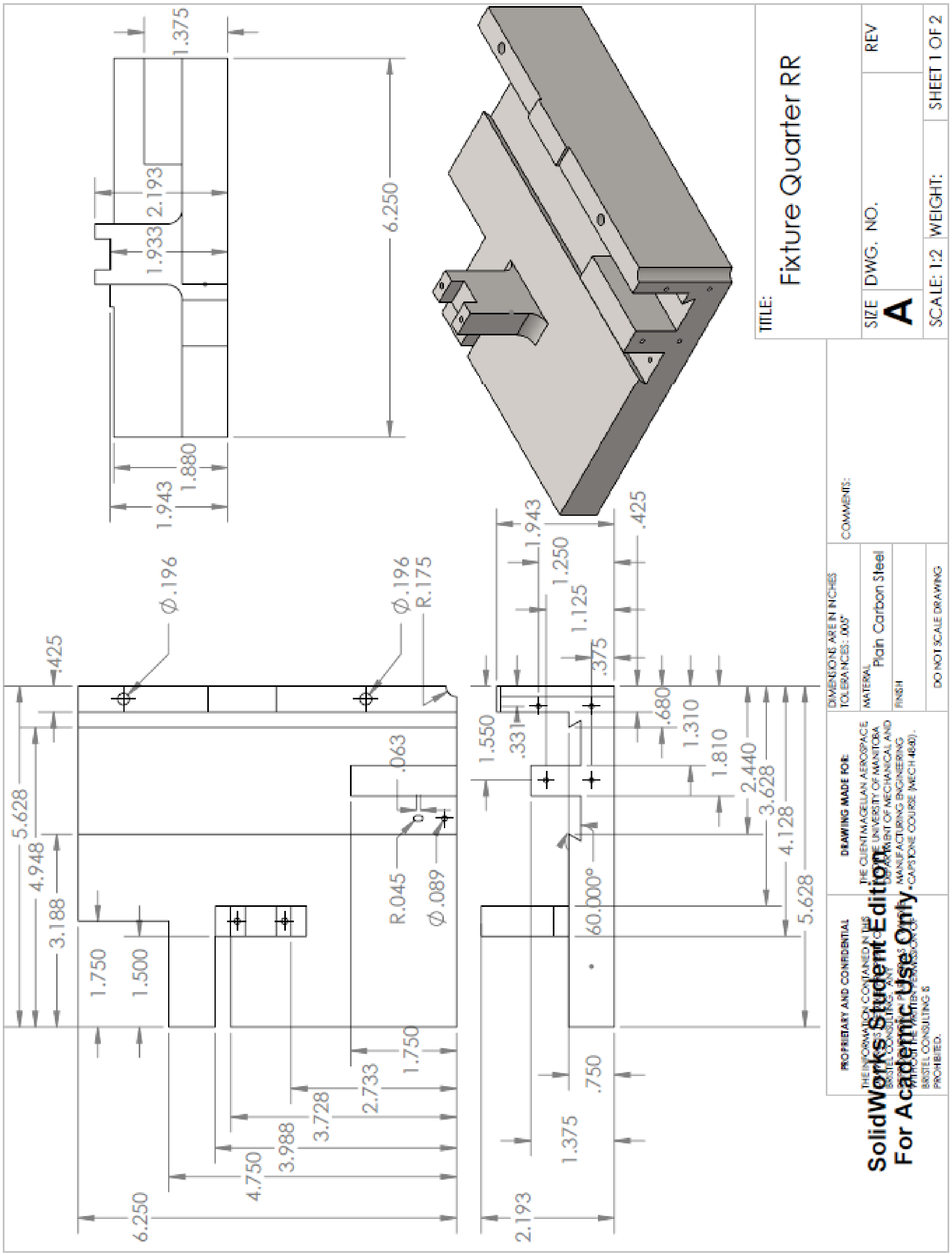


Figure 8: Fixture Quarter RR (page 1 of 2)

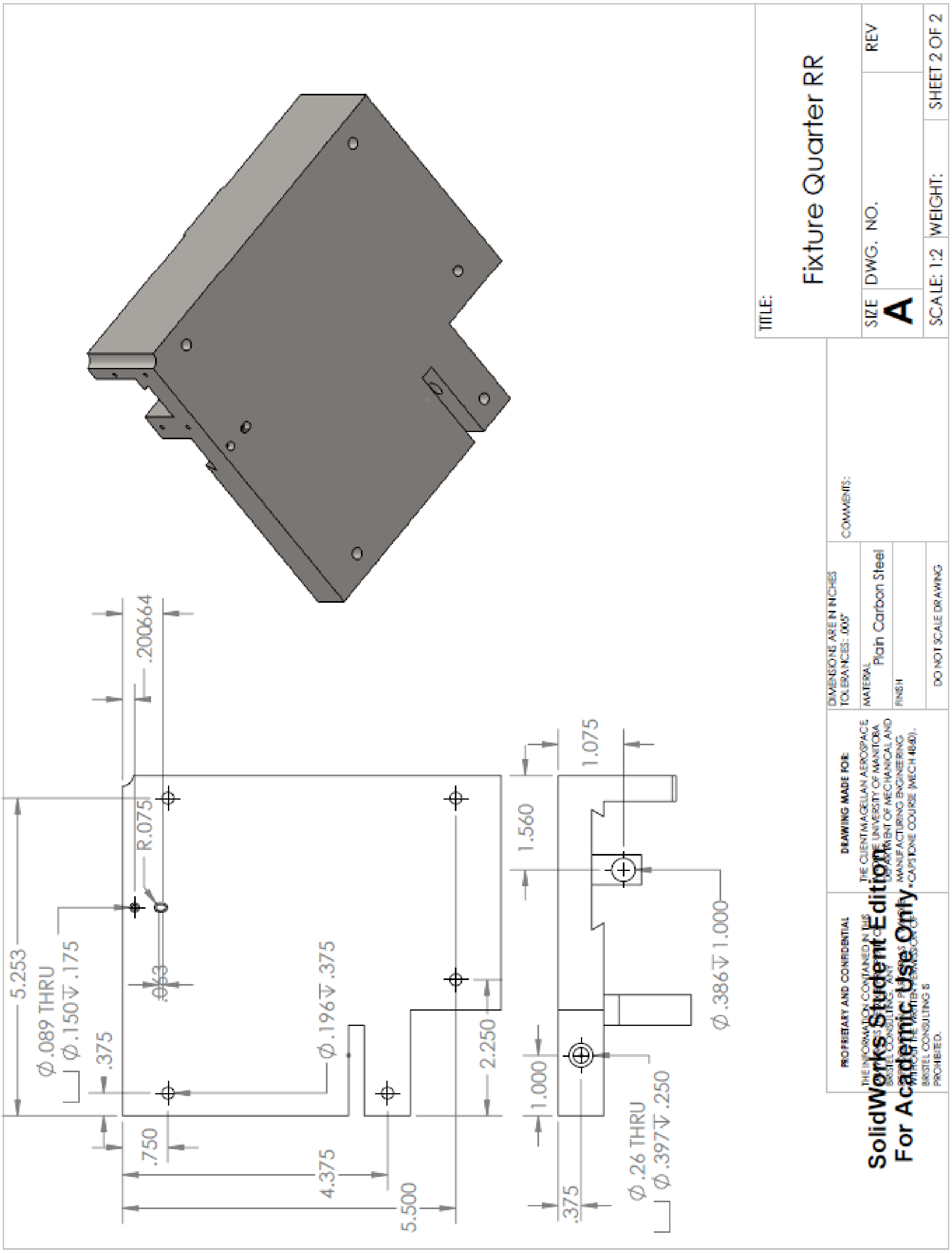


Figure 9: Fixture Quarter RR (page 2 of 2)

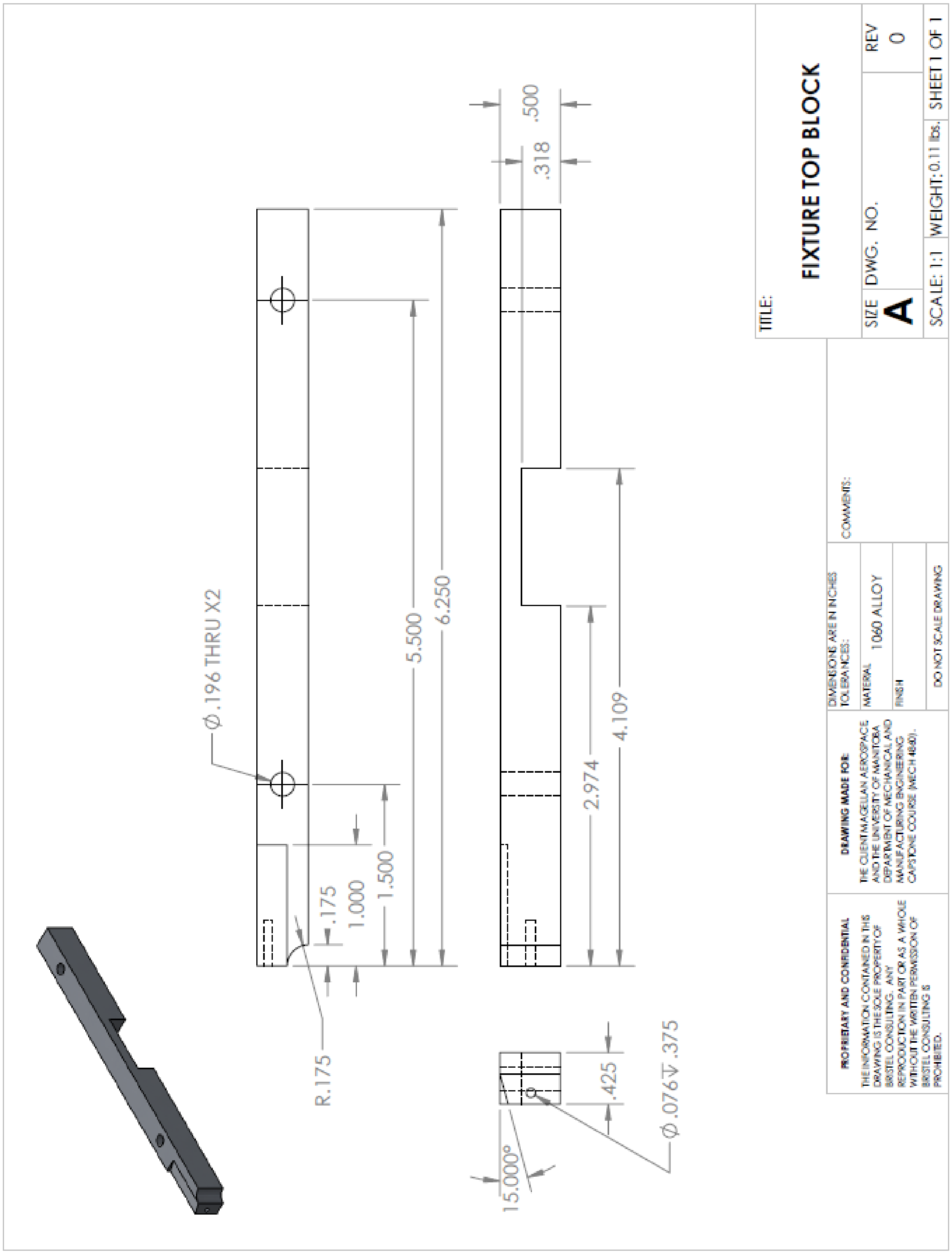


Figure 10: Fixture Top Block

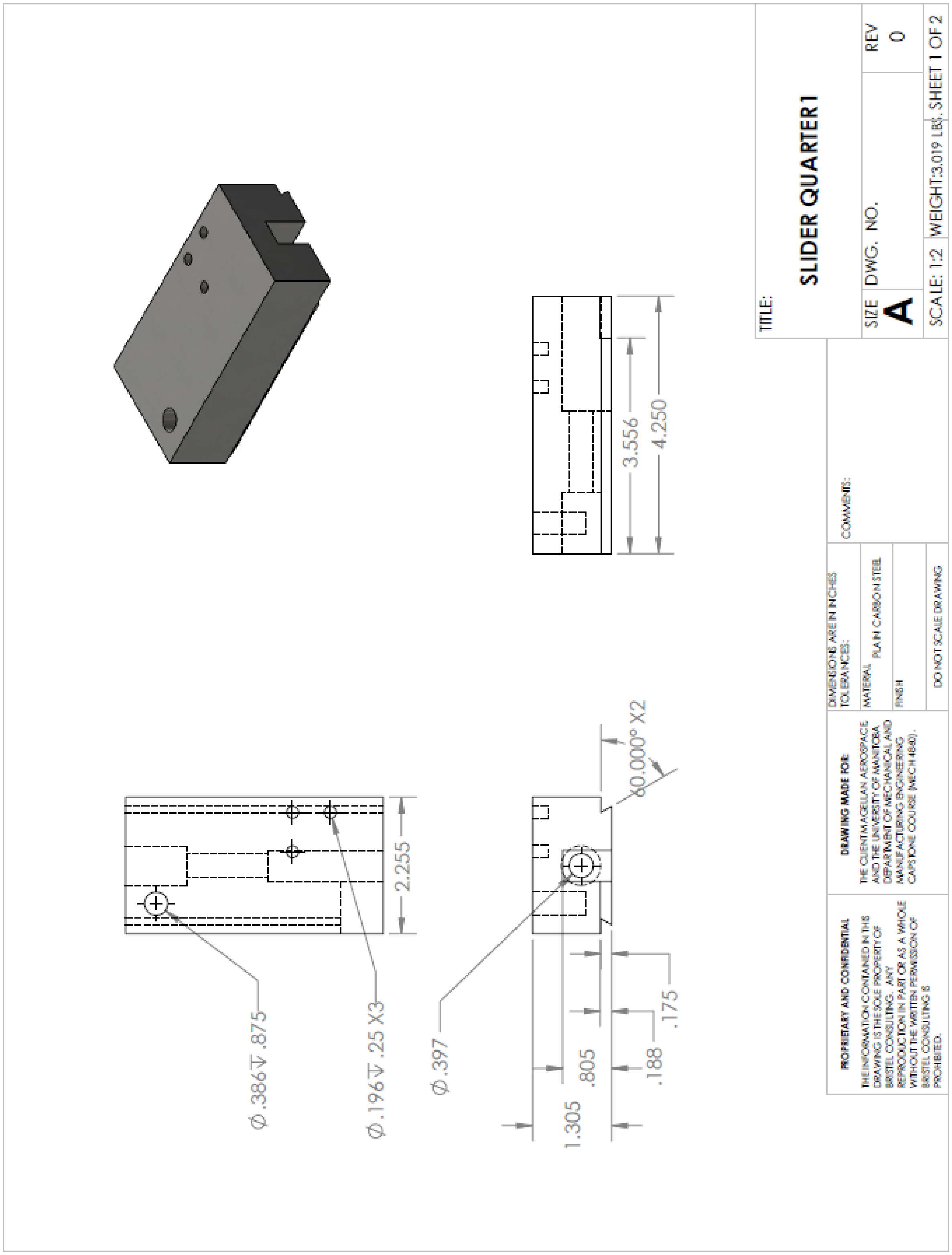


Figure 11: Slider Quarter 1 (Page 1 of 2)

