Final Project Report

1815 - Connector Insert Stake Machine

Amphenol Fiber Systems International

Fiber Focus

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Executive Summary

Amphenol Fiber Systems International (AFSI) is a fiber optic connectivity manufacturing company that requires a device that performs the staking operation for low-volume production. Staking refers to the plastic deformation of an aluminum ring inside of a connector shell to create a permanent joint between a connector insert and shell.

Our solution is as staking machine that utilizes a custom die-set (tooling) installed on a retrofitted pneumatic press driven with a Programmable Logic Controller (PLC) and Human Machine Interface (HMI) which allows the operator to perform calibration and staking operations along with a retraction operation for resolving jams. Our machine integrates a pneumatic pressure regulator, load cell, and linear potentiometer, allowing for variable-parameter-closed-loop pressure control with position and force feedback in order to accurately and reliably apply the required staking force.

The tooling is comprised of three key sub-assemblies: a die-set frame for maintaining alignment independent from the press, a floating tool holder enabling manual pre-alignment of the punch in the shell, and a clamp arm to secure the connector during tool retraction. The tooling is equipped with compression springs for passive retraction of the tool after actuation, and the tool holder allows for interchangeable punch tooling. These features enable the press to consistently perform the staking operation while also streamlining machine assembly and servicing.

Our team successfully produced a staking machine prototype that meets and exceeds the client's specifications, and we are confident that the machine will see factory-use for AFSI's low-volume staking requirements.

The staking machine faced unexpected setbacks that added challenge to the project, but ultimately was successful in meeting requirements. Completing minimum viable product ahead of schedule, we were able to take additional safety measures by implementing press guards and pneumatic lockout tagout (LOTO).

We performed extensive testing to dial-in the applied force of the punch on the connector. Initial testing revealed large variances in the accuracy of the load cell, which underwent several trials of troubleshooting. Ultimately, we determined that the purchased load cell was out-of-spec as it did not match the provided calibration certificate. To tackle this setback, the team devised a solution using the pressure regulator to bypass the load cell and hit the target loads within specification.

Our recommendations to the client for improving the staking machine include replacing the load cell and amplifier to improve sensor accuracy along with applying surface treatments to the machined parts to increase durability.

A link to an electronic repository containing all software source files, CAD files, electrical schematics, and other electronic files associated with this project will be provided to the sponsor by UTDesign.

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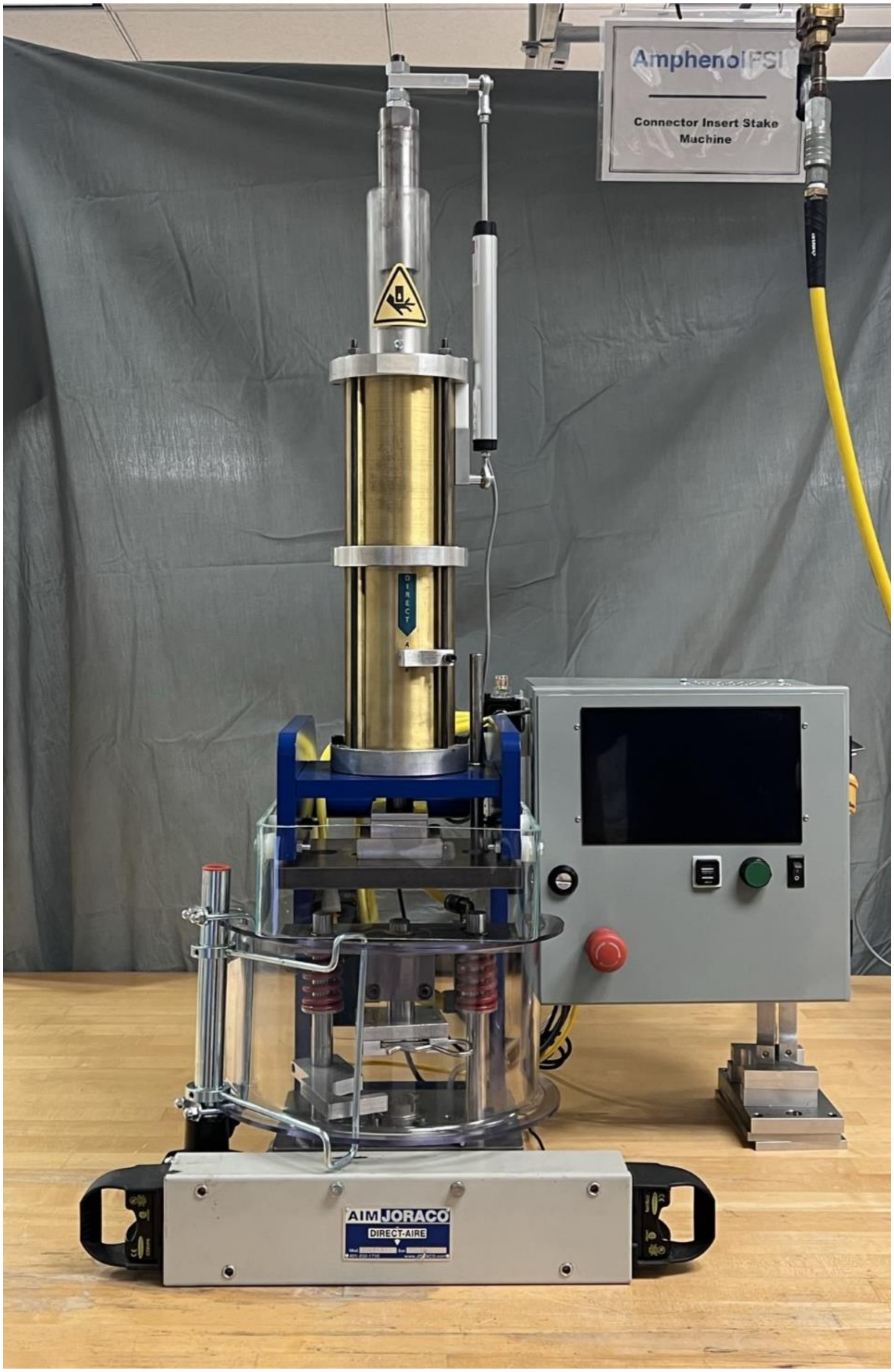


Figure 1: Final Product in Press

1 - Introduction

This project was sponsored by Amphenol Fiber Systems International (AFSI), a full-service fiber optic company specializing in the fabrication of fiber optic connectivity products. AFSI's main products are fiber optic cable connectors consisting of three parts: a shell, insert, and staking ring, **Figure 2**. This project focuses on the staking process of these connectors.

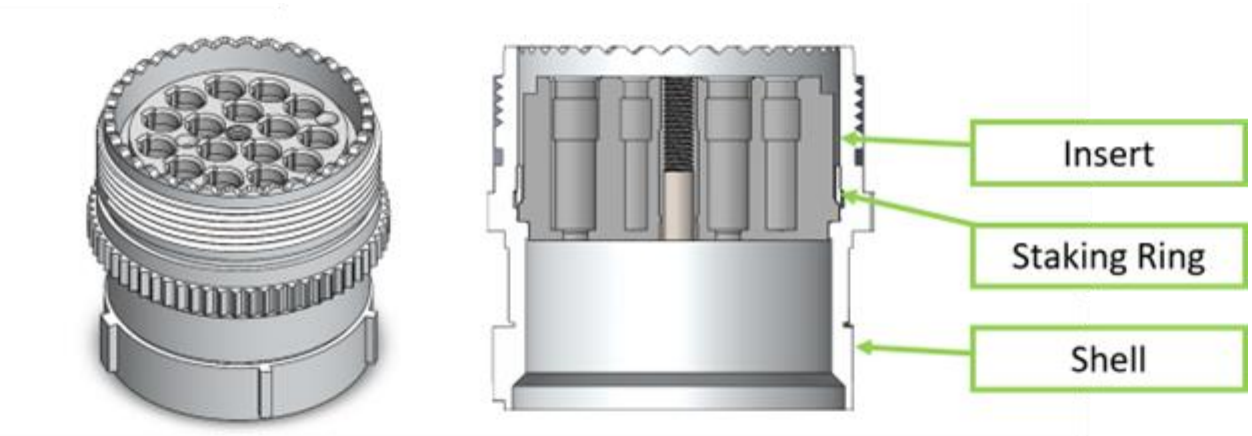


Figure 2: Fiber Optic Connector

AFSI utilizes a connector style where a metal staking ring joins the shell and insert. During assembly, the insert is placed into the shell, and the staking ring is positioned between them. Using a punch tool (punch), the staking ring is deformed, or "staked," to fill the space between the shell and insert, creating a permanent mechanical connection, **Figure 3**. The punch is a thin-walled cylinder with rectangular castellations. Fully staking the ring requires two stakings spaced 90° apart so that the castellations can apply enough load around the ring's perimeter.

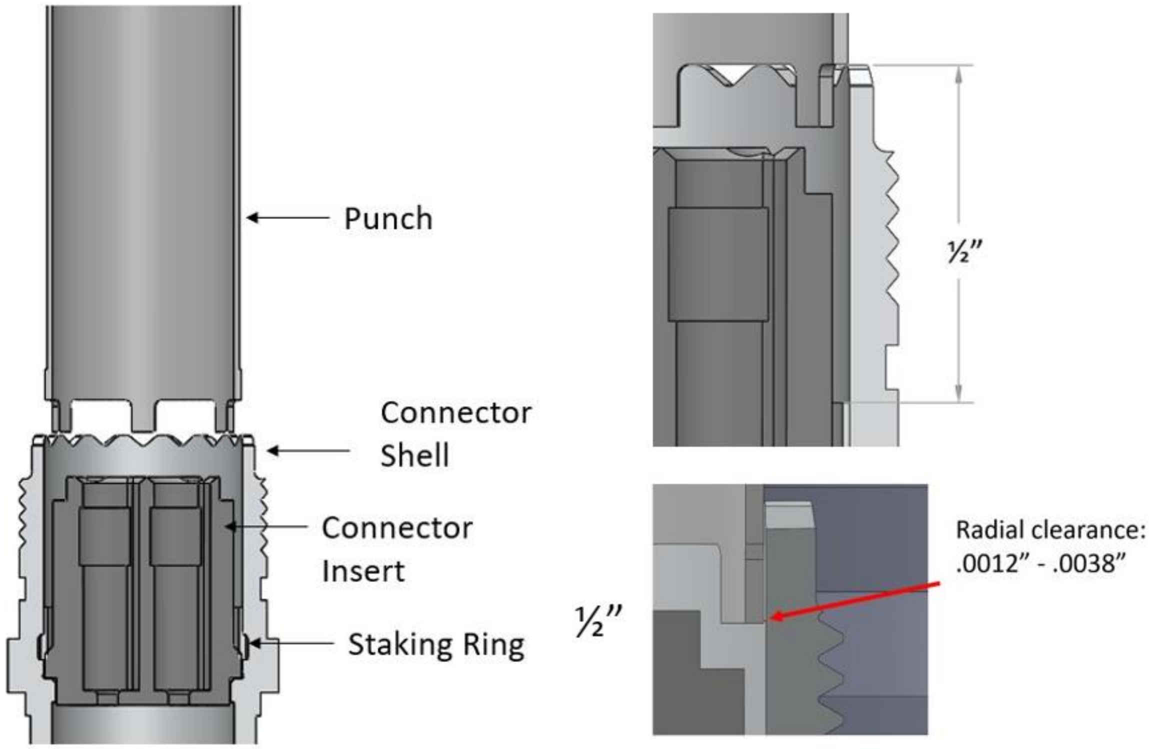


Figure 3: Cross-section of connector and punch

1.1 - Problem Statement

AFSI currently outsources its connector staking operations to AAO, which uses a production line machine for high-volume runs. However, AFSI occasionally needs custom inserts for lower volume projects, increasing costs. To address this, AFSI sought a mechanical device to perform staking operations in-house, allowing greater control over connector assembly and to reduce overhead. AFSI attempted various solutions to stake inserts, with minor success using a manual bottle jack. However, limited force control and inability to align connector components within tolerance hindered progress.

Staking rings require a specific force to deform, shown in **Table 1**. Higher forces risk damage to the punch and connector. The inspection force required to verify that the staking was successful also varies for each shell size, **Table 2**.

Table 1: Staking Force by Shell Size

Staking Force	
Shell Size	**Force (lb.)**
11	330
13	410

Staking Force	
15	500
17	587
19	780
21	888
23	995
25	1250

Table 2: Inspection Force by Shell Size

Inspection Force	
Shell Size	**Min Test Force (lb.)**
11	30
13	35
15	50
17	65
19	80
21	100
23	125
25	150

1.2 - Specifications

The specifications for the Connector Insert Stake Machine are detailed in **Table 3**.

Table 3: Functional Requirements of the Connector Insert Stake Machine

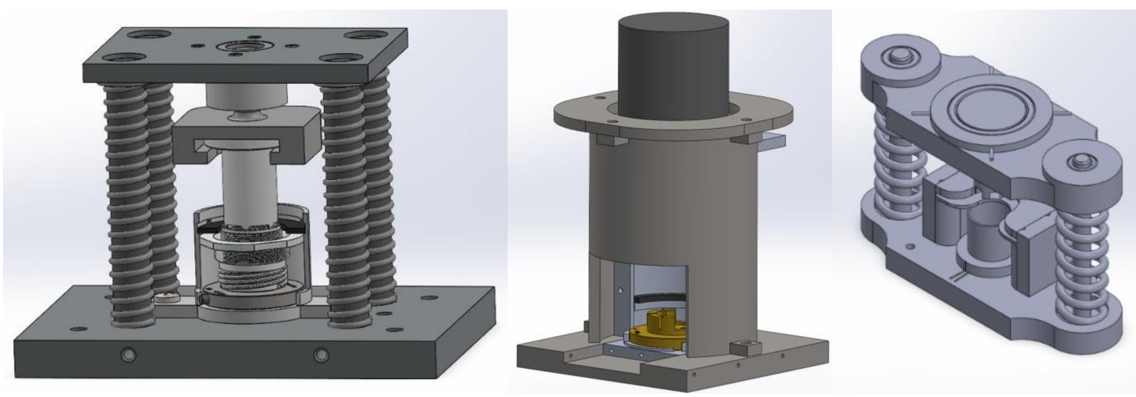
Ref.	Functional Requirement
1	Throughput of 20 connectors per business day
2	Punch OD and connector shell ID must be concentric within 0.004"
3	Top and bottom plates of press must be parallel within 0.005"
4	Split in connector ring must not be aligned with keyway (Operator instruction, not criteria for machine)
5	Insert key must be aligned with shell keyway to prevent rotation (Operator instruction, not criteria for machine)
6	Must not damage the connector within tolerances described by AFSI surface and plating inspection criteria
7	Must be adjustable for the size 15 & 21 connectors with corresponding press die configurations

Ref.	Functional Requirement
8	PLC controller used with press to apply loads specified in **Table 1**
9	Punch must apply loads specified in **Table 1** ± 5%
10	Punch must be applied at 2 locations on staking ring at a multiple of 30° ± 5° apart
11	Punch must be interchangeable and able to be locked into machine
12	Connector holder must either be interchangeable or allow for multiple connector sizes
13	Prototype must have a safety stop if press operation is automated and not direct manual operation
14	Connector holder must hold connector in place and prevent unintentional rotation
15	Staking Machine must not be excessively large in horizontal cross-sectional area, <10' sqft
16	Must require a two-hand safety switch to be engaged in order for the press to operate
17	Must be able to select at least two force set points through user interface that connects to the PLC
18	PLC must have at least 6 Digital I/O points and 4 Analog I/O points
19	PLC must display active force measurements to the user interface
20	Insert's Z-height displacement must be .003" or less after inspection force from **Table 2** is applied (Staking valuation criteria performed independent of machine)

2 - Design Alternatives

At the outset of the project, the Client donated a pneumatic press of unknown status. Our first idea for this project was to simply use the press as-is and attach a "floating" mechanism to the bottom plate for shell alignment with the press. We quickly came to understand that it would be some time before the press was functional and ready for testing, and that to make the press fully operational would take some funding, on par with labor and material costs for creating a die set. So, knowing that we would be in trouble if the press wasn't properly aligned within the tolerances of **Table 2** and if we didn't have an alternative ready, we decided to start designing a die set.

During the conceptual design phase two main groups of designs took precedent. The first group were "die-set" inspired systems to align the staking operation, designing for the emphasis of pre-alignment, having the user pre-align the punch into the connector. The second design group was "plunger" based designs focused on controlling the concentricity and axial alignment of the staking operation, with an emphasis on constraining the system. The plunger designs did this by constraining the staking operation inside of a hollow tube, having a plunger be the interaction point between the press and tooling. The die-set and plunger-based designs are shown in **Figures 4 through 6**.



Figures 4-6: Die-Set concept 1 (left); plunger concept (middle); Die-Set concept 2 (right)

To converge on a solution, the team split concept evaluation into two rounds, initial concepts that the team brainstormed and preliminary concepts to present to the client during the preliminary design review (PDR), with a trade study at the end of each round. The idea being that the best designs from the trade study of the first phase would be further innovated upon for the second trade study that determined which three designs to present to the client. The trade studies that the team conducted were Pugh Matrix trade studies. Further details about both evaluation phases can be found in the conceptual evaluation subsection.

The preliminary designs will first be presented in the preliminary design section and then the details of the 2-phase concept evaluation, evaluation criteria, and evaluation methodologies will be explored in the concept evaluation section.

At the end of the conceptual design phase, the team presented three concepts to the client during their PDR: Concept A – Plunger Housing, Concept B – Die-Set with Pre-alignment by Floating Tool, Concept C – Die-Set with Pre-alignment by Adjustment Screws

2.1 - Concept A – Plunger Housing

Concept A focused on having a fixed control on axial alignment throughout actuation, resulting in the cylindrical system in **Figure 7**. The main idea of the plunger housing design was to design all parts to fit with one cylindrical housing structure, allowing for both tool and connector to slide out of the assembly via two grooved channels.

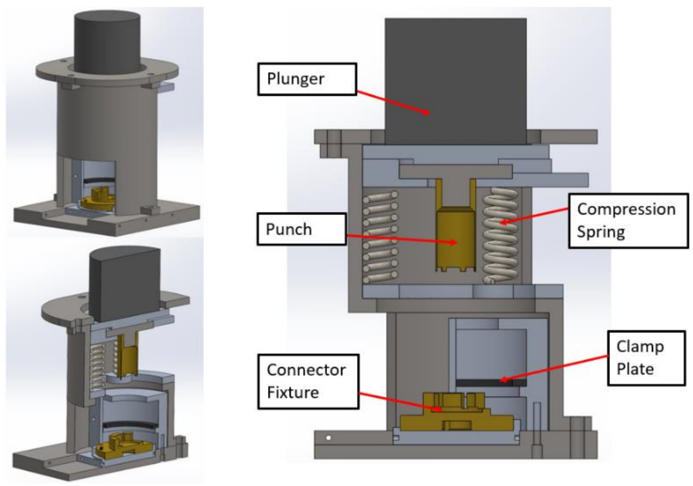


Figure 7: Isometric and cross section views of Concept A

A sliding plate then allows for the connector fixture to move easily in and out of the device (**Figure 8**). An interchangeable clamp plate and clamp housing structure are then bolted directly to the bottom plate. The tooling is then held within its tool housing which is kept in position with compression springs that help with retracting the tool. The plunger then comes in during actuation displacing the tooling downward and staking a connector.