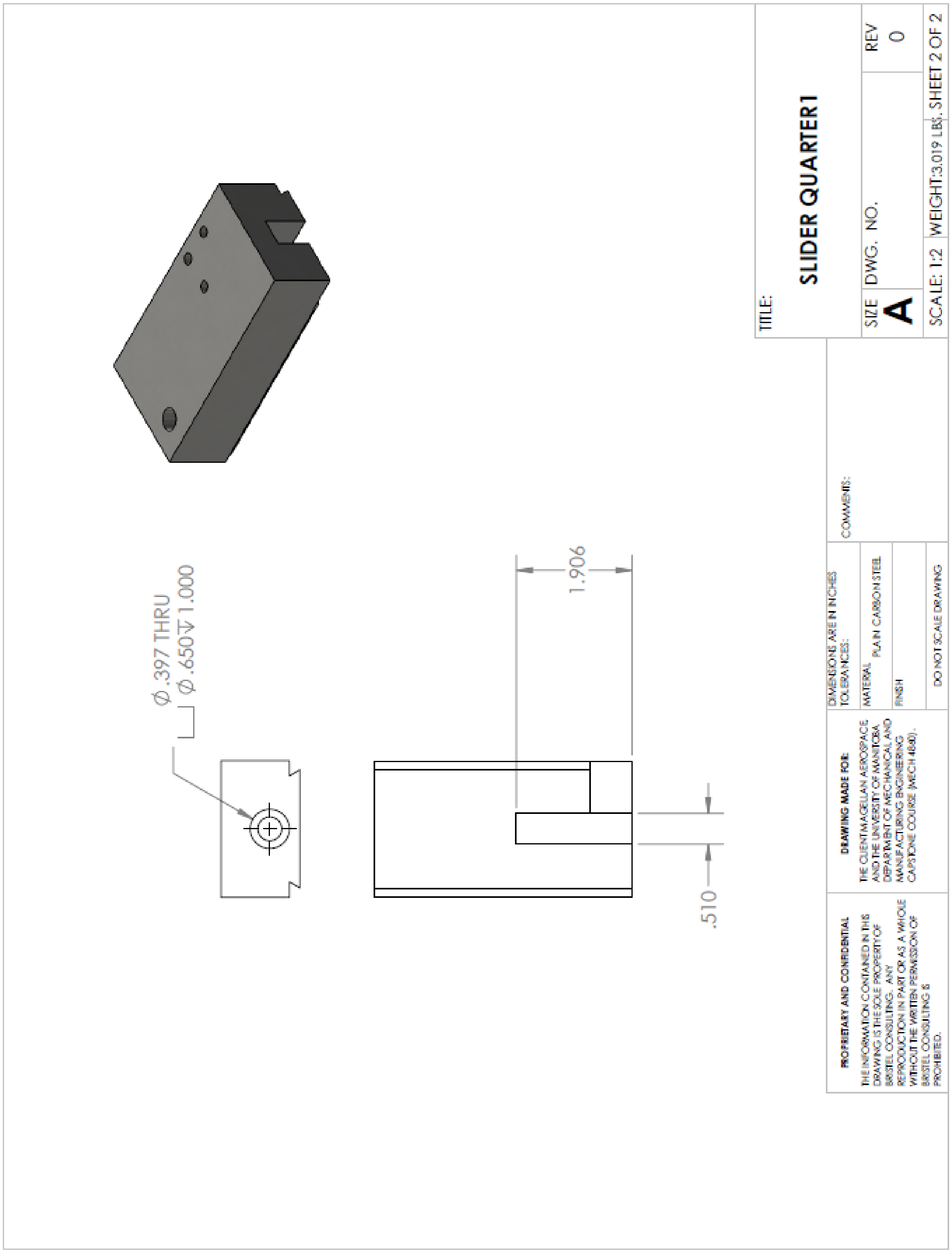


Figure 12: Slider Quarter 1 (Page 2 of 2)

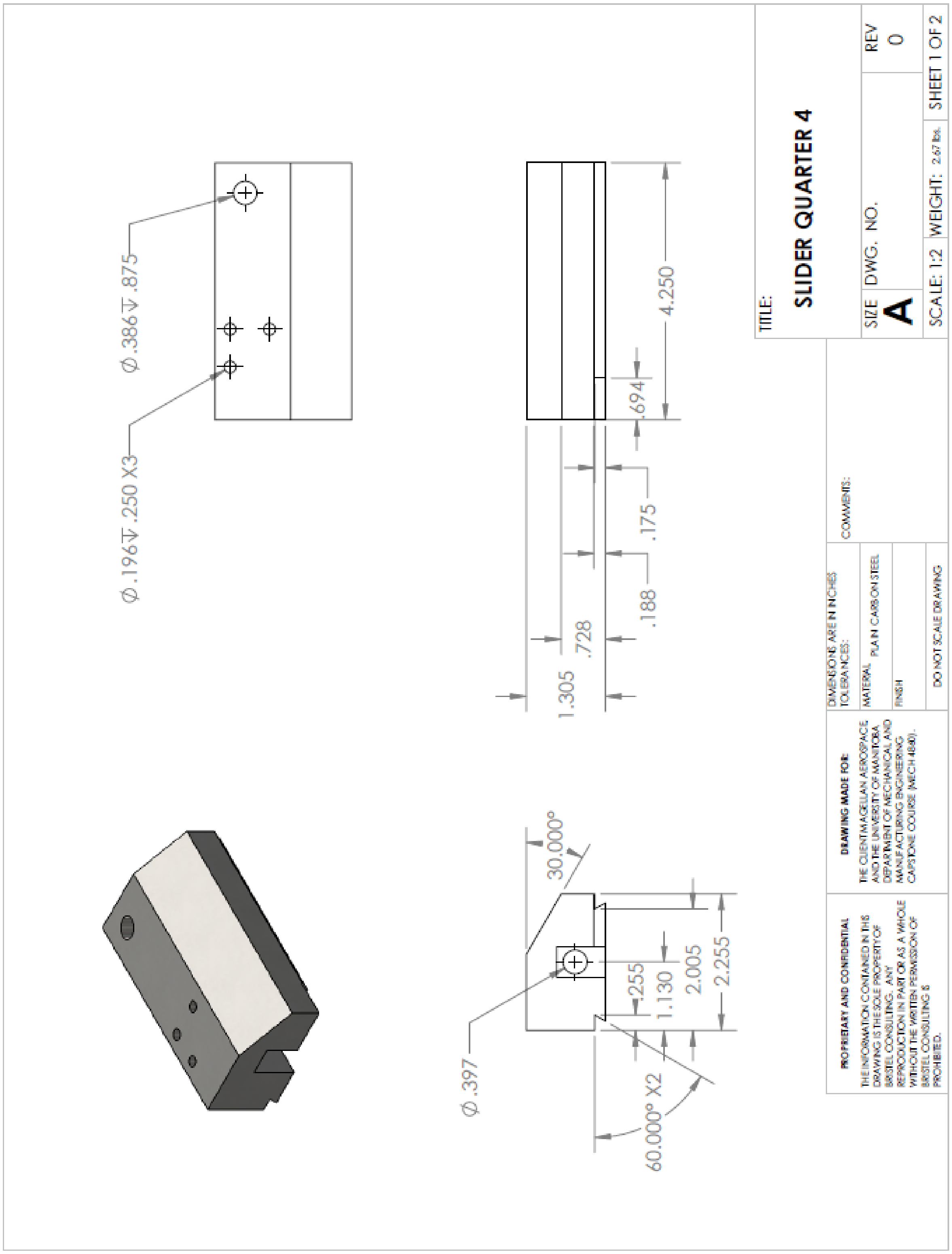


Figure 13: Slider Quarter 4 (Page 1 of 2)

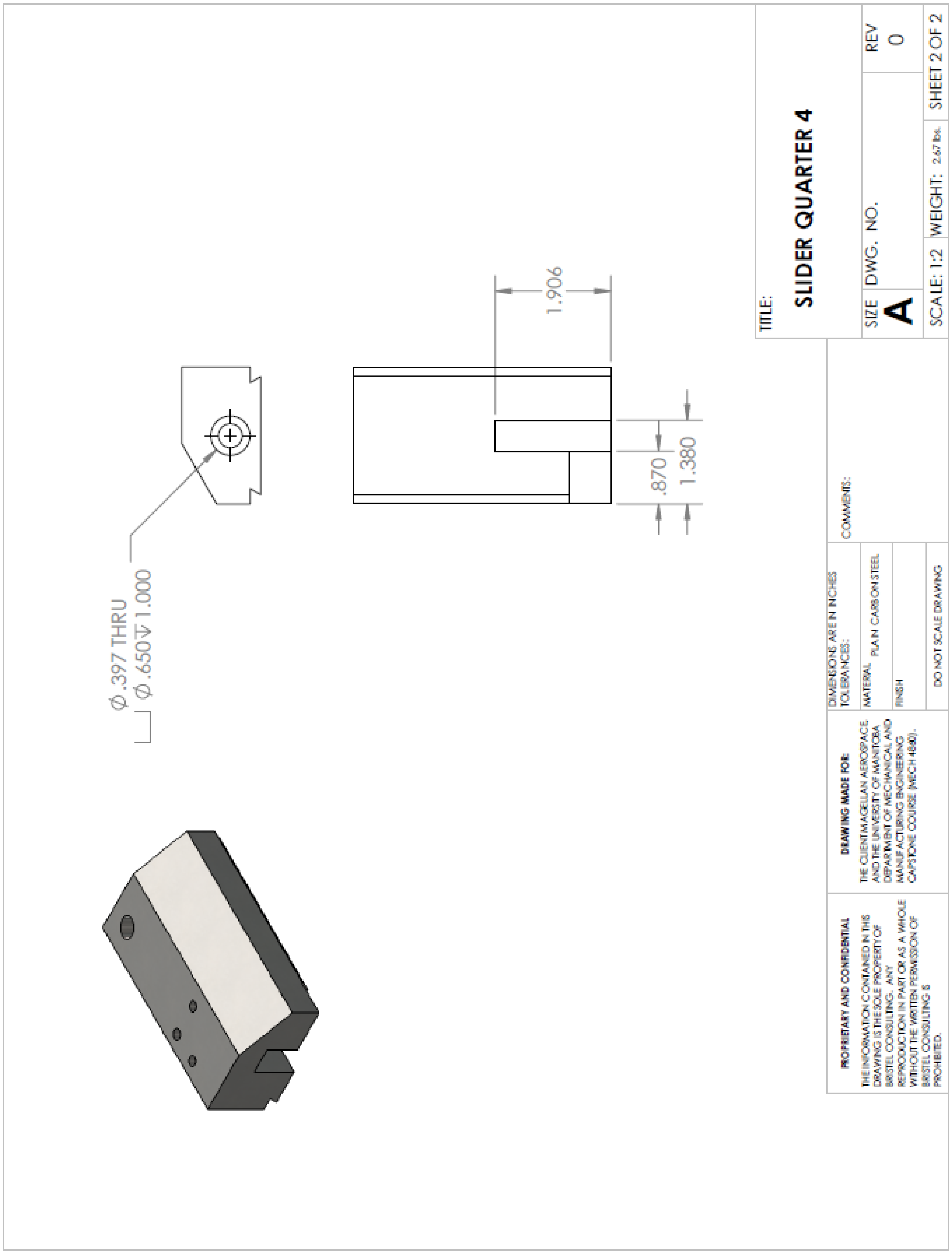


Figure 14: Slider Quarter 4 (Page 2 of 2)