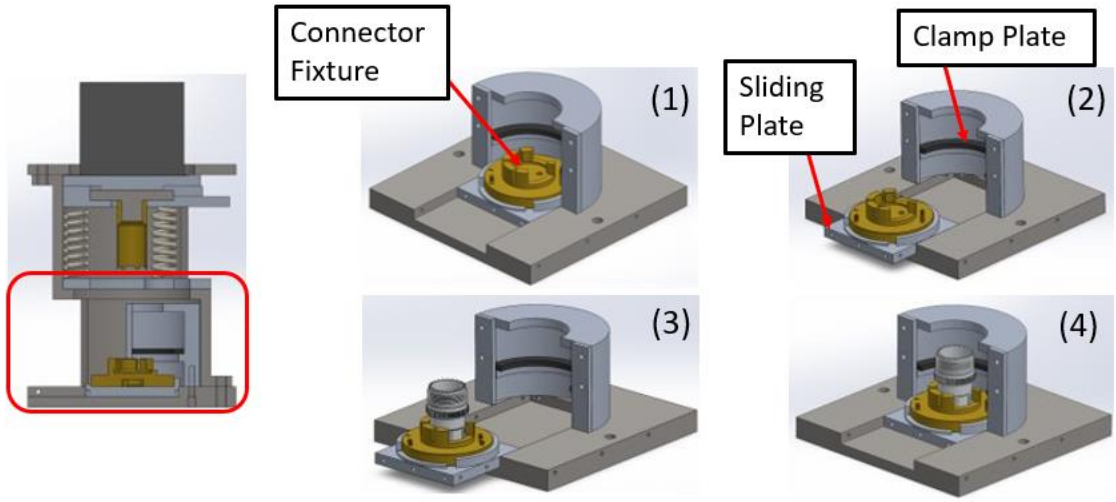


Figure 8: Sliding plate subassembly of Concept A

The tool punch operates on a similar sliding mechanism to the sliding plate that is built inside of the housing structure. However, there is a tool locking mechanism, **Figure 9**, consisting of two plates that lay atop each other. When the plunger is disengaged, the two plates are free to move against each other within the housing structure. The bottom punch lock plate acts as the rail for the punch to slide into the plunger mechanism, having fallen into a recess that locks the tool rotationally. The top punch lock plate then rests loosely atop the bottom plate to allow the tool punch to slide freely into the recess of the bottom plate. Then, when the plunger comes down and engages the system, an extruded feature on the top pushes the top punch down into bottom plate, geometrically locking the tool punch and the plates. The system is then ready for the staking operation.

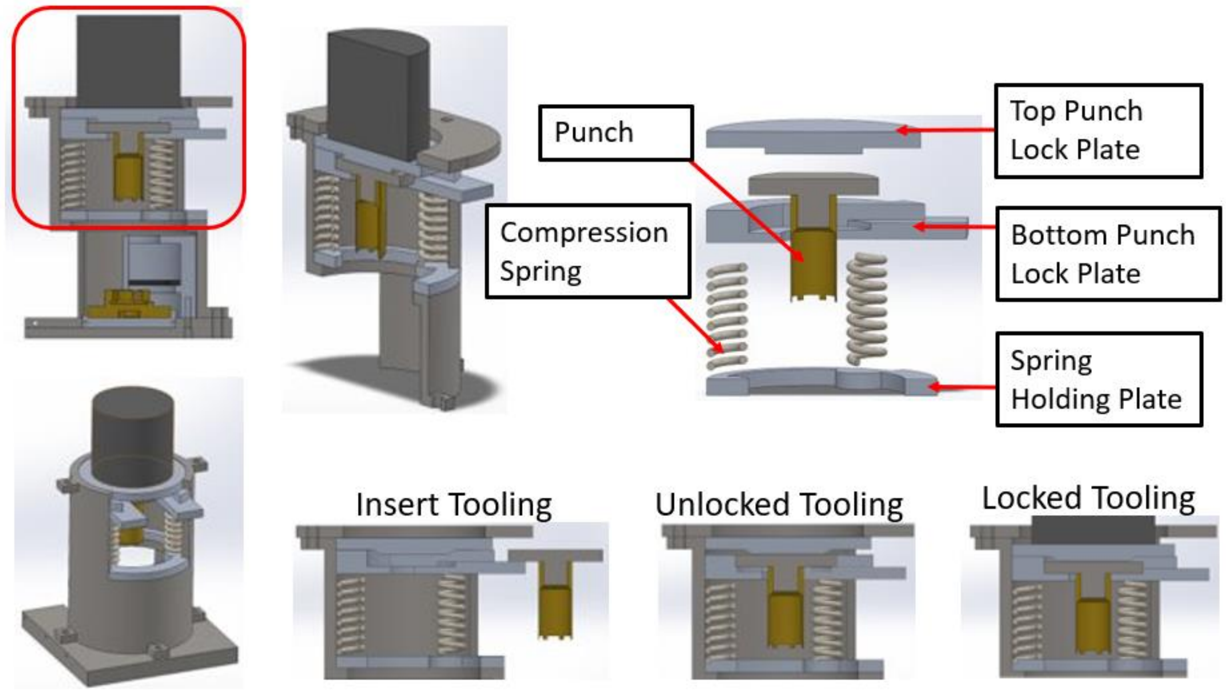


Figure 9: Tool Punch Lock Subassembly of Concept A

2.2 - Concept B – Pre-alignment with Floating Tool

In concept B, the staking is performed with a fixed connector and a tool with flexibility, or "floating", in its position relative to the tool plate. The necessity of a floating tool was identified early in the project because of the tight fit observed when handling the samples provided by the client. As shown in **Figure 10**, Concept B uses a die set with 4 linear guide rods to ensure perpendicular alignment between the punch and shell is maintained.

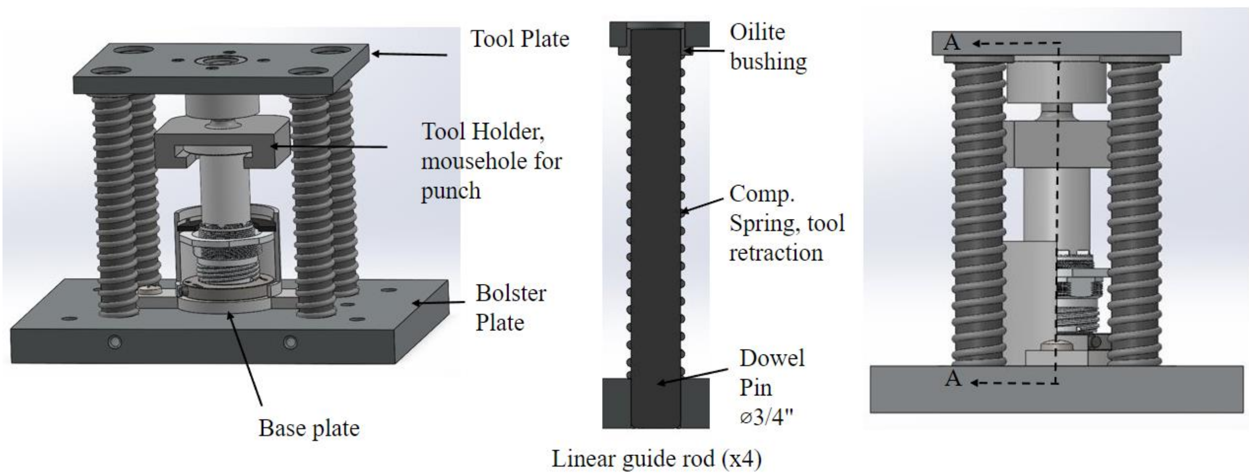


Figure 10: Assembly isometric views and guide rod section views of Concept B

A base plate has a pressed dowel pin which the connector fixture is placed onto, as shown in detail C of **Figure 11**. Also shown in the detail, a clamp plate is used to secure the connector as the tool retracts and attempts to lift the shell; the clamp plate can slide out of the base plate for exchanging clamp plates corresponding with different shell sizes. For the tool, the punch can slide into the tool holder, allowing for easy exchange for different size punches. The tool holder features a vertical rod with a disc on top, referred to as a puck; the puck is housed in the cradle and has clearance for floating.

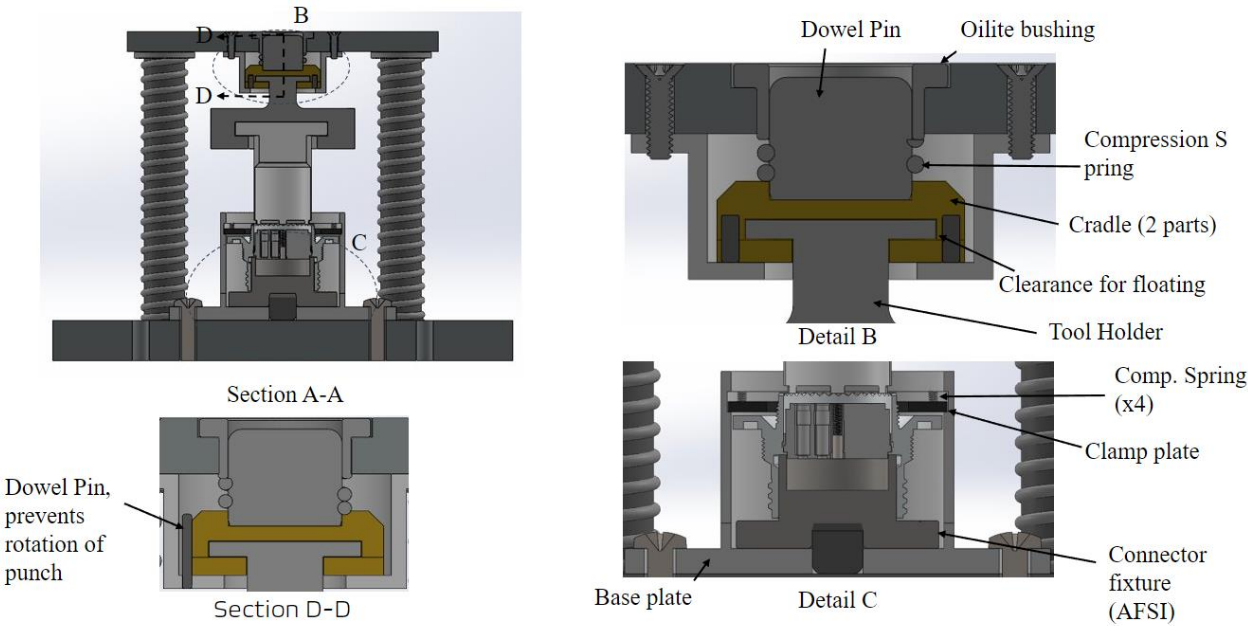


Figure 11: Detail views of Concept B

2.3 - Concept C – Pre-alignment with Adjustment Screws

Concept C, shown in **Figure 12**, focused on simplicity in an alignment housing that is not dependent on a specific press. It builds off the same early design as Concept B but attempts to overcome the shortcomings of the earlier design in different ways.

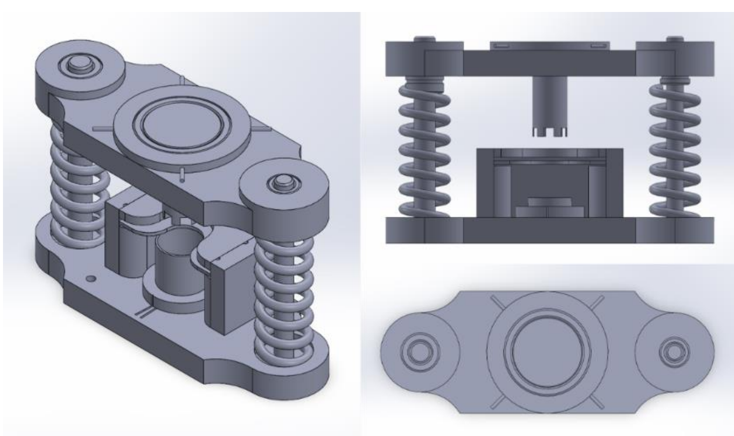


Figure 12: Isometric, front, and top views of Concept C

Like Concept B, it is similar to a modified die-set from the early design. It also features springs for tool retraction, callout 1 in **Figure 13**, and a similar structure for holding the connector in the z-direction while the tool pulls out (2). The most notable difference from Concept B, besides relying on two alignment rods instead of four (3), is its use of adjustment screws (4) instead of the floating tooling holder for controlling alignment with the shell. The decision to switch to two alignment rods instead of four was meant to relieve concerns about over-constraining and maintaining axial alignment. The adjustment screws were implemented to provide an alternative to floating that would still allow for some level of pre-alignment.

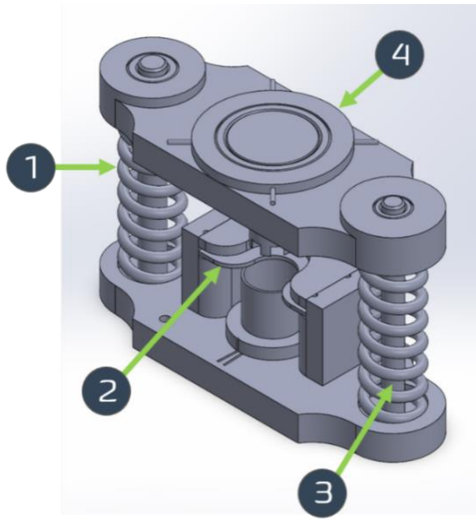


Figure 13: Component callouts from Concept C

The shell-holding structure, shown in **Figure 14**, prevents the connector from moving along the z-axis during tooling retraction. The premise is the same as that of Concept B, just in slightly different geometry. A shell-specific plate (1 - shown in yellow) is inserted into the structure and has a mouse hole sized to contact the shell without interfering with the punch tooling. The outer components of the structure (2 - shown in blue) are sturdy and can be sized to function as a hard-stop for the system. The connector fixture, or puck, keeps the shell from translating in the x and y-directions by fitting on a properly sized peg (3 - shown in pink) in the center of the base plate. The red components in the figure (4) represent the size 21 shell and puck provided by AFSI.

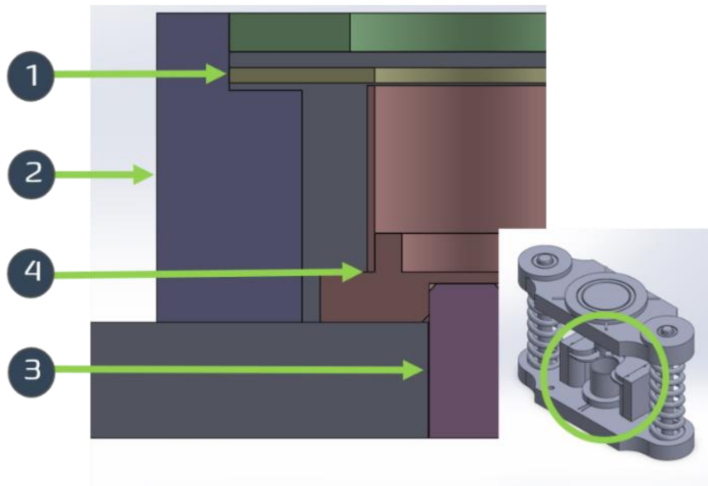


Figure 14: Section view of Concept C shell-holding structure

As noted earlier, the alignment adjustment mechanism is the most notable difference between Concepts B and C. Concept C relies on adjustment screws, shown in **Figure 15**, to tweak the alignment instead of the floating tool holder design shown in Concept B. The screws (1 – shown in pink) are installed on an outer ring (2 - shown in yellow) that is machined into the top-plate. These screws can be adjusted generate small lateral movements to the inner ring (3 - shown in blue). The punch tooling (shown in red) is nested in the inner ring and moves with it during adjustment. A spacer (4 - shown in green) sits on top of the tooling to prevent it from moving along the z-axis during staking.

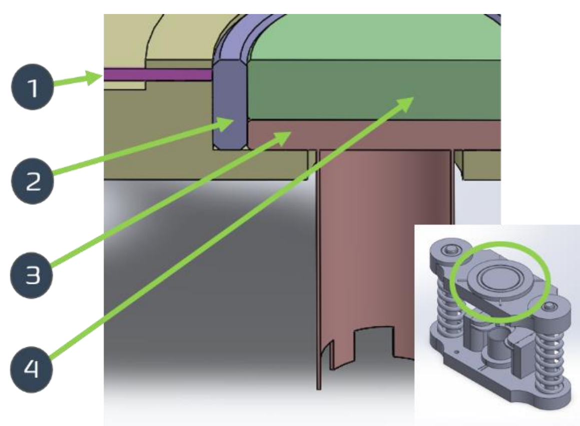


Figure 15: Section view of Concept C tool-holding and alignment adjustment structure

2.4 - Concept Evaluation

During the conceptual design phase of the project, the team performed several iterations of brainstorming and rough design to generate viable concepts for the staking machine. Evaluating the designs were then split into two rounds: initial concept evaluation and preliminary concept evaluation. By the end of the conceptual design phase, 11 designs would be considered by the team: 7 initial designs and 4 designs considered for preliminary designs. To evaluate and compare these concepts, the team constructed a Pugh Matrix with 19 selection criteria they deemed essential for the project's success:

- Z-Holding (Shell): How well the design restricts the movement of the shell along the z-axis.
- X-Y Holding (Shell): How well the design restricts the movement of the shell along the x and y axes.
- Rotational Holding (Shell): How well the design restricts the rotation of the shell along the z-axis.
- Z Holding (Tooling): How well the design restricts the movement of the punch tooling along the z-axis.
- X-Y Holding (Tooling): How well the design restricts the movement of the punch tooling along the x and y axes.
- Rotational Holding (Tooling): How well the design restricts the rotation of the punch tooling along the z-axis.
- X-Y Alignment: How well the design maintains the concentric alignment between the shell and the punch tooling.
- Axial Alignment: How easy it is to maintain parallelism between all the axes of the design.
- Ease of Use: How easy the design is to use for the operator.
- Modularity: How easy it is to switch between the different connector sizes.
- Simplicity: The overall complexity of the design.
- Overall Cost: The anticipated cost of the design is based on how difficult the team believes it would be to machine the required custom parts.
- Retraction of Tool: Whether the design accounts for retracting the punch tooling to remove it from the connector after staking is complete.
- Reliability: How consistently the design is expected to perform during repeat use.
- Durability: How easy the design is to damage.
- Does it fit? (Z-Height): How well the design fits in the available space in the operating area of the press provided by the client (8").
- Indexing: If design accommodates the needed 90-degree rotation of the connector needed between the two punches required for staking.
- Overall Force Requirements: If design requires more force applied by the press than the staking forces defined by **Table 1.**
- Removing Connector: How easy it is to remove the staked connector from the device after completion and replace it with the next connector to be staked.

These selection criteria were used to construct the first round Pugh Matrix, shown in **Table 4**, meant to evaluate the concepts generated in the team's brainstorming sessions. There were originally seven concepts to be evaluated, however Concept 1 was withdrawn from consideration before the evaluation based on feedback from the team mentor and client about safety and viability concerns. Concept 2 was chosen as the reference concept and therefore given a (0) score for all the selection criteria to establish a baseline. From there, each concept was compared to the reference concept along all the selection criteria to see whether they performed better (+), worse (-), or the same (0) when compared to the reference. These selection criteria were not weighted as the team felt they did not yet have a thorough enough understanding of all the needs of the project to make that decision at this early stage.

Table 4: First round Pugh Matrix

Selection Criteria	**2 (REF)**	**3**	**4**	**5**	**6**	**7**
Z Holding (Shell)	0	+	+	0	-	0
X-Y Holding (Shell)	0	0	0	0	0	+
Rotational Holding (Shell)	0	0	0	0	0	0
Z Holding (Tooling)	0	0	0	0	0	0
X-Y Holding (Tooling)	0	0	0	0	0	0
Rotational Holding (Tooling)	0	0	0	0	0	0
X-Y Alignment	0	-	+	+	0	+
Axial Alignment	0	-	-	-	-	0
Ease of use	0	+	+	+	+	+
Modularity	0	+	+	+	+	+
Simplicity	0	-	-	-	+	+
Overall Cost	0	-	-	-	+	-
Retraction of Tool	0	0	0	0	0	0
Reliability	0	-	+	+	+	0
Durability	0	0	-	0	+	0
Does it fit? (z-height)	0	+	0	0	+	0
Indexing	0	0	0	0	-	-
Overall force requirements	0	0	0	0	-	-
Removing Connector	0	+	+	+	+	+
Sum +'s	0	5	6	5	8	6
Sum 0's	20	10	10	12	8	11
Sum -'s	0	5	4	3	4	3
Total Score	**0**	**0**	**2**	**2**	**4**	**3**
Rank	4	4	3	3	1	2

This Pugh Matrix put Concept 6 as the then lead concept, with Concept 7 coming in second and concepts 4 and 5 tied for third. Concept 4 was then withdrawn from consideration by its originator over concerns of manufacturability raised by the machine shop lead, Andrew Bittner, leaving the team with three ranked concepts.