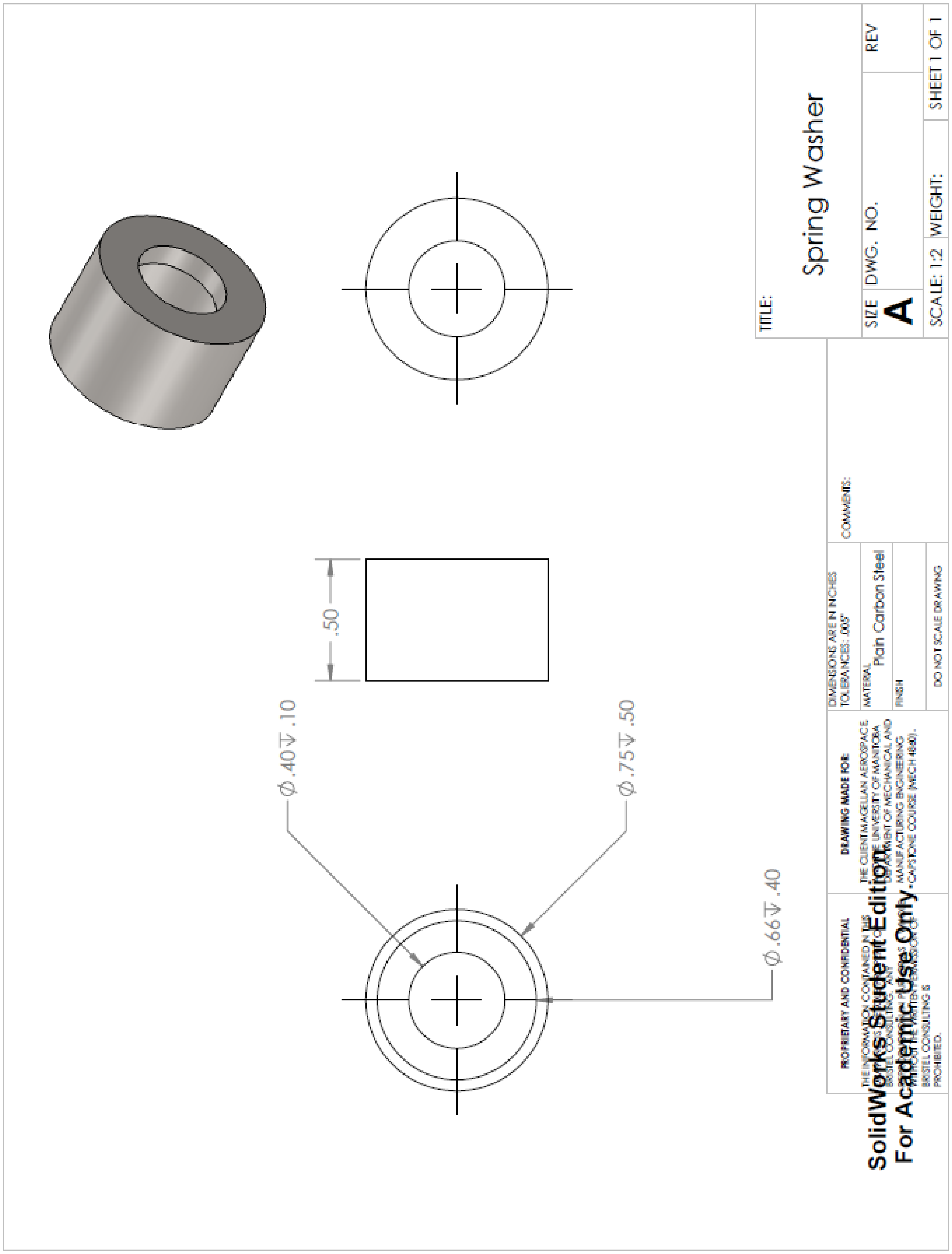


Figure 15: Spring Washer

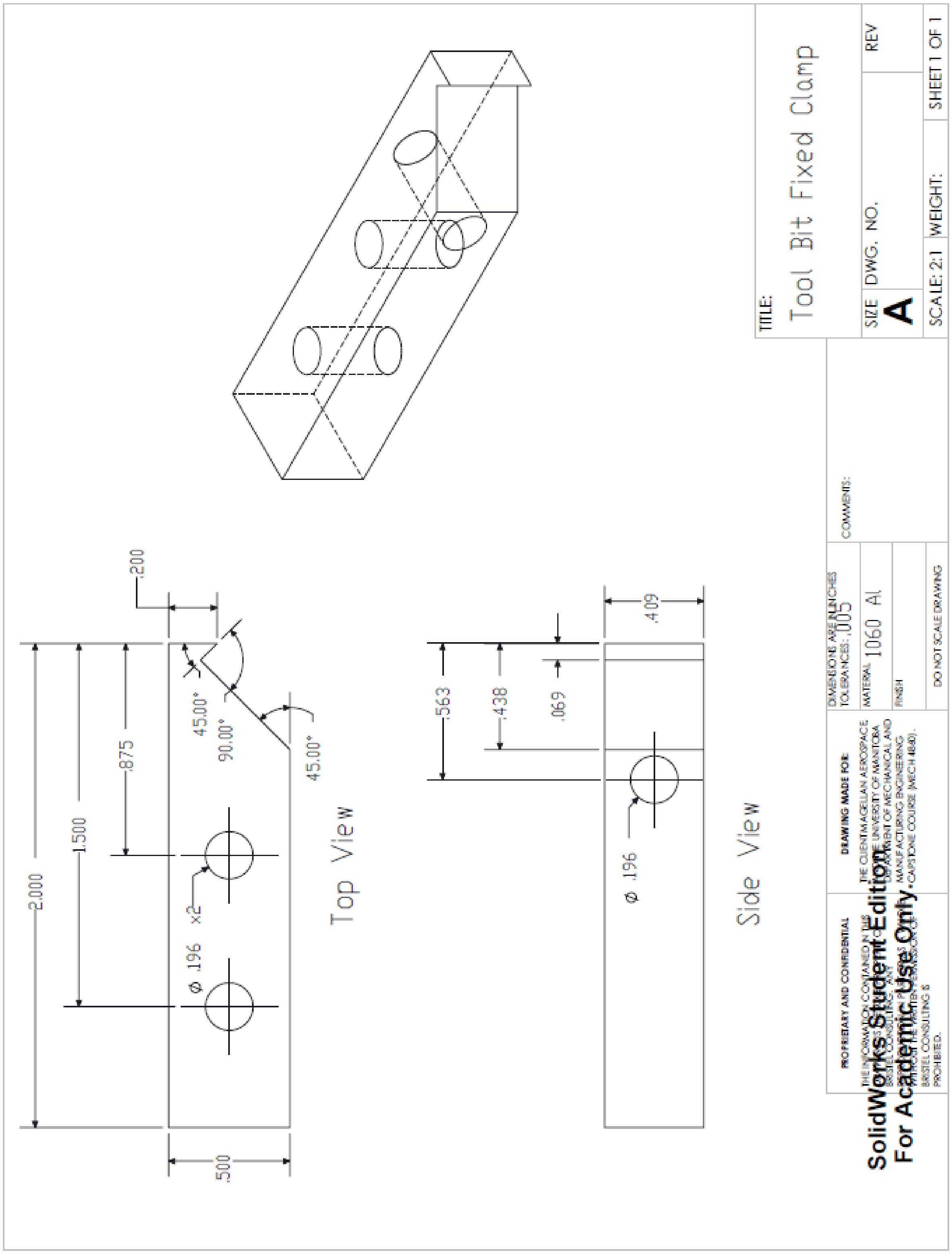


Figure 16: Tool Bit Fixed Clamp

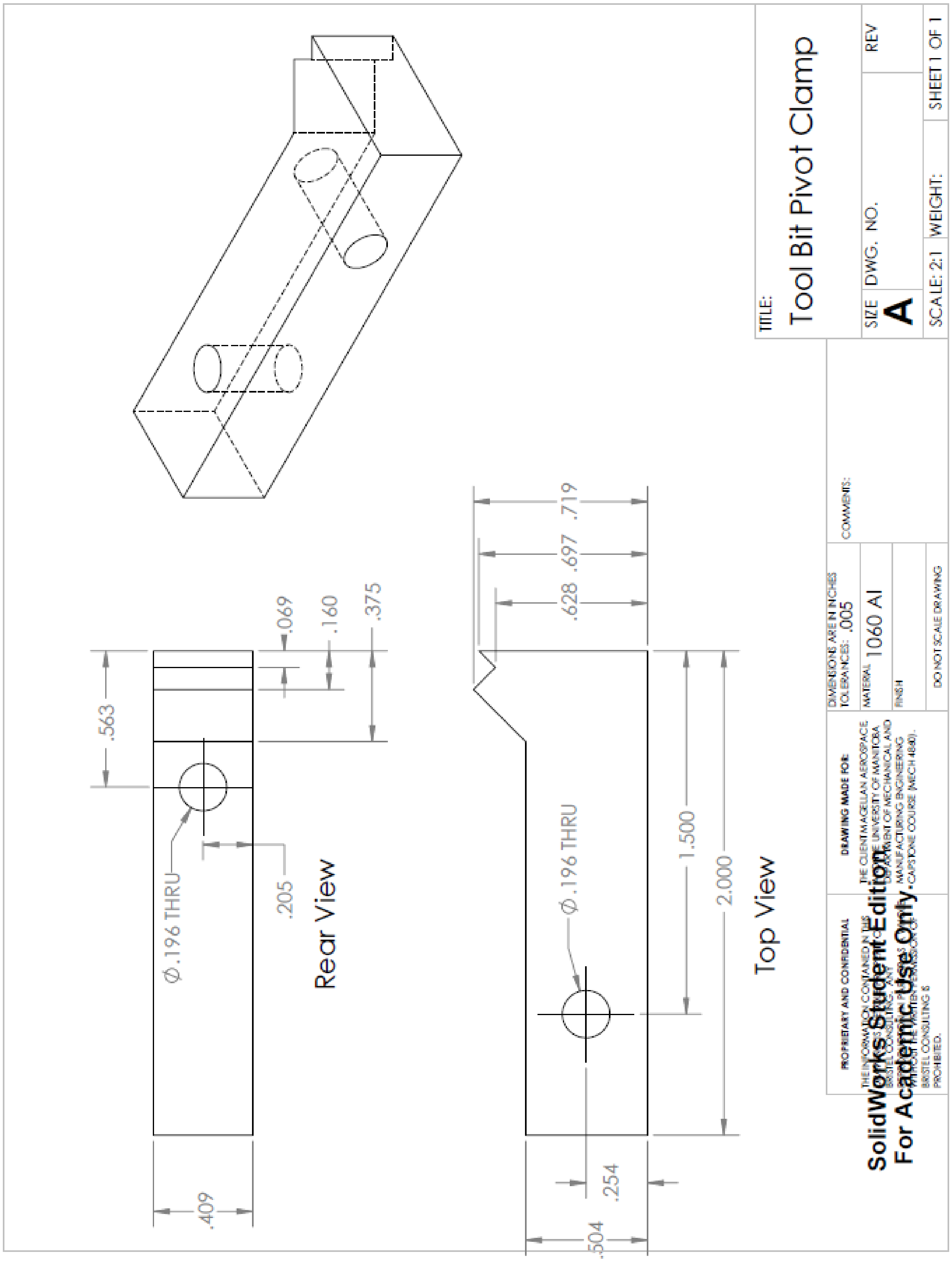


Figure 17: Tool Bit Pivot Clamp

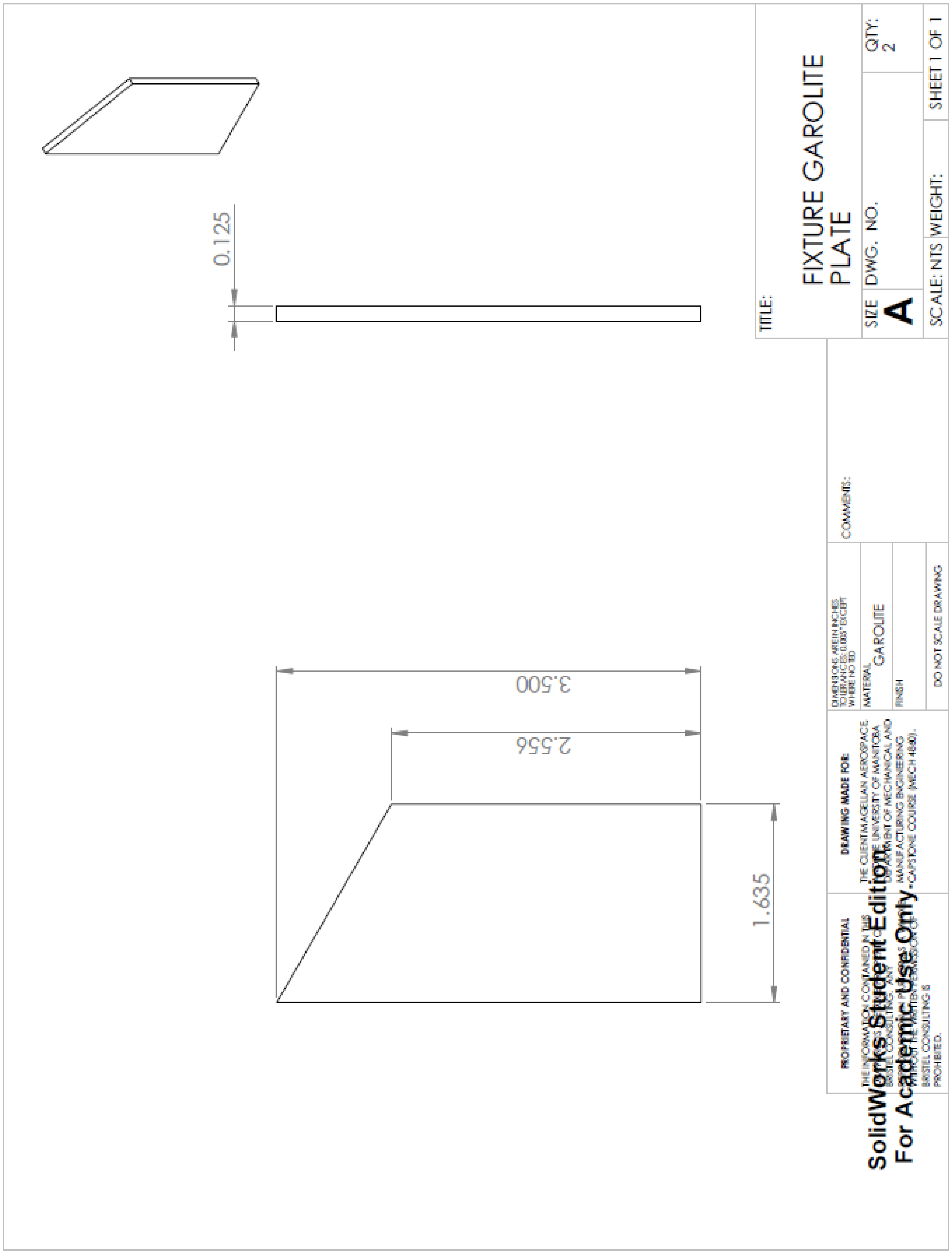


Figure 18: Fixture Garolite Plate

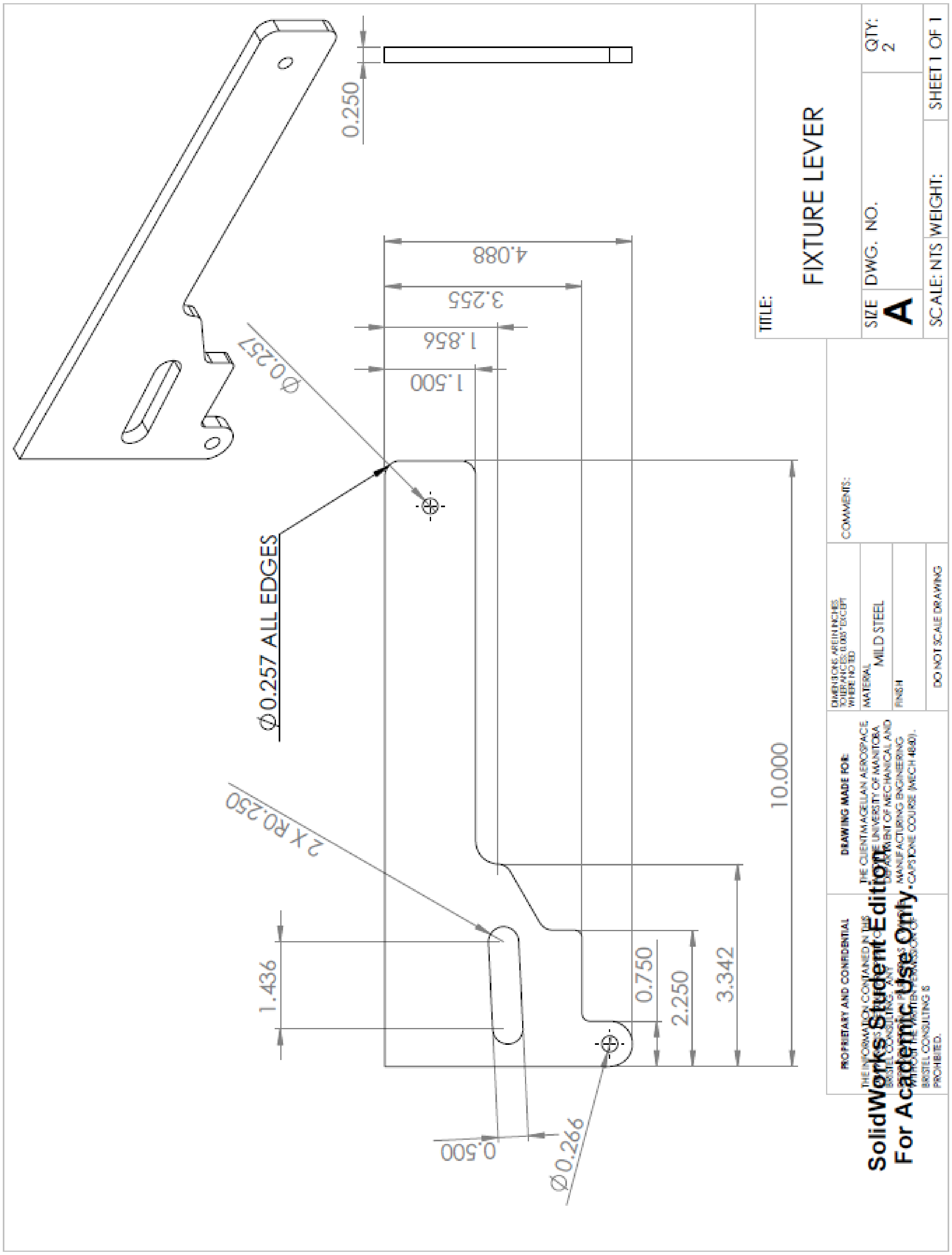


Figure 19: Fixture Lever

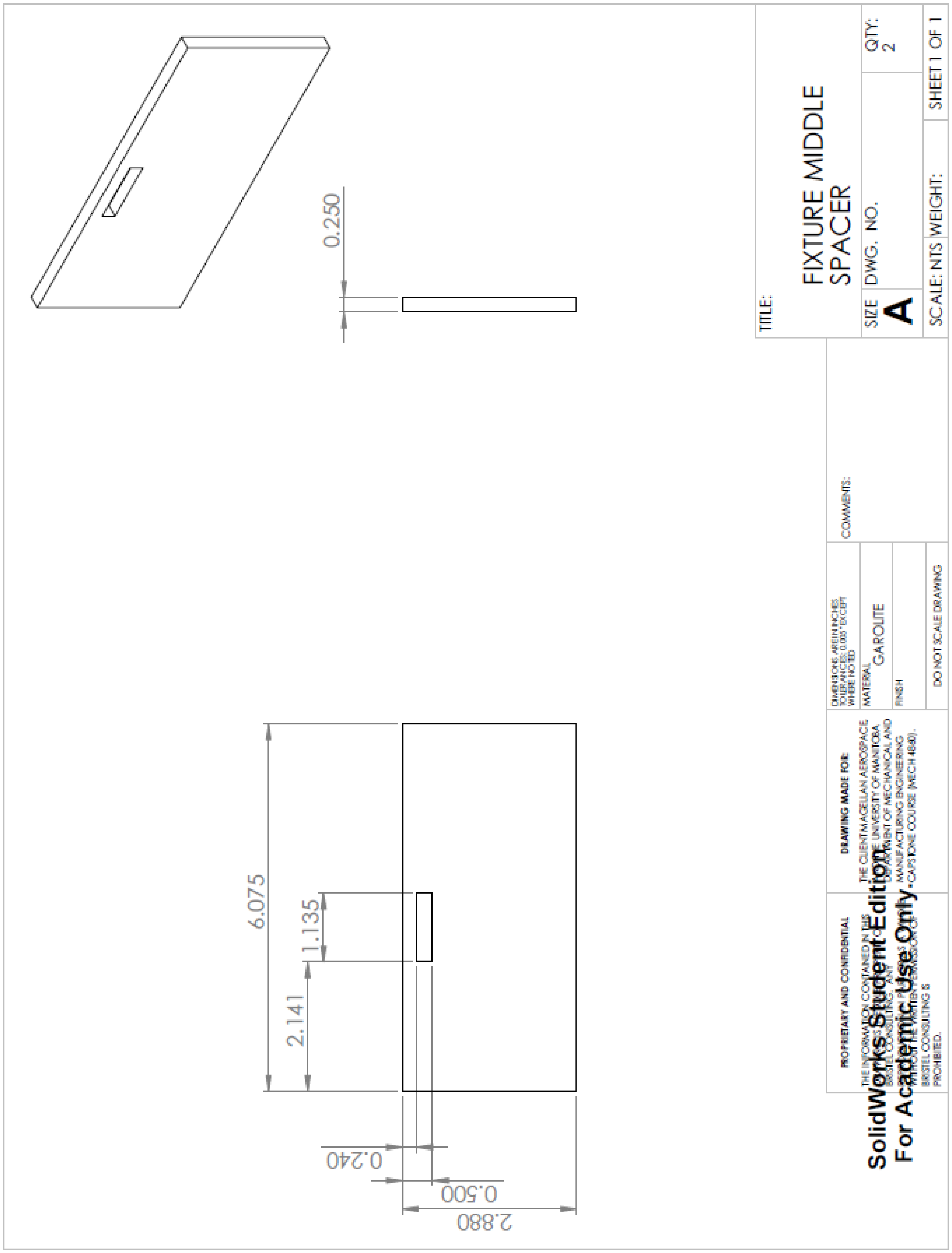


Figure 20: Fixture Middle Spacer

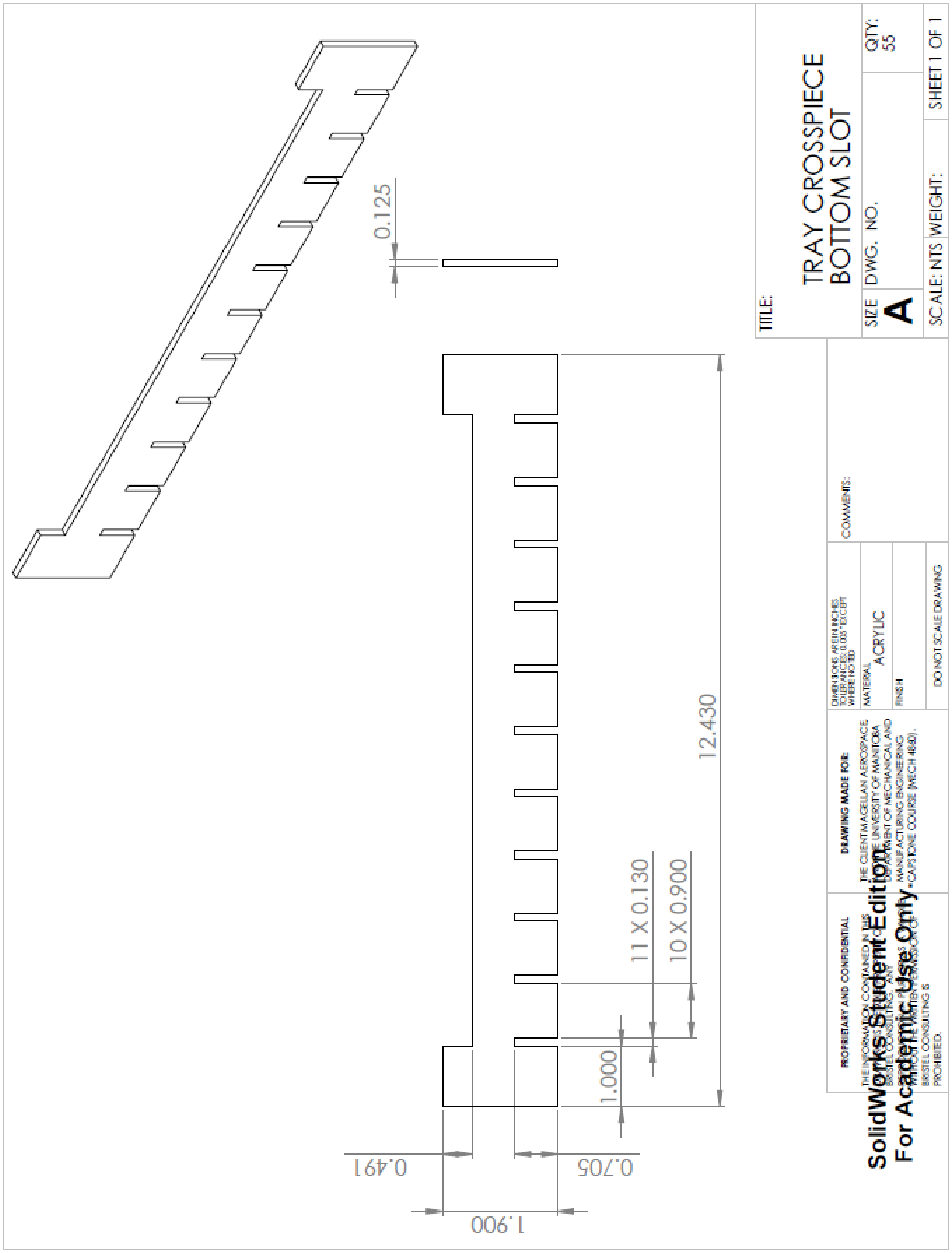


Figure 21: Tray Crosspiece Bottom Slot

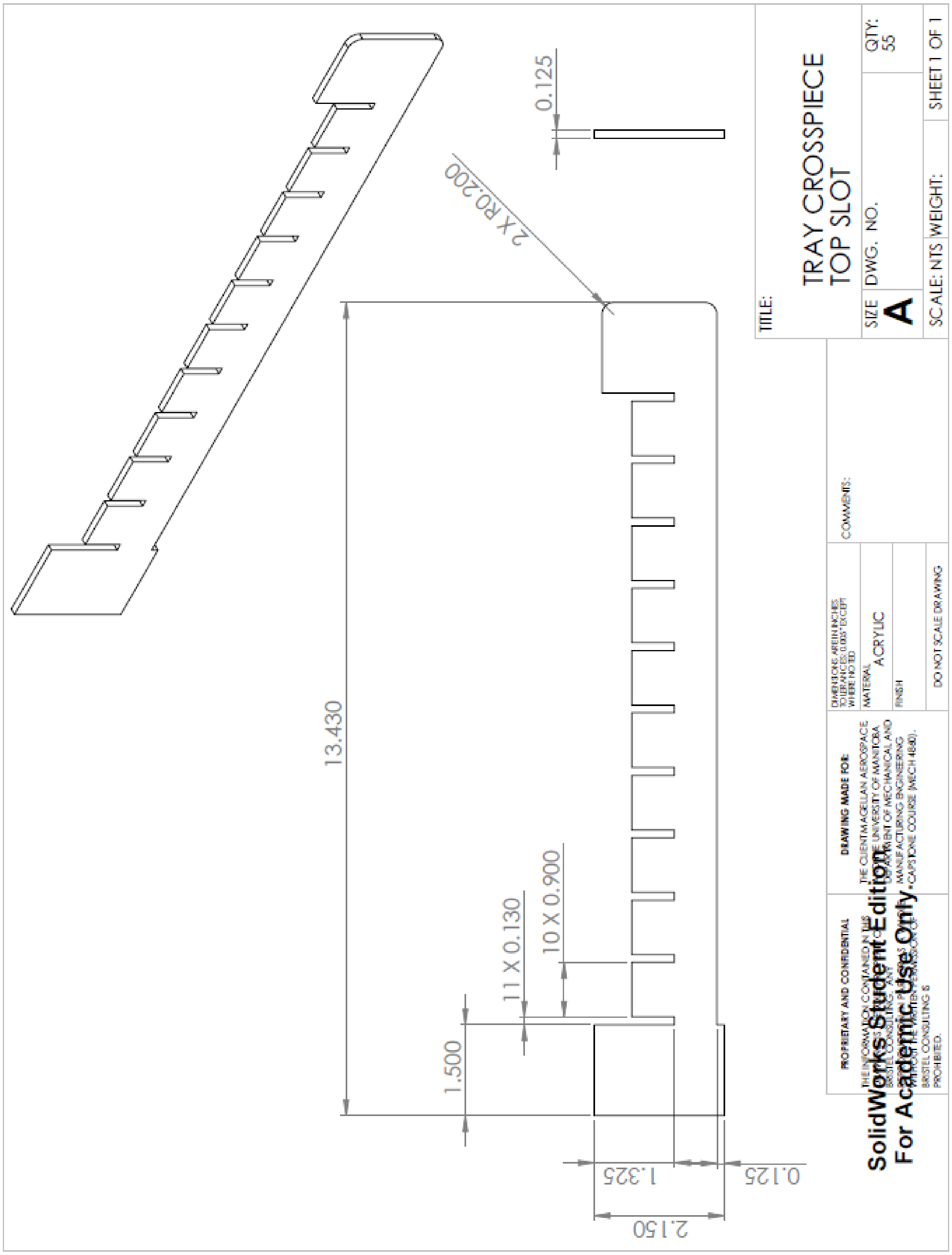


Figure 22: Tray Crosspiece Top Slot

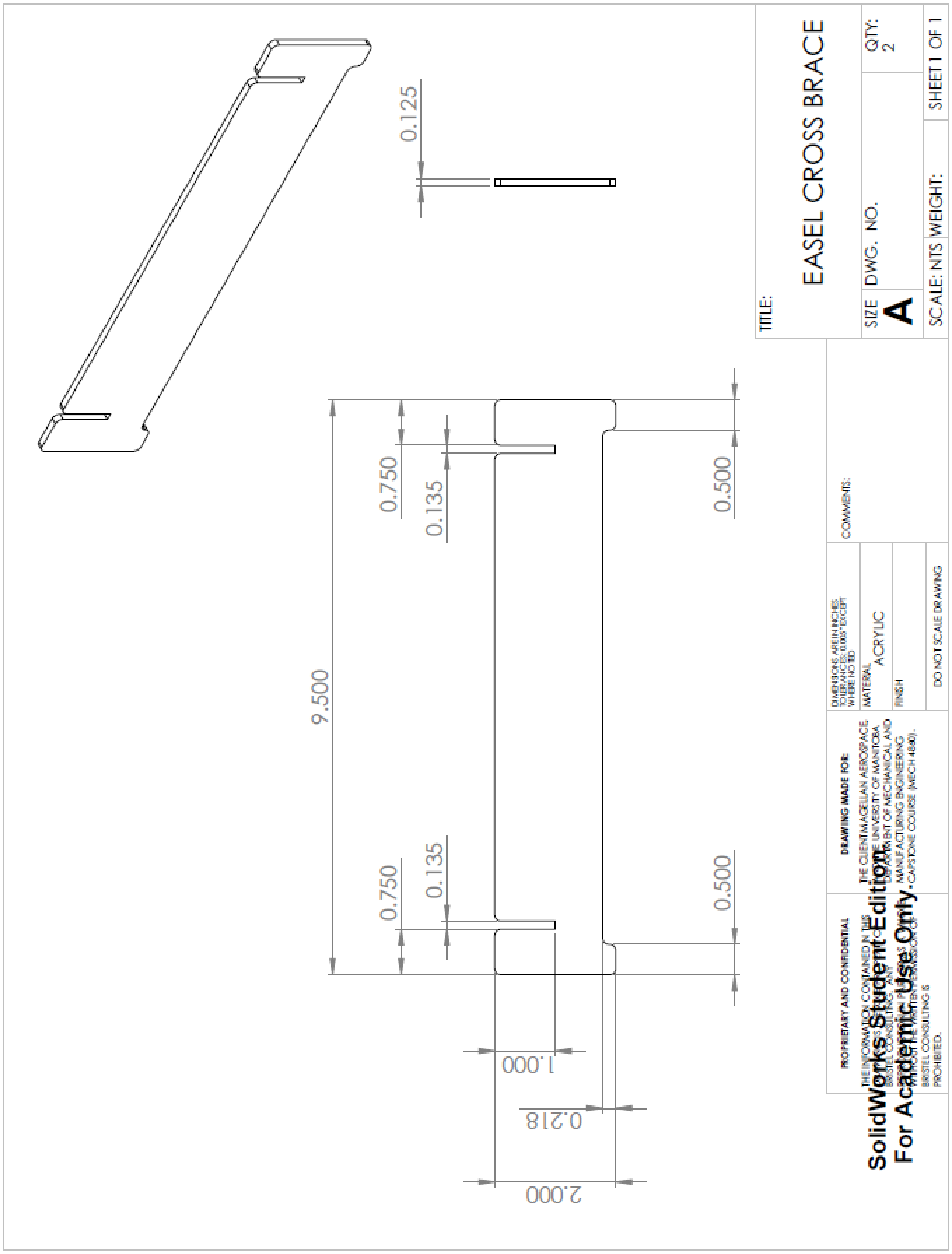


Figure 23: Easel Cross Brace

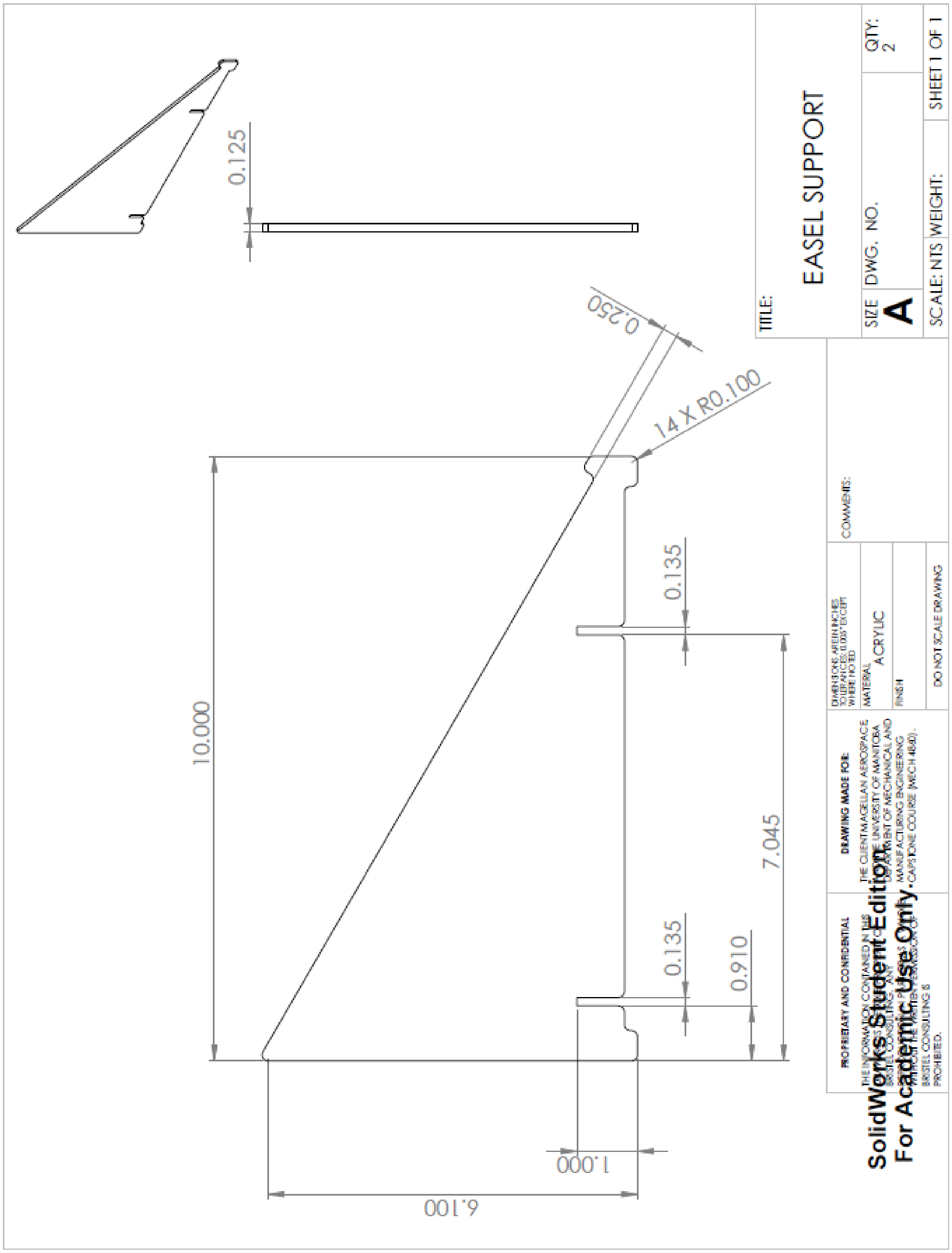


Figure 24: Easel Support

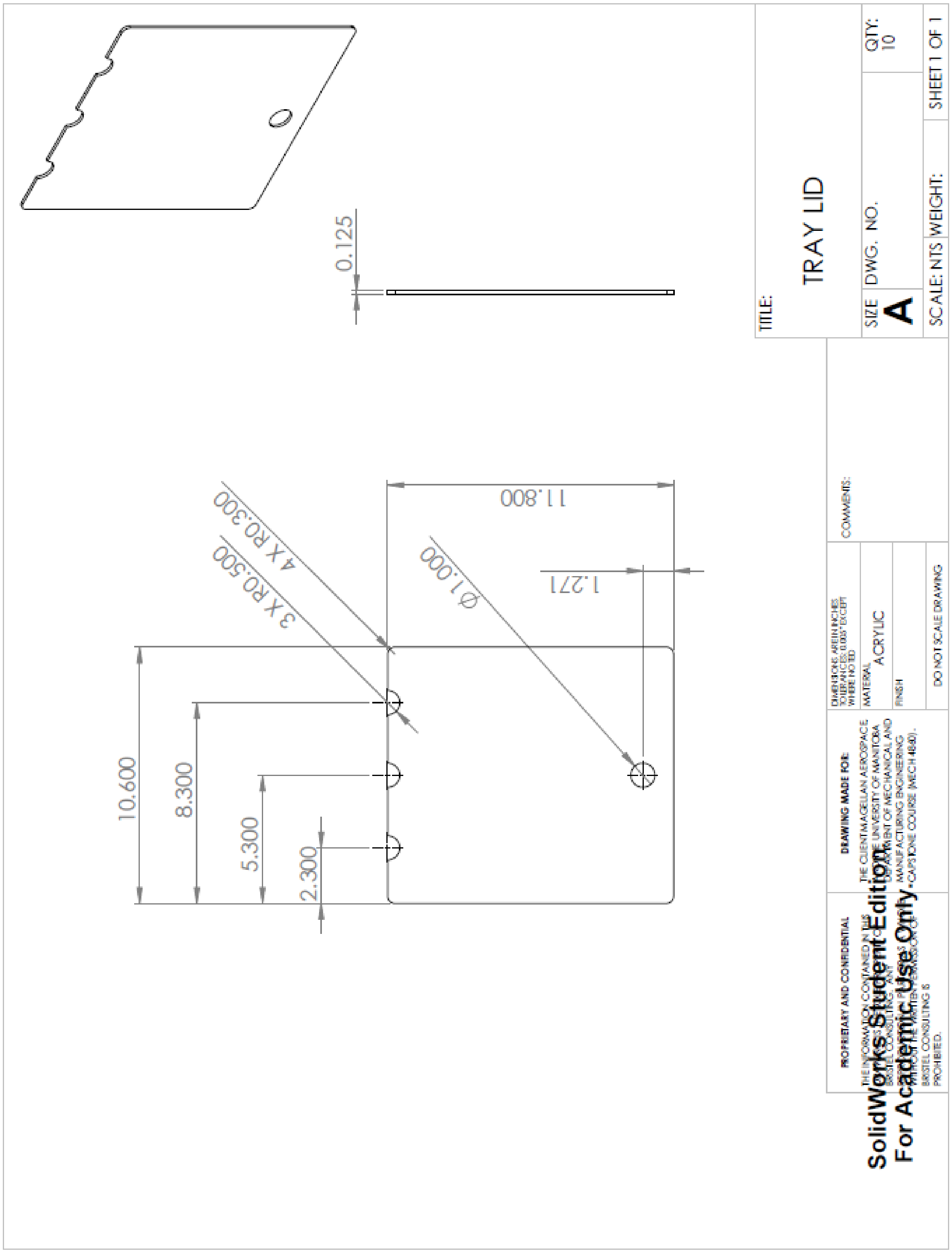


Figure 25: Tray Lid

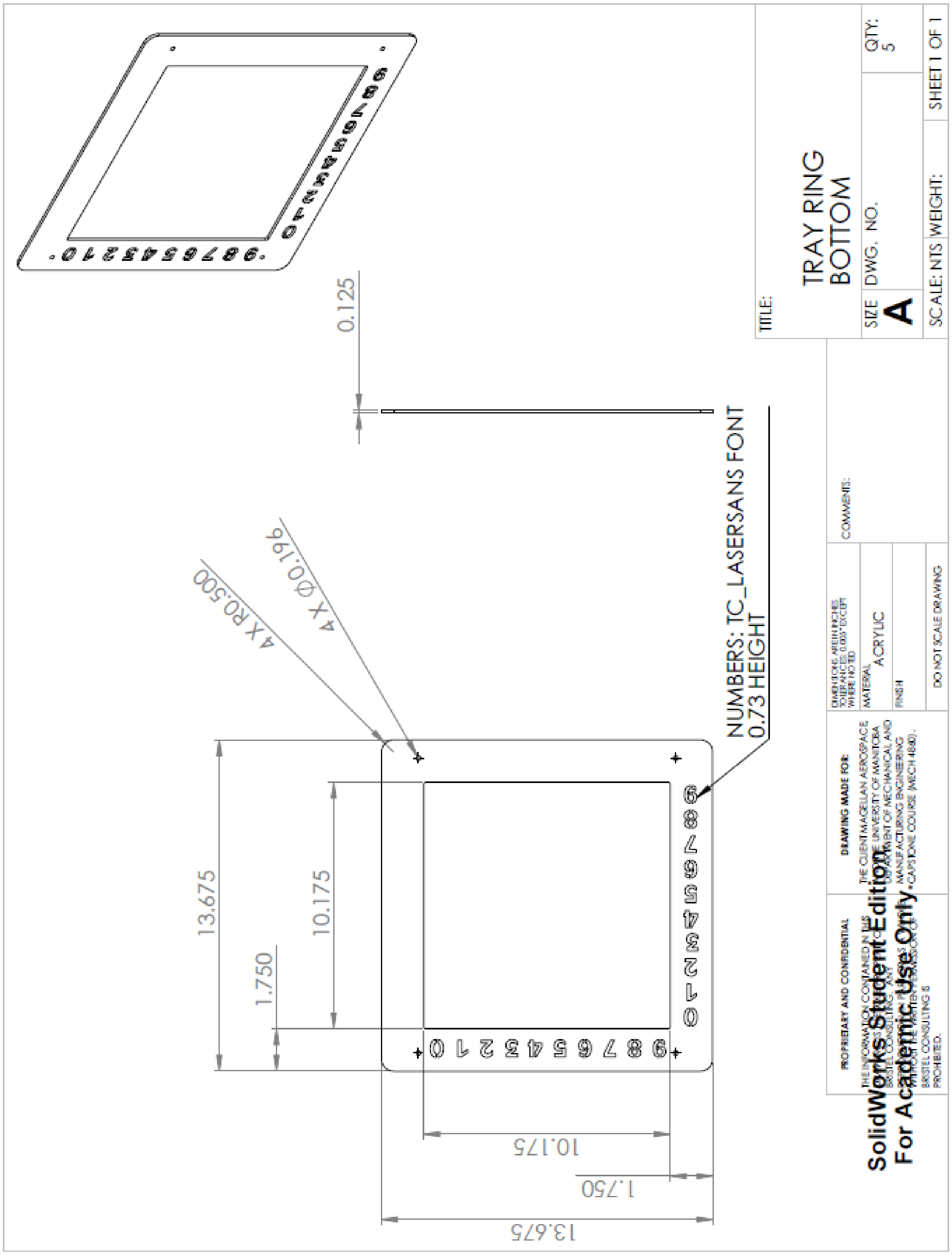


Figure 26: Tray Ring Bottom

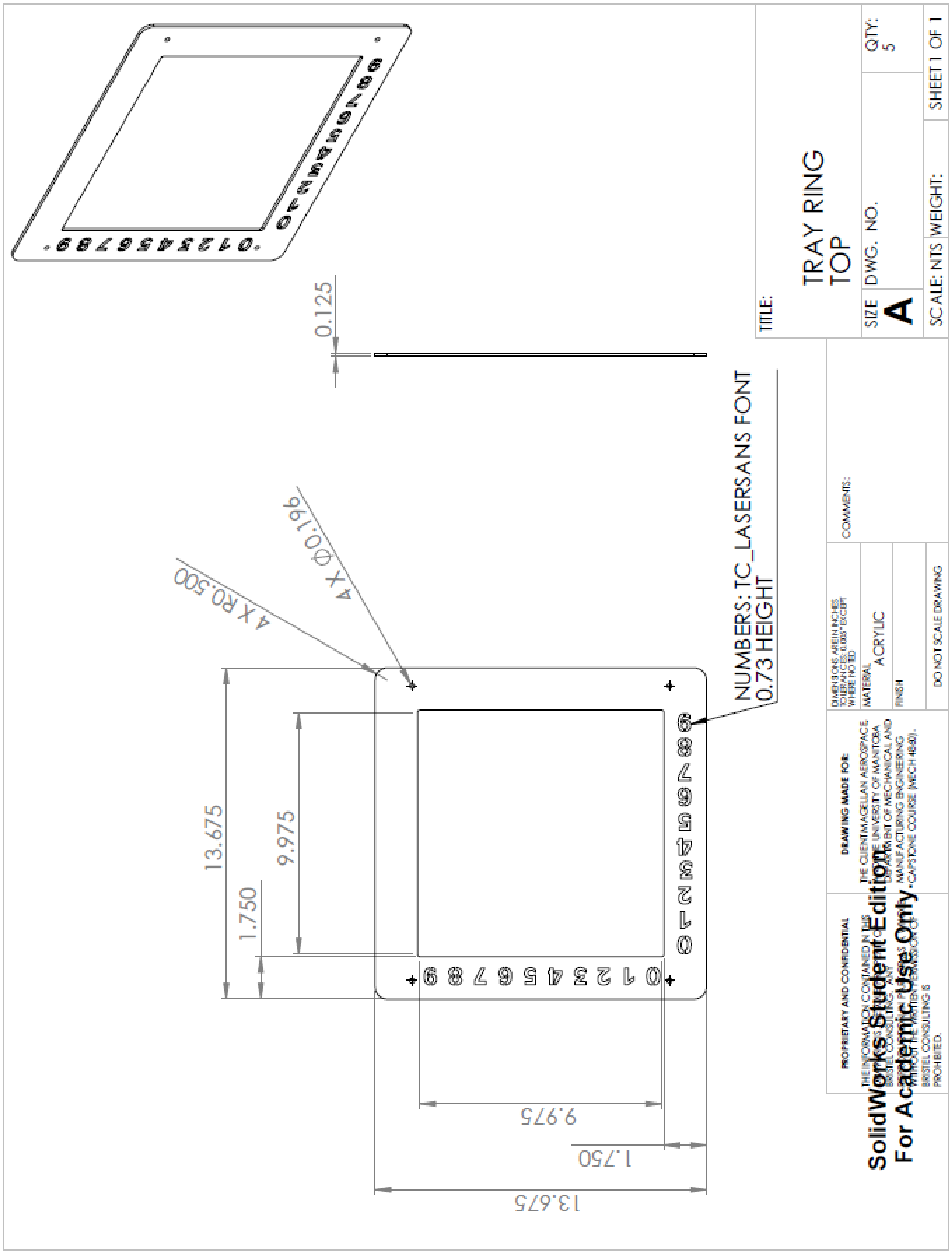


Figure 27: Tray Ring Top

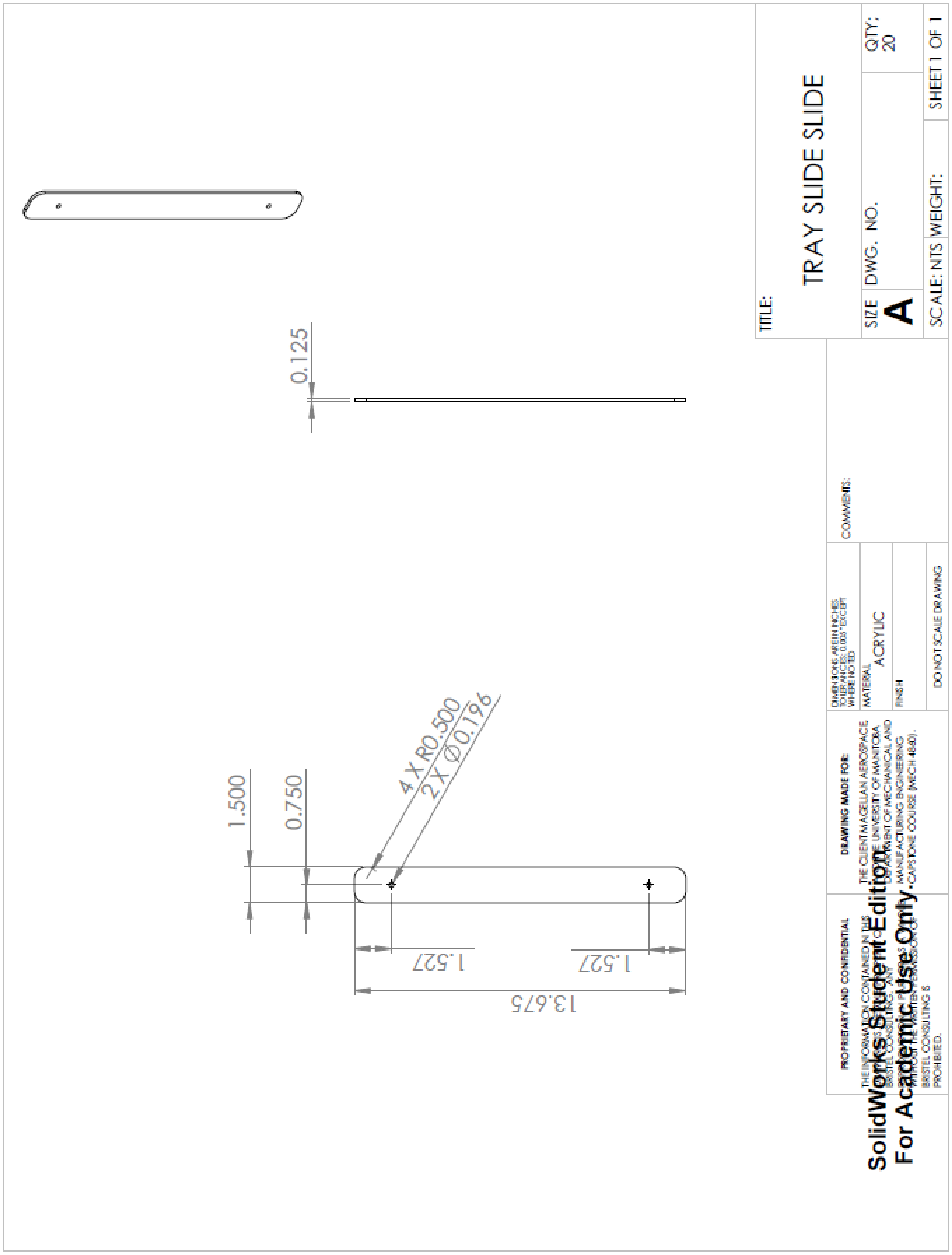


Figure 28: Tray Side Slide

Appendix D: Wire Pinch Force Test Summary

LIST OF FIGURES

LIST OF TABLES

In order to move forward with the concept of pinching wires through the Kapton insulation to gain electrical contact, the team set out to measure the pinching force required. The value of the measured force was then used to design the fixture which provides the pinching force by hand lever actuated springs. This test summary includes the objective, procedure, results, and conclusions from the test performed by the team.

Test Report   Date: **October 30th, 2013**

Test Name:	**Kapton Insulation Pinch Through Force**
Tester:	**Johnathon Nixon**
Location:	**University of Manitoba**
Report From:	**Clark Hnatiuk**
Observers:	**Clark Hnatiuk, Glenn Buist, Curtis Matthews**
Equipment:	**Bobbins, Digital Scale, Metal plates, HSS tool bits, Fluke Multimeter**

Field Notes:

Test Summary:

-Purpose: Determine force required for tool bits to pinch through Kapton insulation on bobbin wires. The value of force is required for designing the fixture that connects the bobbin wires to an ohmmeter.

-Method: Set up tool bits to pinch wire between a 90 degree edge and flat edge. Used multimeter to test for continuity between wire and tool bits. Incrementally added force via metal plates until continuity was achieved. Calculated force applied by measuring weight of plates on scale.

-Results: Highest force measured force required to pinch through a pair of bobbin wires was 8 lbf. Concluded that fixture should be designed to exert 10 lbf.

Objective:

To determine the required force for tool bits to pinch through Kapton coating electrical insulation and electrically connect to the bobbin wires. The value of force will be used to design the fixture so that it is capable of exerting the required amount of force between the tool bits.

Procedure:

1. Select a test bobbin with wire insulation in original condition.

2. Pair red and yellow wires together on both ends.

3. Strip the insulation off one end of red and yellow wires.

4. Connect a multimeter test lead to one stripped wire end.

5. Connect the second multimeter test lead to one tool bit.

6. Set up tool bits, unstripped wire pairs and scale as shown in Fig. 1 through 3.

7. Gradually add steel plates on top of upper tool bit until multimeter shows steady continuity (indicates tool bit is electrically connected to wire).

8. Record reading on scale.

9. Repeat procedure with nine other bobbins.

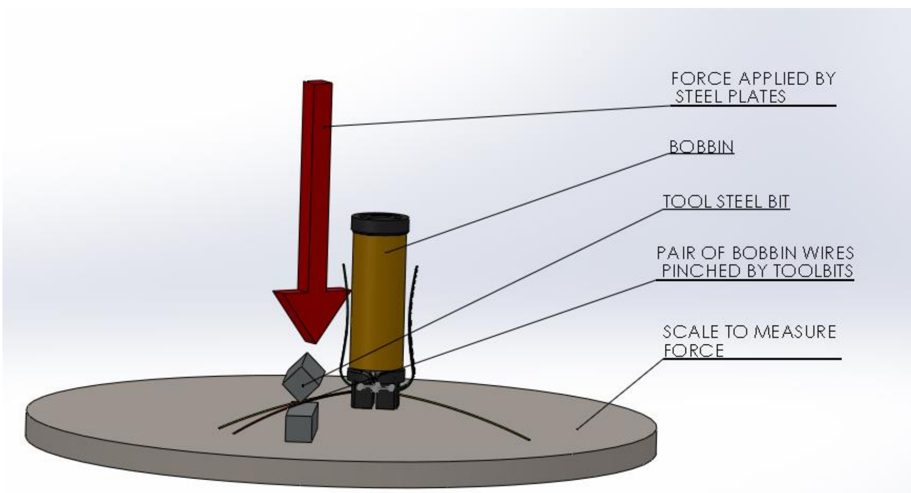


Figure 1: Labelled diagram showing configuration of parts in apparatus.

Figure 2: Photo of apparatus setup showing multimeter test lead connections to bobbin wire and tool steel bit.

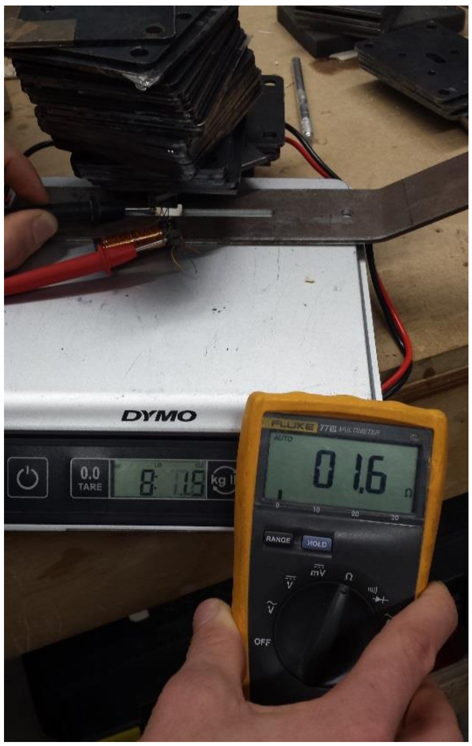


Figure 3: Photo of apparatus setup showing multimeter measuring continuity and scale measuring pinch force.

Results:

Ten trials were completed with the measured forces varying from 6-8 lbf. Table I shows the results of the test:

TABLE I: TEST RESULTS OF WIRE PINCH FORCE

Trial	Force (lb,oz)
1	6,5
2	6,3
3	7,2
4	7,11
5	8,1
6	6,2
7	7,3
8	6,13
9	7,4
10	8,0

The results showed that the maximum force required to pinch through the Kapton insulation is 8 lbs and 1 oz. There were no extreme outliers in the selected sample size. This indicates that the Kapton was applied with an even thickness and consistency to the tested wires. The multimeter started to show intermittent continuity with around 4 lbs of force applied for every wire. As the applied force increased, the electrical connection became steady.

Conclusion:

This test verified that a stable electrical connection can be established by pinching two toolbits together with a force of 8 lbs and 1 oz. If the resources were available, a larger sample size than the 10 pairs of wires tested could be tested to account for manufacturing tolerances in Kapton thickness. To account for any wires with different Kapton thicknesses the fixture shall be designed to exert 10 lbf to pinch through each pair of wires.

END

Appendix E: Requirements Based Software Design

A requirements based breakdown for the automation software has been created to aid in the development of the software. The breakdown is as follows:

1. The program will interface between components of the measurement process

1.1. The program will interface with a spreadsheet to record resistance data

1.1.1. The program will manage the Microsoft Excel spreadsheet

1.1.1.1. The program will prompt the user to select a new or existing spreadsheet to work in

- The program will prompt the user to enter a password when accessing existing spreadsheets
- The program will prompt the user to accept changes made when altering data in an existing spreadsheet