After evaluating the first-round concepts on the Pugh Matrix, the team iterated on the leading designs to improve the areas in which they scored (-) to drive up the overall quality of the design. During this process, four new designs were created from the lead initial concepts: Concepts 5, 6, and 7 evolved into Concept 5B and 6B, and 10 respectively. Concept 8 was a new design methodology inspired by AFSI's current staking method at their sister company. Concept 8 was included in the second round and not the first due to the when the operation information was discovered and reverse engineered. These new designs were then evaluated against the same selection criteria in a new Pugh Matrix, shown in **Table 5**. Concept 6B, which would later be renamed as Concept C was chosen as the reference concept. It was evaluated against concept 6, the lead design from the original Pugh Matrix, to establish a baseline as any new concept that performed worse on the matrix than the original lead concept would not be considered. Then, the remaining new concepts were compared to the reference design to generate the new concept ranking.

Table 5: Second round Pugh Matrix

Selection Criteria	6	10 Concept A	5B	6B (REF) Concept C	8 Concept B
Z Holding (Shell)	-	0	-	0	0
X-Y Holding (Shell)	0	0	0	0	0
Rotational Holding (Shell)	0	0	0	0	0
Z Holding (Tooling)	0	0	0	0	0
X-Y Holding (Tooling)	0	0	0	0	0
Rotational Holding (Tooling)	0	0	0	0	0
X-Y Alignment	-	0	+	0	+
Axial Alignment	-	+	0	0	0
Ease of use	+	+	-	0	+
Modularity	0	+	+	0	+
Simplicity	+	0	-	0	0
Overall Cost	+	-	-	0	-
Retraction of Tool	0	0	0	0	0
Damage to Connector	0	0	-	0	-
Reliability	0	0	+	0	+
Durability	-	0	-	0	0

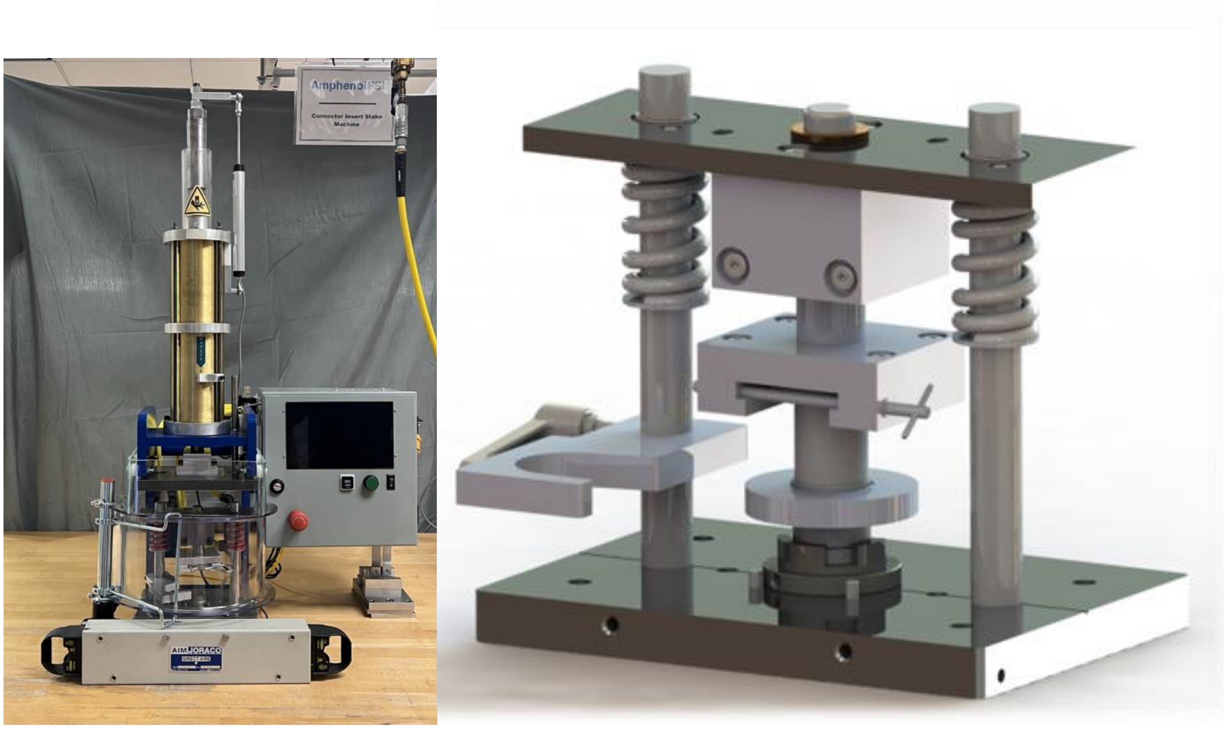
Selection Criteria	6	10 Concept A	5B	6B (REF) Concept C	8 Concept B
Does it fit? (z-height)	0	0	0	0	0
Indexing	-	0	0	0	0
Overall force requirements	0	0	+	0	0
Removing Connector	-	0	+	0	0
Sum +'s	3	3	5	0	4
Sum 0's	11	16	9	20	14
Sum -'s	6	1	6	0	2
Total Score	**-3**	**2**	**-1**	**0**	**2**
Rank	4	1	3	2	1

Concepts 10, 8, and 6B (now A, B, and C) emerged as the top choices after team evaluation using the Pugh Matrix. Each concept's originator presented its design, operation, research, vendors, and potential failures. The team then voted on selection criteria, leading to a tie between Concepts A and B. A tiebreaker discussion involved client questions, mentor input, and advice from the UTD Machine Shop. Concept B was favored due to easier access and minimal connector damage concerns. Machinability also favored Concept B. Consequently, Concept B was chosen as the lead concept for further development after the PDR.

3 - Final Design Solution

3.1 - Description of Design

The team was responsible for the mechanical, electrical, and software development needed to run the machine, as well as the systems integration and control of the staking machine. The staking machine, **Figure 16**, features a custom die-set installed in a retrofitted pneumatic press.



Figures 16 & 17: Staking machine (left) and rendering of tooling (right)

The staking machine tooling, **Figure 17,** was designed for axial alignment, allowing manual pre-alignment of the punch into the connector. The tooling also features a passive retraction system using die springs to retract the punch with 200 lbs. of force after actuation. The tooling was then installed into a retrofitted Direct Aire Model 400T pneumatic press.

The pneumatic press was originally donated by the client in a manual control configuration. The team then determined that in order to have an accurate digital control, the press would need to be upgraded with the following: air filtration system, digital pressure regulator, pneumatic line auto oiler, potentiometer, linear potentiometer for distance sensing, 2,000 lb rated load cell with transducer, as well as an Arduino Portenta programmable logic controller (PLC) for system control and a 9-inch touch-screen display connected to a Raspberry PI that serves as the human-machine interface (HMI).

3.2 - Staking Machine Tooling

In order to fulfil the high precision and alignment requirements, the staking machine tooling was designed with emphasis on control and usability. The staking machine tooling (**Figure 18**) was designed for axial alignment and constraint by riding on two guide posts mounted to a bolster plate. Pre-alignment is then possible through the floating housing that the tool holder sits in. The tool holder then allows for interchangeable tool punches to be used. A set of die springs is then utilized to create a passive retraction system that applies a 200 lb upward load after the actuation to retract the punch.

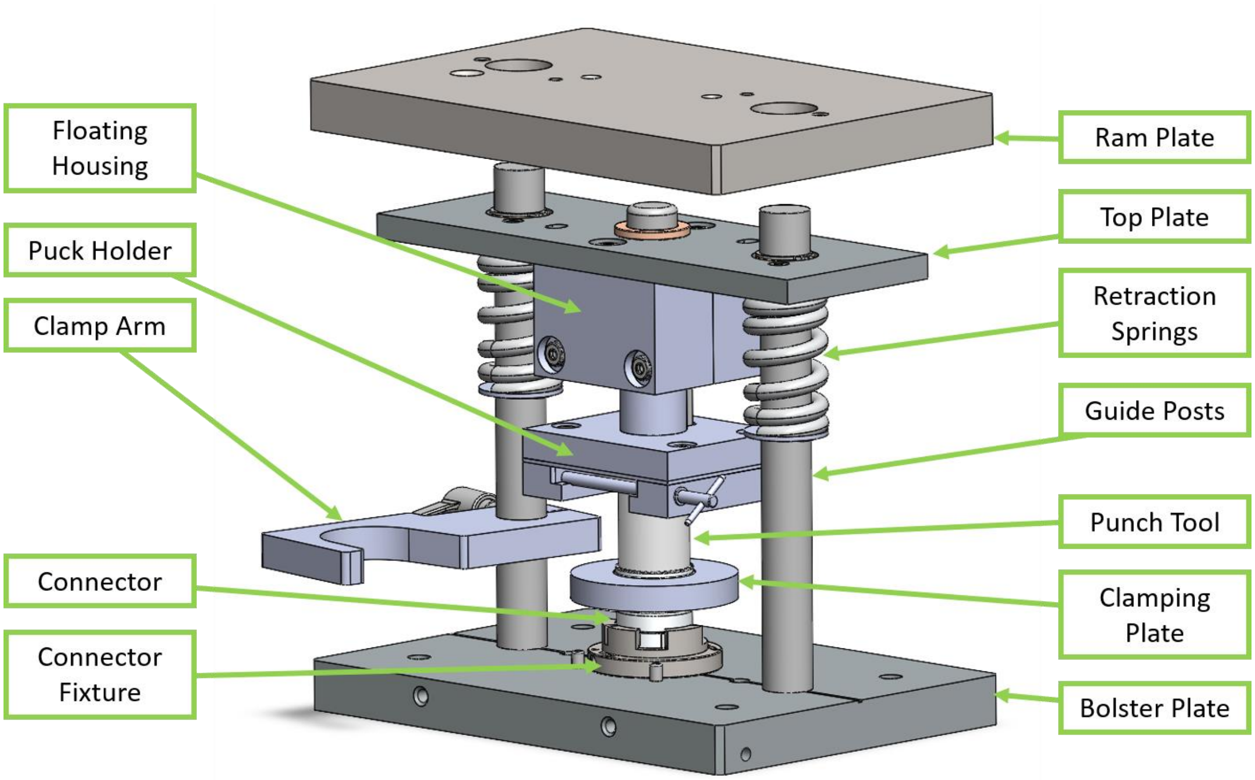


Figure 18: Tooling assembly with component callouts

The tooling consists of a bolster plate with two alignment guide posts connecting the top plate, and a central dowel pin to hold the connector fixture, allowing for 90° rotation between two press-fit hard stops (**Figure 19)**.