1.1.1.2. The program will set up new spreadsheets

- The program will automatically name each spreadsheet according to a naming convention
- The naming convention for spreadsheets shall be "YY-MM-DD BatchXX"

1.1.2. The program will fill the spreadsheet with resistance values

1.1.2.1. The spreadsheet will have four (4) columns, which indicate the resistance values corresponding to each of the four wires of the bobbin.

1.1.2.2. The spreadsheet will have rows which correspond to the values for each individual BFC's batch serial number

- Batch serial numbers range from 1-500

1.2. The program will have read-only connection to an ohmmeter

1.2.1. The program will automatically connect to the ohmmeter COMM port upon program start

1.2.1.1. The program will automatically troubleshoot connection issues

- The program will prompt the user to correct connection issues until issues are resolved

1.2.2. The program will decode the resistance measurement channel input from the ohmmeter

1.2.2.1. The serial connection will use CRC to check for corrupt data

1.3. The program will interface with a serial relay

1.3.1. The program will automatically connect to the serial relay COMM port upon program start

1.3.1.1. The program will automatically troubleshoot connection issues

1.3.1.2. The program will prompt the user to correct connection issues

1.3.2. The program will control which of the BFC wires are measured by the ohmmeter using the serial relay

1.3.2.1. The program will have five configurations for resistance measurement

- The first four configurations control the serial relay to switch between BFC wires which are connected to the ohmmeter
- The fifth configuration controls the serial relay to measure the resistance of a ready sensor
- Each configuration corresponds to an unsigned 16 bit integer

2. The program will have a calibration function

2.1. The calibration function will have adjustable values for the range of acceptable resistance values for inspection

2.2. The calibration function will prompt the operator to conduct the calibration procedure

2.2.1. The calibration function will record calibration data for each configuration used to measure BFC resistance values

2.2.2. The calibration function will prompt the user to set the timeout period for a steady BFC reading

3. The program will conduct the process of BFC measurement

3.1. The program will determine when the measurement fixture is ready to conduct measurement

3.1.1. The program will control the serial relay in order to connect a ready sensor to the ohmmeter

3.1.1.1. The program will read the resistance value of the ready sensor to determine if the fixture is ready to conduct the measurement process

- The fixture is ready to conduct measurement (tool bits are in contact with wire pairs) when the resistance value of the ready sensor is between 0 and 0.1 ohms.

3.2. The program will record the measurement data from its serial connection when the measurement fixture is ready.

3.2.1. The program will measure each set of BFC wires' resistance one at a time by controlling the serial relay

3.2.1.1. The program will wait for wire resistances to achieve a steady signal before accepting a value

- A signal is steady when its resistance varies by less than .05Ohms in the designated timeout period

3.2.2. The program will compare resistance values received from the serial connection to the tolerable limits (acceptable range of values offset by its calibration data)

3.2.2.1. The BFC passes inspection when resistance values are within the tolerable limits

- The tolerable resistance values for channels 1 and 3 are between 9.00 and 12.83 ohms
- The tolerable resistance values for channels 2 and 4 are between 1.19 and 1.87 ohms

3.2.3. The program will create a record of BFC resistance values for BFC's which pass inspection

3.2.3.1. The program will prompt the user to apply a the appropriate serial number tag after accepting a BFC measurement

4. The program will troubleshoot failed BFC inspections

4.1. The program will prompt the operator to open and shut the measurement fixture when resistance values do not reach a steady resistance value within the timeout period

4.1.1. The program will detect when the measurement fixture has been opened and shut

4.1.1.1. The measurement fixture has been opened when the ready sensor resistance becomes dis-continuous

4.1.1.2. The measurement fixture has been shut when the ready sensor resistance value is between 0 and 0.1 ohms and the fixture has been opened

4.2. The program will identify a potential systematic measurement error when 5 out of 500 of the bobbins measured have failed inspection

4.2.1. A potential error will require the fixture to be re-calibrated before continuing BFC inspection.

4.3. The program will Identify a systematic measurement error when more than 20 out of 500 BFC's measured in the active spreadsheet have failed inspection

4.3.1. The program will flag all bobbins in the current spreadsheet to be re-measured when a systematic measurement error is detected

4.3.2. The program will force the operator to re-calibrate the measurement fixture before continuing BFC inspection.

4.4. The program will randomly select 10% of the BFC's to undergo a second measurement in order to generate a reliability report

4.4.1. The reliability report will compare the standard deviation of the DIFFERENCE of the two resistance measurement values

4.4.2. The reliability report will be generated automatically.

Appendix F: Supplementary Cost Analysis Information

TABLE OF CONTENTS

LIST OF TABLES

The following tables provide detailed supplementary information on part descriptions, part numbers, and suppliers not found in the cost analysis section of the main report.