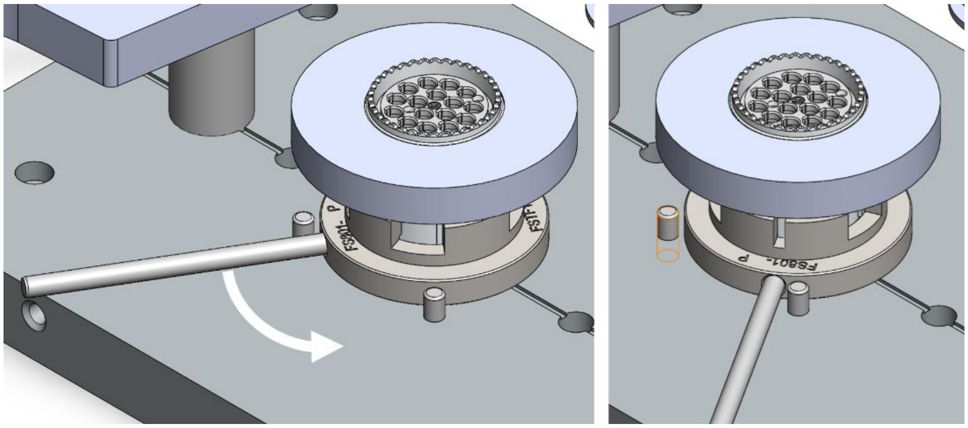


Figure 19: 90° rotation of connector between pin stops

The guide posts are grooved to support snap rings and washers that hold a set of die springs for retraction (**Figure 20**).

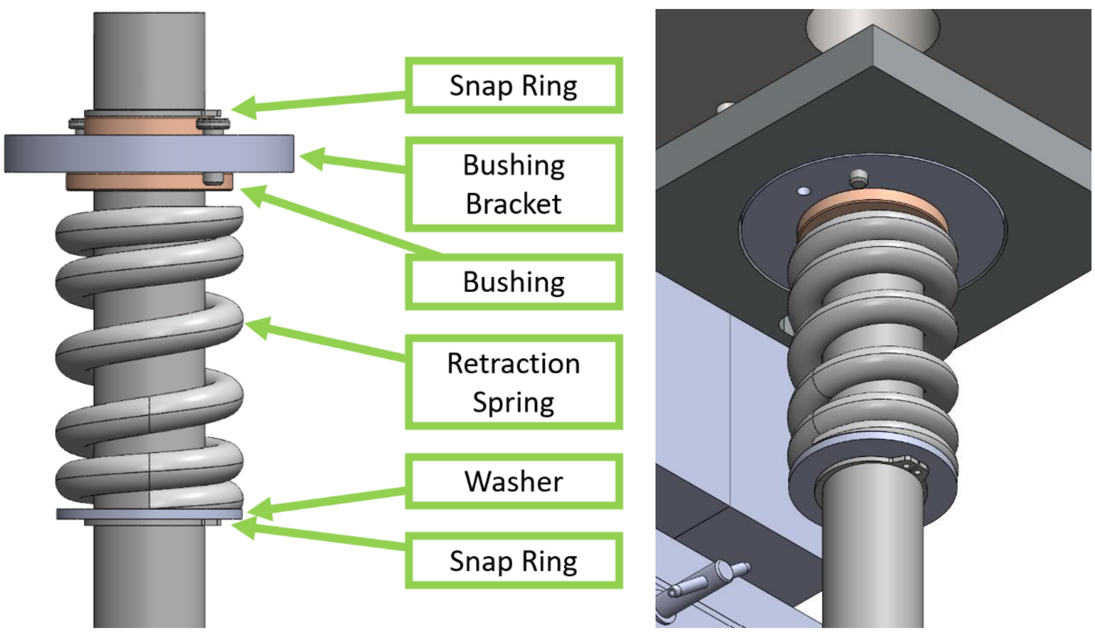


Figure 20: Retraction components on guide posts (left)
and installation to underside of top plate (right)

The top plate rests on the springs, maintaining alignment through bushings on the alignment rods **(Figure 20)** and is held in position by snap rings. This allows the top plate to displace downwards with the ram plate. The machine retracts into its original position after actuation from the stored energy in the springs.

The top plate is connected to a two-piece floating housing (**Figure 21**, allowing the tool holder sub-assembly to "float" in the oversized cavity, moving laterally within tolerance. The housing is keyed with the tool holder to prevent excessive rotation about the z-axis.

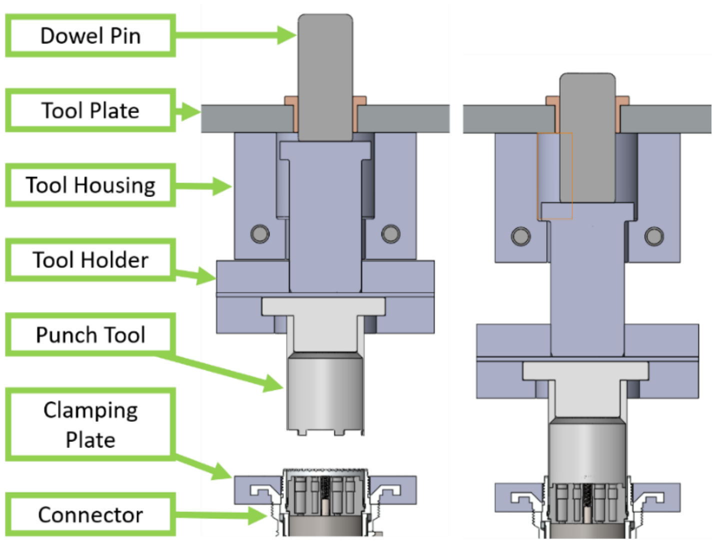


Figure 21: Cross-section of tool holder in housing

The tool holder features a locking pin to secure the punch, preventing accidental shifts during operation.

3.3 - System Controls and Software Design

The staking machine uses an Arduino Portenta Machine Control PLC (PMC) for software operations and data collection management. The on-board load cell was then replaced with a 2,000 lb rated load cell to be accurate within the 200 lb - 1800 lb operating range. A linear potentiometer provides z-height displacement readings, a pressure regulator controls variable pressure command input, an air filtration and oiling are used to clean and prepare the air for the actuating mechanisms in the regulator, solenoids, and cylinder. A Raspberry Pi then operates a 9-inch touchscreen HMI display, and a lockout tagout system prevents unauthorized use (**Figure 22**).

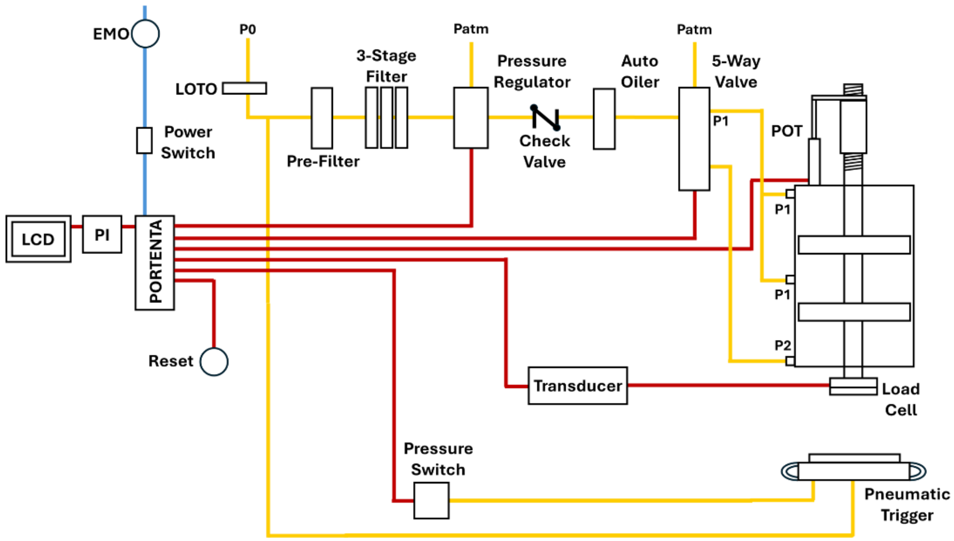


Figure 22: Block diagrams of the system

An overview of the pneumatic system is shown in **Figure 23**. Note that the minimum air supply is 60 psi and that the air supply is set with a 100-psi pressure release valve on the air filtration system. It is recommended that operation of the staking machine is done at 100 psi air supply. Also, note that the pneumatic cylinder has three chambers and is configurable. The current two chambers for the top of the cylinder and one chamber for the bottom of the cylinder. This configuration allows the cylinder to achieve a higher application force during the downstroke of actuation.