1 Part Costs

In order to ensure a realistic cost estimate for the material used in the measurement fixture, the stock cut sizes for each part were determined, and then appropriate sized material was priced out. Tables I through IV show the stock cut sizes and material costs.

TABLE I: MEASUREMENT FIXTURE STOCK MATERIAL SIZES USED TO DETERMINE COSTS

Part	Material	Stock Type	Stock Cut Size	QTY
Adjustment Block	Plain Carbon Steel	Square Bar	0.5X0.25X0.75	8
Bobbin Peg	UMHW	Round Bar	0.75X2.5	1
Cam Plate	UMHW	Plate	8.5X12.25X0.5	1
Fixture Base	UMHW	Plate	13X14X1.5	1
Fixture Quarter Front Right	Plain Carbon Steel	Bar	6.25X4.75X2.25	1
Fixture Quarter Front Left	Plain Carbon Steel	Bar	6.25X4.75X2.25	1
Fixture Quarter Rear Right	Plain Carbon Steel	Bar	6.25X4.75X2.25	1
Fixture Quarter Rear Left	Plain Carbon Steel	Bar	6.25X4.75X2.25	1
Fixture Top Block	6061 Aluminum	Square Bar	0.5X0.5X6.25	2
Fixture Top Block Mirror	6061 Aluminum	Square Bar	0.5X0.5X6.25	2
Slider Front Right	Plain Carbon Steel	Square Bar	1.5X4.25X2.5	1

Slider Front Left	Plain Carbon Steel	Square Bar	1.5X4.25X2.5	1
Slider Rear Right	Plain Carbon Steel	Square Bar	1.5X4.25X2.5	1
Slider Rear Left	Plain Carbon Steel	Square Bar	1.5X4.25X2.5	1
Spring Washer	Plain Carbon Steel	Round Bar	1X0.5	4
Tool Bit Fixed Clamp	6061 Aluminum	Square Bar	0.5X0.5X2	4
Tool Bit Pivot Clamp	6061 Aluminum	Square Bar	1X0.5X2	4
Handle	UMHW	Round Bar	1X12	1

TABLE II: MEASUREMENT FIXTURE PART COSTS [1], [2], [3], [4]

Item	Description	Quantity	Unit Cost	Expense	Supplier	Part No.
Compression Spring	4" Long, 0.72" OD, 21 lb/in	4	$1.38	$5.52	McMaster-Carr	9657K462
Track Roller	No-lube stud mount 3/4"	4	$11.12	$44.48	McMaster-Carr	6721K3
Nylon Insert Nut	3/8"-16	2	$0.13	$0.26	Fastenal	37024
Socket Head Cap Screw	3/8-16X1-1/4"	2	$0.34	$0.68	Fastenal	23307
Socket Head Cap Screw	3/8-16X5"	4	$1.04	$4.16	McMaster-Carr	91251A644
Tool Bit	HSS 0.25X0.25X2.5"	4	$1.54	$6.16	Enco	383-5316
Machine Screw	10-24 X 1" Philips Zinc Plated	36	$0.06	$2.16	Fastenal	28982
Machine Screw	1-64X1/4" Philips SS	8	$0.23	$1.84	Fastenal	173393
Garolite	1/8" 12X24" Machineable	1	$29.33	$29.33	McMaster-Carr	8474K122
Tool Steel Sheet	O1, 1/16X1 3/4X18"	1	$17.97	$17.97	McMaster-Carr	9516K9
Adjustment Block	Milled Carbon Steel	8	$0.15	$1.16	Online Metals	N/A
Bobbin Peg	Milled UHMW	1	$3.22	$3.22	Online Metals	N/A
Cam Plate	Milled HDPE	1	$18.75	$18.75	Online Metals	N/A
Fixture Base	Milled Carbon Steel	1	$72.14	$72.14	Online Metals	N/A
Fixture Quarter Front Right	Milled Carbon Steel	1	$37.70	$37.70	Online Metals	N/A

Fixture Quarter Front Left	Milled Carbon Steel	1	$37.70	$37.70	Online Metals	N/A
Fixture Quarter Rear Right	Milled Carbon Steel	1	$37.70	$37.70	Online Metals	N/A
Fixture Quarter Rear Left	Milled Carbon Steel	1	$37.70	$37.70	Online Metals	N/A
Fixture Top Block	6061 Aluminum	2	$0.80	$1.60	Online Metals	N/A
Fixture Top Block Mirror	6061 Aluminum	2	$0.80	$1.60	Online Metals	N/A
Slider Front Right	Milled Carbon Steel	1	$26.81	$26.81	Online Metals	N/A
Slider Front Left	Milled Carbon Steel	1	$26.81	$26.81	Online Metals	N/A
Slider Rear Right	Milled Carbon Steel	1	$26.81	$26.81	Online Metals	N/A
Slider Rear Left	Milled Carbon Steel	1	$26.81	$26.81	Online Metals	N/A
Spring Washer	Milled Carbon Steel	4	$0.84	$3.35	Online Metals	N/A
Tool Bit Fixed Clamp	6061 Aluminum	4	$0.66	$2.64	Online Metals	N/A
Tool Bit Pivot Clamp	6061 Aluminum	4	$0.66	$2.64	Online Metals	N/A
Handle	UMHW	1	$3.75	$3.75	Online Metals	N/A
		Proposed:		**$481.45**		

TABLE III: ORGANIZATIONAL TRAY PART COSTS [2], [3]

Item	Description	Quantity	Unit Cost	Expense	Supplier	Part No.
Machine Screw	10-24 X 2.5 Philips Zinc Plated	20	$0.14	$2.80	Fastenal	29485
Acorn Nut	#10 Nickel Plated	20	$0.19	$3.80	Fastenal	37705
Acrylic	48X48X1/8" clear sheet	1	$76.73	$76.73	McMaster-Carr	8560K263
Acrylic	48X96X1/8" clear sheet	1	$137.02	$137.02	McMaster-Carr	8560K264
Electrical Tape	3/4" X 20 yd black	1	$1.06	$1.06	McMaster-Carr	7619A11
		Proposed:		**$221.41**		

TABLE IV: ELECTRONIC HARDWARE PART COSTS [5], [6], [7], [8]

Item	Description	Quantity	Unit Cost	Expense	Supplier
DPDT Relay	4-Channel 1-Amp DPDT Relay Controller with RS-232 and Relay Interface	1	$109.00	$109.00	National control devices
Serial Cable	RS-232 Serial Cable (6ft)	2	$6.00	$12.00	National control devices
Power Supply	Power Supply 12 Volt, 1.25 Amp	1	$24.00	$24.00	National control devices
Insulated Wire	One-Conductor Solid Hook-Up Wire (20-gauge, 3 spools, 75 ft)	1	$14.99	$14.99	The Source
PC	Core i3-3220, 4GB, 1TB, DVD+/-RW (PC)	1	$414.99	$414.99	Memory Express
Push Button Switch	Push Button	1	$3.08	$3.08	Memory Express
Dual Serial Port Card	2S1P Native PCI Express Parallel Serial Combo Card with 16550	1	$54.99	$54.99	Star Tech
		Proposed:		**$633.05**	

2 MANUFACTURING AND DEVELOPMENT COSTS

To accurately determine the costs for machining the parts in the fixture, each part was analyzed for machining operation durations. Durations were based off of recommended material removal rates as well as team member firsthand machining experience. Tables V through X show the breakdown of manufacturing operation times for each part.

TABLE V: MEASUREMENT FIXTURE BREAKDOWN OF MANUFACTURING OPERATION TIMES FOR ALL PARTS [9]

	Manufacturing Operation Durations For Each Part [hr]									
Part	**Cut Stock**	**Turning**	**Facing**	**Drilling**	**Boring**	**Milling**	**Setup**	**Total Time [hr]**	**QTY**	**Total Time [hr]**
Adjustment Block	0.008	0.000	0.167	0.050	0.000	0.000	0.500	0.725	8	5.800
Bobbin Peg	0.017	0.167	0.167	0.000	0.000	0.250	0.500	1.100	1	1.100
Cam Plate	0.083	0.000	0.167	0.067	0.000	0.500	0.750	1.567	1	1.567
Fixture Base	0.333	0.000	0.167	0.217	0.000	0.667	1.000	2.383	1	2.383
Fixture Quarter Front Right	0.250	0.000	0.333	0.133	0.000	2.000	0.350	3.067	1	3.067
Fixture Quarter Front Left	0.250	0.000	0.333	0.133	0.000	2.000	0.350	3.067	1	3.067
Fixture Quarter Rear Right	0.250	0.000	0.333	0.133	0.000	2.000	0.350	3.067	1	3.067
Fixture Quarter Rear Left	0.250	0.000	0.333	0.133	0.000	2.000	0.350	3.067	1	3.067
Fixture Top Block	0.033	0.000	0.033	0.067	0.000	0.500	0.500	1.133	2	2.267
Fixture Top Block Mirror	0.033	0.000	0.033	0.067	0.000	0.500	0.500	1.133	2	2.267
Slider Front Right	0.133	0.000	0.500	0.417	0.167	0.500	0.400	2.117	1	2.117
Slider Front Left	0.133	0.000	0.500	0.417	0.167	0.500	0.400	2.117	1	2.117
Slider Rear Right	0.133	0.000	0.500	0.417	0.167	0.500	0.400	2.117	1	2.117

Slider Rear Left	0.133	0.000	0.500	0.417	0.167	0.500	0.400	2.117	1	2.117
Spring Washer	0.017	0.167	0.050	0.050	0.167	0.000	0.083	0.533	4	2.133
Tool Bit Fixed Clamp	0.033	0.000	0.083	0.050	0.000	0.167	0.083	0.417	4	1.667
Tool Bit Pivot Clamp	0.033	0.000	0.083	0.033	0.000	0.250	0.083	0.483	4	1.933
							Total:	30.208		41.850

TABLE VI: MEASUREMENT FIXTURE MANUFACTURING COSTS [9], [10]

Item	Description	Part Quantity	Part Labour [hr]	Labor Cost [$/hr]	Expense
Adjustment Block	Milled Carbon Steel	8	0.725	$90.00	$522.00
Bobbin Peg	Milled UHMW	1	1.100	$90.00	$99.00
Cam Plate	Milled HDPE	1	1.567	$90.00	$141.00
Fixture Base	Milled Carbon Steel	1	2.383	$90.00	$214.50
Fixture Quarter Front Right	Milled Carbon Steel	1	3.067	$90.00	$276.00
Fixture Quarter Front Left	Milled Carbon Steel	1	3.067	$90.00	$276.00
Fixture Quarter Rear Right	Milled Carbon Steel	1	3.067	$90.00	$276.00
Fixture Quarter Rear Left	Milled Carbon Steel	1	3.067	$90.00	$276.00
Fixture Top Block	Milled 6061 Al	2	1.133	$90.00	$204.00
Fixture Top Block Mirror	Milled 6061 Al	2	1.133	$90.00	$204.00
Slider Front Right	Milled Carbon Steel	1	2.117	$90.00	$190.50
Slider Front Left	Milled Carbon Steel	1	2.117	$90.00	$190.50
Slider Rear Right	Milled Carbon Steel	1	2.117	$90.00	$190.50
Slider Rear Left	Milled Carbon Steel	1	2.117	$90.00	$190.50
Spring Washer	Milled Carbon Steel	4	0.533	$90.00	$192.00
Tool Bit Fixed Clamp	Milled 6061 Al	4	0.417	$90.00	$150.00
Tool Bit Pivot Clamp	Milled 6061 Al	4	0.483	$90.00	$174.00
		Proposed:			**$3,766.50**

TABLE VII: ORGANIZATIONAL TRAY LINEAR INCHES OF CUT BREAKDOWN FOR LASER CUTTING PARTS

Part	Perimeter [in]	QTY	Total Perimeter [in]
Slide Side	30.7	20	614
Lid	49.1	10	491
Outer Ring	165.3	10	1653
Cross Top Slot	47.6	55	2618
Cross Bottom Slot	45.1	55	2480.5
		Total	7856.5

TABLE VIII: ORGANIZATIONAL TRAY MANUFACTURING COSTS [11], [12]

Item	Description	Quantity	Unit Cost	Expense
Laser Cutting	0.125" Acrylic +-0.005"	1.5	$110.00	$165.00
Labour	Simple Assembly	0.5	$75.00	$37.50
		Proposed:		**$202.50**

TABLE IX: SOFTWARE DEVELOPMENT COST [13]

Item	Description	Quantity	Unit Cost	Expense	Supplier
Labour	Hourly Programming	24	$24.50	$588.00	Outsourced
		Proposed:		**$588.00**	

3 OPERATING COSTS

TABLE X: OPERATING COST BREAKDOWN FOR NEW PROCESS [1], [2]

Item	Purpose	Description	Quantity/Batch	Unit Cost	Expense	Supplier	Part No.
Tool Bit	Pinch Wires	HSS 0.25X0.25X2.5"	0.0167	$1.54	$0.03	Enco	383-5316
Labels	Bobbin ID	Consecutively Numbered	1.0000	$14.97	$14.97	McMaster-Carr	1530T22
			Proposed:		**$15.00**		

REFERENCES

[1] *Item Details.* (2013). [Online]. Available: http://www.use-enco.com/CGI/INSRIT?PMAKA=383-5316&PMPXNO=939967&PARTPG=INLMK32 [Nov. 10, 2013].

[2] *Fastening & Joining.* (2013). [Online]. Available: http://www.mcmaster.com [Nov. 8, 2013].

[3] *Fasteners.* (2013). [Online]. Available: http://www.fastenal.com/web/products/fasteners/_/Navigation?r=~|categoryl1:%22600000%20Fasteners%22|~ [Nov. 10, 2013].

[4] *Metals Shopping for Orders of Every Size and Shape* (2013). [Online]. Available: http://www.onlinemetals.com/index.cfm [Nov. 28, 2013].

[5] National Control Devices. (2013). [Online]. Available: http://www.controlanything.com/Relay/Device/R41DPDTCNRS [Dec 1, 2013].

[6] The Source. (2013). [Online]. Available: http://www.thesource.ca/estore/product.aspx?language=en-CA&catalog=Online&category=Hook+Up+Wire&product=2781305 [Dec 1, 2013].

[7] Memory Express. (2013). [Online]. Available: http://www.memoryexpress.com/Products/MX47699 [Dec 1, 2013].

[8] StarTech. (2013) [Online]. Available: http://ca.startech.com/Cards-Adapters/Serial-Cards-Adapters/2S1P-Port-PCI-Express-Parallel-Serial-Combo-Card-16550-UART~PEX2S5531P [Dec 1, 2013].

[9] K.C. Polgar, “Simplified Time Estimation Booklet for Basic Machining Operations” [PDF], M.S. Thesis, Mech Eng., MIT, Cambridge, MA, 1996. Available: http://web.mit.edu/2.810/www/readings/Polgar_Time_Est.pdf [Nov. 28, 2013].