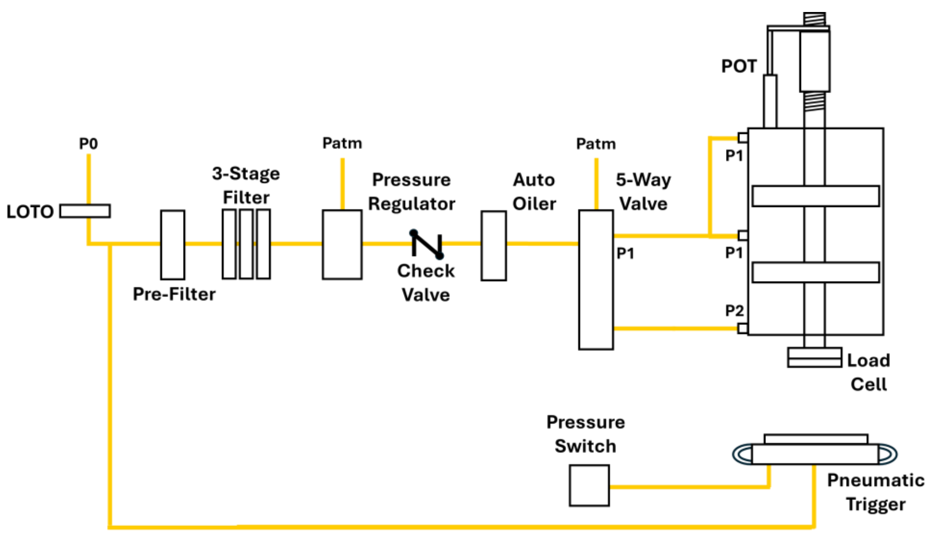


Figure 23: Pneumatics schematic for Staking Machine

The HMI manages the user input and operation instructions, communicating them to the PLC via Modbus RTU protocol, which controls pneumatic actuation, force control, and sensory readings. **Figure 24** shows the software architecture overview. Operation logic flow charts for staking and backup retraction can be found in **Appendix A**.

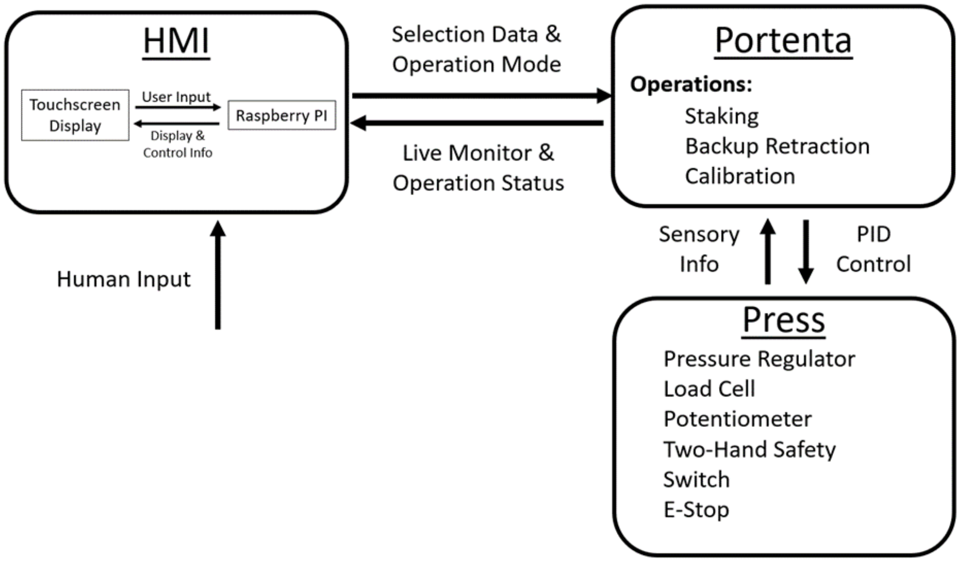


Figure 24: System architecture of press control system

3.4 - Operation of Design

The staking machine has three main operations: staking, retraction, and calibration. The staking operation is the primary function, while the retraction operation allows for manual retraction in case of jamming. Calibration involves a 5-point calibration test with an external load cell to update the parameters within the PLC software.

Staking Operation:

Step 1: Prepare Staking Machine – Swing the clamp arm open, insert the appropriate size punch into the holder, and lock punch using locking pin (**Figure 25**).

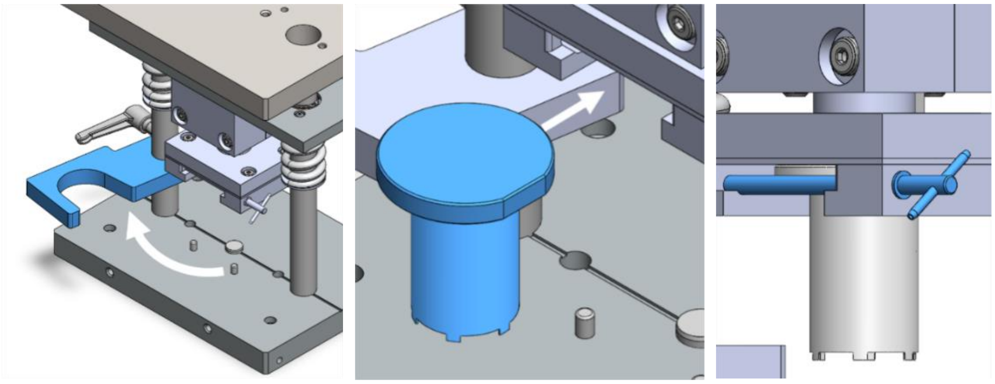


Figure 25: Open clamp arm (left), insert punch into tool holder (center), and lock punch with pin (right)

Step 2: Run Touch off Sequence – Load the reference block onto the center pin of the bolster plate, then click to run the automated calibration sequence in the HMI. The PLC runs the press to touch the punch to the reference block to get the z-height location of the punch tip (**Figure 26**). Remove reference block once complete.

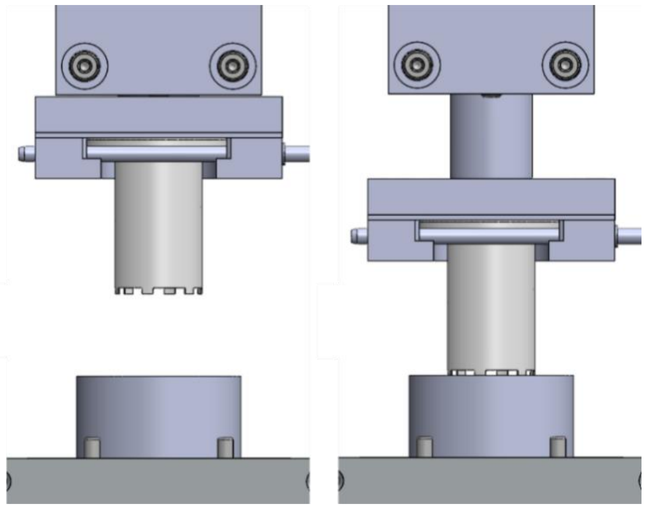


Figure 26: Touch off sequence

Step 3: Prepare Connector Shell – Prepare a connector with an insert and staking ring before placing the prepared connector on the corresponding connector fixture. Place the appropriate clamp plate onto the connector shell so the clamp arm can restrain the connector (**Figures 27 & 28**).

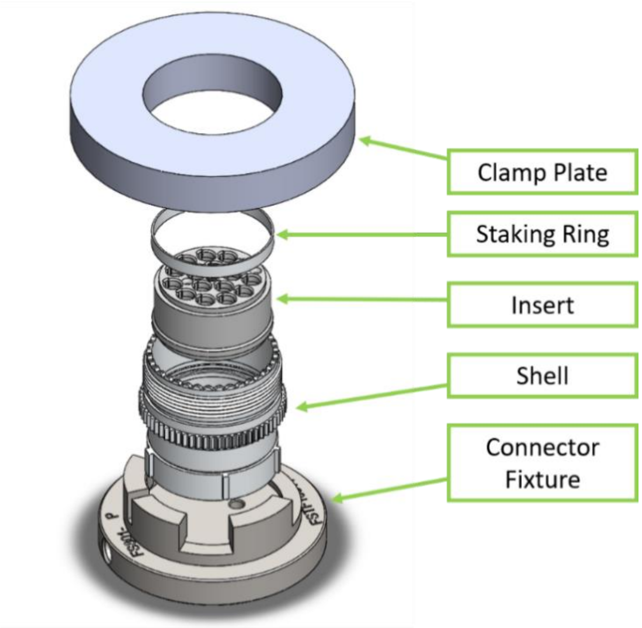


Figure 27: Exploded view of connector assembly

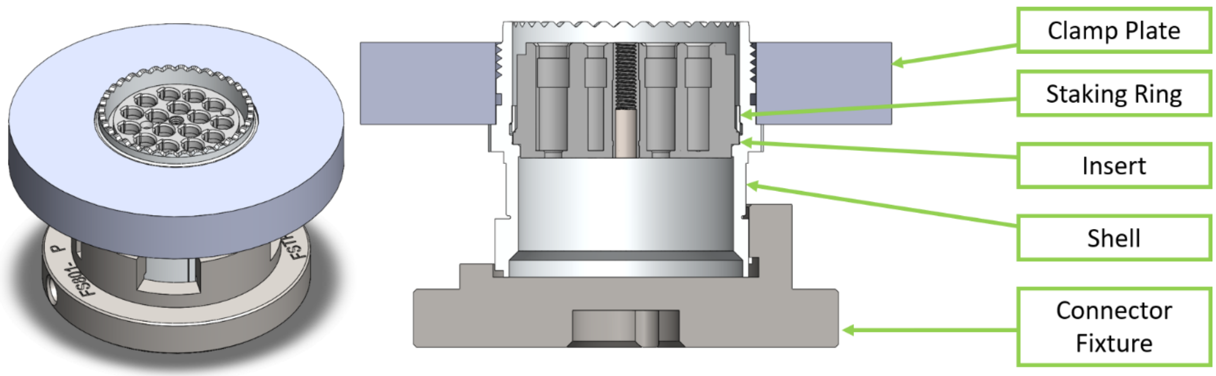


Figure 28: Connector assembly together

Step 4: Load Connector Assembly – Lift the tool holder while inserting the connector assembly into the staking machine (**Figure 29)**.