[10] *Machine Shop*. (2013). [n.d.]. Available: http://www.science.uottawa.ca/services/machine-shop.html [Nov. 10, 2013].

[11] V. Sumaling. (2013, Nov. 22). “Laser Cutting.” Personal e-mail.

[12] Tim Christopherson. (2002). *Laser Processing of Plastic Sheet* [PDF]. Available: http://www.precoinc.com/PDF/PlasticsPaper.pdf [Nov. 19, 2013].

[13] Michael Zapp (private communication), Nov. 12, 2013.

Appendix G: Manufacturing Design Considerations - Organizational Tray

LIST OF FIGURES

During the design of the tray special consideration was taken to increase the manufacturability of all associated parts. Laser cutting, tolerances, and assembly were factored into all design decisions.

The relatively low melting temperature of the acrylic material used in the design poses potential issues when laser cutting. If part geometry requires a sharp and thin point to be laser cut, heat from the laser will buildup in the point and melt the material, resulting in altered part geometry. This issue was avoided by designing all parts to have sufficient material between adjacent cuts.

The majority of cuts for the parts are along straight lines, minimizing the amount of curve fitting interpolation during the CNC machine operation. This will avoid having feed rates limited by processing power of the CNC system.

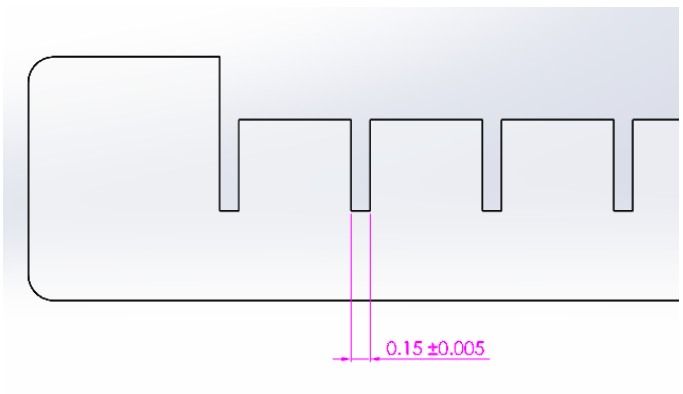


Figure 1: Dimension and tolerance for slots in the slats which form tray compartments.

The function of the tray is not affected by laser cutting tolerances, however the tolerance of individual parts is critical during assembly. To reduce costs, a laser cutting tolerance of ±0.005" is specified. This is on the loose side of laser cutter capabilities, which will allow for the parts to be cut at faster feed rates at higher power, reducing manufacturing costs. Special attention was paid to the tolerancing of the slots in the slats which form the tray compartments. Accounting for thickness tolerances in the sheet material, the maximum sheet thickness is 0.140". In addition, each cut along the sides of the slot could be 0.005" off of the tool path. The slots were then sized to a width of 0.150" (0.140"+0.005"+0.005"), allowing for easy assembly without the need for filing the slot after laser cutting. Fig. 1 shows a dimensioned drawing of the slots. All slots and holes in the parts are much wider than the laser kerf, which eliminates issues with overlapping cuts.

Another consideration taken during the design process was to use standard size fasteners. The total tray thickness was adjusted so that 2.5" long machine screws could be used without the need for trimming threads.

In conclusion, design of the organizational tray has been optimized for manufacturability at low volume (five trays) production levels. If production levels were much higher, further optimization of the design would be of greater benefit to the client.

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Appendix H: Organizational Tray Cost Reduction

LIST OF FIGURES

LIST OF TABLES

Several steps were taken to reduce the cost for manufacturing a set of five trays. Material choice, material utilization, and part geometry all played a role in the total cost.

The first effort at cost reduction was to select a sheet material of sufficient rigidity and weight for the design. Since the design lends itself to laser cutting so well, the top material options were acrylic (0.125") and aluminum (0.63") sheet. The total cost of aluminum would be $505.50 whereas acrylic would cost $213.75, which is less than half the price of aluminum [1], [2]. Due to the much lower material cost, acrylic sheet was selected.

Next, part nesting software was used to minimize the amount of material required. By specifying a 0.075 inch minimum part spacing, the software calculated a stock material requirement of one 48X96" and one 48X48" sheet [3]. Fig. 1 shows how the nesting configuration of all parts for five trays reduce material waste.

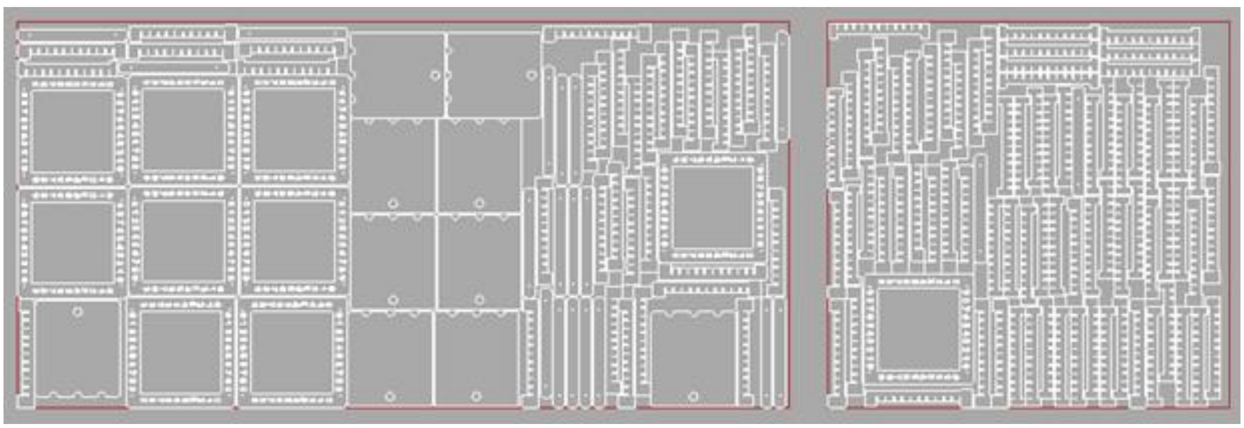

Figure 1: Nested parts for all five trays on one 48X96" and one 48X48" sheet.

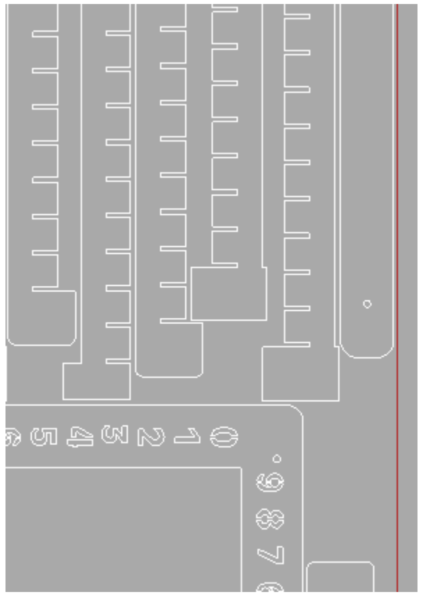

Figure 2: Nested part detail.

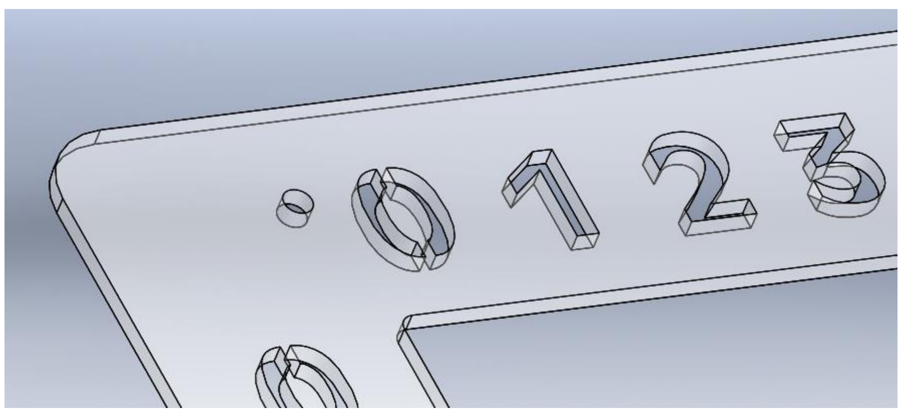

Figure 3: Laser cut numbers on tray outer ring identify rows and columns.

The last step taken to reduce manufacturing cost was to optimize part geometry to reduce laser cutting costs. Realizing that the cut out numbers on the tray's outer rings require extensive laser cutting, several options for reducing this amount of laser cutting were investigated. Fig.3 shows numbers laser cut out into the outer ring of the tray.

Originally, the outer rings were to have numbers along all edges to make compartment identification easy for the operator. The next option was to have the numbers only along two edges, and the last option was to not have any cut out numbers and use vinyl stickers instead.

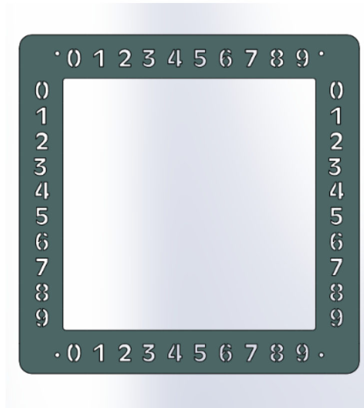

Figure 4: Outer ring of organizational tray with laser cut numbers along four edges.

Having numbers cut out along all four edges of the outer ring (Fig. 4) requires 1168.7 linear inches of laser cutting for five trays.

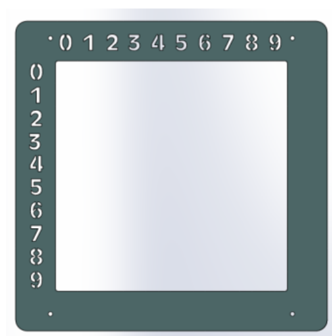

Figure 5: Outer ring of organizational tray with laser cut numbers along two edges.

Having numbers cut out along only 2 edges of the outer ring (Fig. 5) requires 826.5 linear inches of laser cutting for five trays.

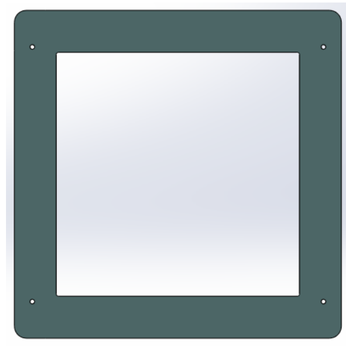

Figure 6: Outer ring of organizational tray without laser cut numbers along edges.

Having zero numbers cut out along the outer ring (Fig. 6) requires 484.0 linear inches of laser cutting for five trays.

To equate the reduction of linear inches cut to cost savings, time taken to cut out the numbers was considered. The high concentration of curved surfaces in the numbers and large amounts of intermittent cuts require slower average laser feed rates. Knowing this, the reduction in cut length for the different numbering options was doubled and that value was used in combination with the total average cut cost per linear inch to determine the cost savings. Having numbers cut out along two edges equates to a cost saving of $16.50, and having no cut out numbers will save $33.00 in laser cutting costs.

As an alternative laser cut outs, numbers could be vinyl stickers applied to the outer rings of the tray. The vinyl numbers are available from McMaster Carr (5838T542) at a cost of $10.77 per set, with a set containing enough numbers for all five trays [4].

There are numerous disadvantages to using vinyl stickers instead of laser cut-out numbers. The first disadvantage is that the overall cost of the five trays is only reduced by $4.48, when the extra 15 minutes of assembly time is taken into account. Other disadvantages of using vinyl stickers are that an extra step is added to the assembly process, additional parts are required, and the vinyl stickers may begin to peel off as the tray becomes more used.

However, by only laser cutting out numbers along two edges of the tray, $16.50 can be saved without affecting the function of the design. Table 1 shows the cost breakdown for the different options of labelling the rows and columns of the five trays.

TABLE 1: COST BREAKDOWN OF LABELLING OPTIONS FOR FIVE TRAYS

No. of Sides Lasered Numbers	Laser Cost ($)	Vinyl Sticker Cost ($)	Assembly Labour Cost ($)	Total Cost
4	165.00	0.00	0.00	165.00
2	148.50	0.00	0.00	148.50
0	132.00	10.77	18.75	161.52

Considering the disadvantages of the vinyl sticker option for labelling, that option was ruled out in favour of using laser cut outs for numbers along two edges of the tray’s outer rings.

4 REFERENCES

[1] McMaster-Carr. (2013) *Acrylic Sheets* [Online]. Available: http://www.mcmaster.com/#acrylic-sheets/=pg44ct [Nov. 12, 2013].

[2] McMaster-Carr. (2013) *Aluminum Sheets* [Online]. Available: http://www.mcmaster.com/#standard-aluminum-sheets/=pbu67s [Nov. 12, 2013].

[3] My Nesting. (2013) *Getting Started* [Online]. Available: http://www.mynesting.com/GetStarted.aspx [Nov. 13, 2013].

[4] McMaster-Carr. (2013) *Peel-and-Stick Characters* [Online]. Available: http://www.mcmaster.com/#vinyl-letters-and-numbers/=pbt48t [Nov. 12, 2013].

Appendix I: Tool Bit Replacement Interval

LIST OF FIGURES

To determine the durability of the fixture tool bits used to pinch through the wire insulation and form an electrical connection with the bobbin wires, material properties and an existing implementation of a similar design were analyzed.

[redacted]

Figure 1: Schleuniger wire stripper replacement blades required for current process [1].

High speed steel was chosen due to the fact that it has a higher hardness than the copper and stainless steel bobbin wires, and it is readily available in the specified rectangular geometry. The automatic wire stripper employed by the current process (Schleuniger UniStrip 2500) requires blade replacement after ten batches of bobbins are stripped. These replacement blades are constructed out of tool steel and have an edge with an angle of approximately 45 degrees [2]. The V-shaped geometry of the replacement blade shown in Fig. 1 concentrates the wear to only the bottom of the “V”.

On the other hand, the tool bits employed in the new process utilize a larger portion of the straight edge, which is also less susceptible to blunting due to the edge being sharpened to 90 degrees instead of 45 degrees. In addition, the fixture only requires a pinching action as opposed to the stripper which utilizes a shearing/dragging action along half an inch of each wire. The pinching action is therefore expected to result in much less wear on the tool bits.

By careful comparison of the similarities and differences between the tool bit design and replacement blades used in the current process, the team confidently concluded that the tool bit replacement interval can be specified as 150% of the replacement interval for the current process. It is important to note that the new process fixture splits up the wire pinching duty between four tool bits. This equates to a replacement interval of four tool bits after every 60 batches. However, each tool bit has four index-able cutting/pinching edges, allowing 240 batches to be tested before total replacement of the tool bits.

5 REFERENCES

[1] USP-1300. [Image]. Available: http://www.griptech.com/mm5/graphics/00000001/USP-1300.jpg [Nov. 18, 2013].

[2] Grip Technologies. (2013). *Spare Parts for Schleuniger UniStrip 2500* [Online]. Available: http://www.griptech.com/c/schleuniger-unistrip-2500-spare-parts/ [Nov. 12, 2013].