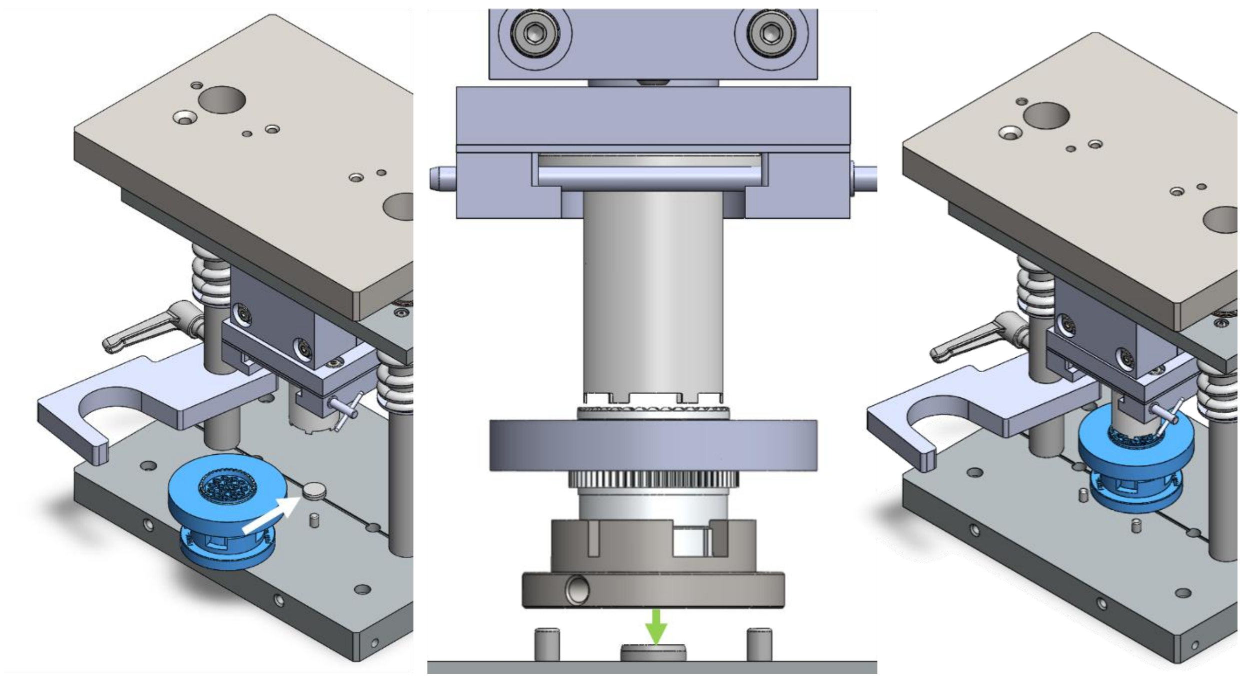


Figure 29: Insert connector fixture into machine

Step 5: Pre-Align Punch & Connector – The punch is lowered and aligned into the connector shell (**Figure 30**).

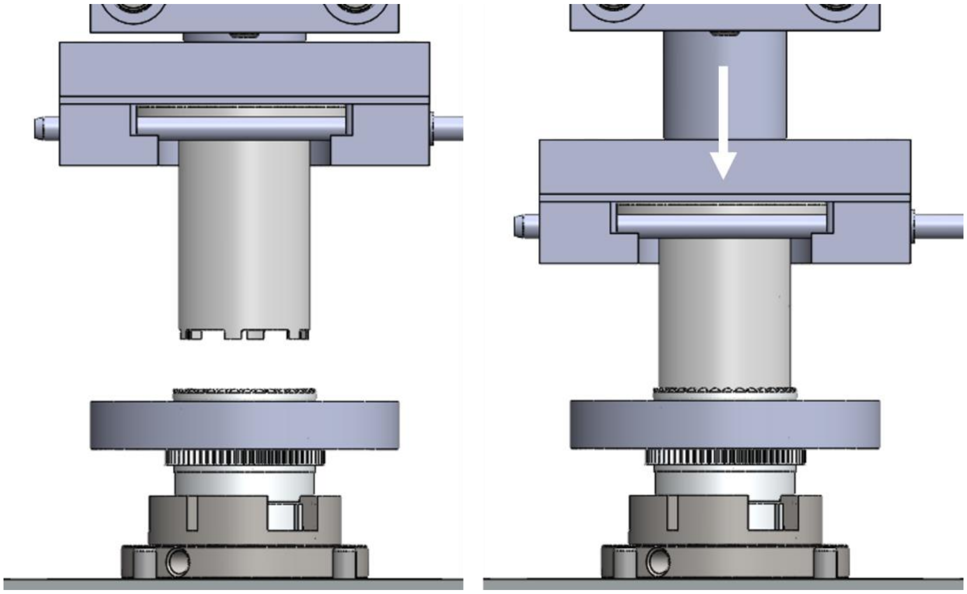


Figure 30: Pre-align punch and lower into connector

Step 6: Close Clamp Arm – Swing the clamp arm closed and tighten handle to secure (**Figure 31**).

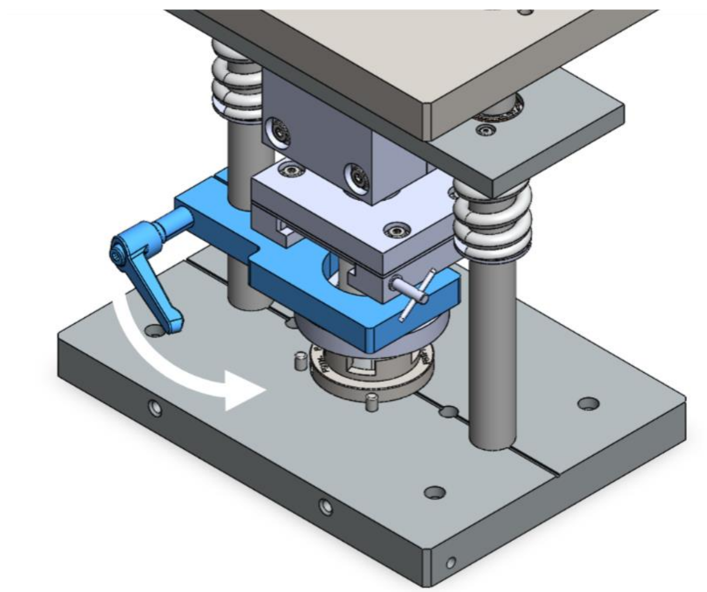


Figure 31: Close clamp arm

Steps 7: Run Staking Actuation—Operator activates the staking actuation using a two-hand safety switch **(Figure 32)**. The press applies the staking force to the punch to deform the staking ring. This action is then repeated after rotating the connector shell 90°.

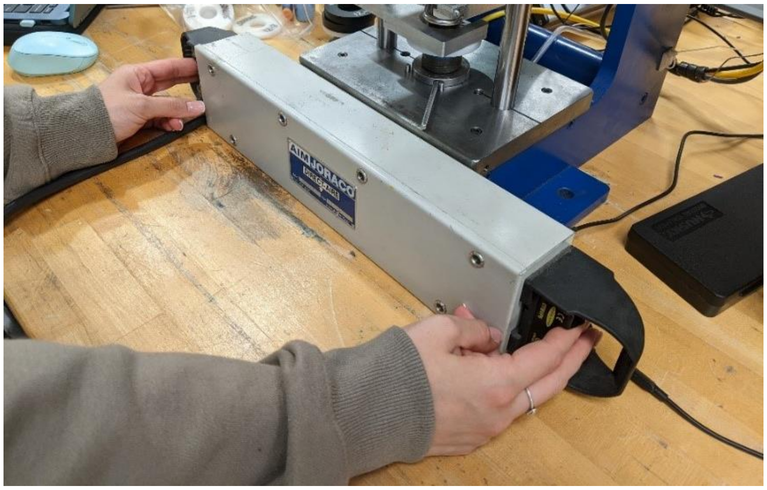


Figure 32: Operator engaging two-finger trigger

Step 8: Staking Complete – The staked connector shell assembly is removed from the staking machine. On the HMI, the operator is given to the choice to stake another connecter of the same type, or go to the main menu.

3.5 - Design Justification

A Direct Aire 400T was provided by the client. The forces the press is rated for by the manufacturer are shown in **Table 6**, with the required staking forces for each shell size shown in **Table 1**. These tables show that the press is capable of staking even the largest shells.

Table 6: Manufacturer Force Chart

Model 400T Force Chart					
Pressure (psi)	**10**	**15**	**20**	**25**	**30**
Force (lb.)	230	345	460	575	690
	35	**40**	**45**	**50**	**55**
	805	920	1035	1150	1265
	60	**65**	**70**	**75**	**80**
	1380	1495	1610	1725	1840
	85	**90**	**95**	**100**	
	1955	2070	2185	2300	

We used SolidWorks to conduct a finite element analysis on load-bearing components with the results in **Table 7** and **Appendix B, Figure 41**. The material properties used in this section were obtained from the MMPDS-10, chapters 2 and 3. We know that Aluminum 6061-T6 has an elastic limit of 40 ksi, while Steel 4130 has an elastic limit of 70 ksi and a fatigue strength of 40 ksi. Al. 6061, rated for 500,000 cycles at 14 ksi, has no fatigue limit. We selected steel 4130 due to cost; however, the clamp arm and tool holder subassembly are Aluminum due to desired density and weight properties of the material. Both parts are lifted by the operator and need to be lightweight for ergonomics.

Table 7: FEA Results

Part #	Part	Material	Yield Strength	Max Stress	Safety Factor
5	Bottom Puck Housing	Al. 6061-T651	35 ksi	2 ksi	>10
6	Top Puck Housing	Al. 6061-T651	35 ksi	4 ksi	8
2	Top Plate	Steel 4140	66 ksi	5.3 ksi	>10
11	Clamp Plate Holder	Al. 6061-T651	35 ksi	14 ksi	2.5

Part #	Part	Material	Yield Strength	Max Stress	Safety Factor
COTS	Snap Rings	Cast Carbon Steel	36 ksi	3.2 psi	>10

Hand calculations were conducted to ensure load-bearing components do not fail under compressive loading, specifically examining the buckling failure mode of the puck holder cylinder. The calculations shown in **Appendix B, Figure 42** show that for both aluminum and steel, buckling does not occur until well above what the press can apply.

Our springs were chosen to provide 200 lb. of retraction force from the staking stroke length, which is believed to be enough to remove punch from the shell, based on impulse force calculations of a slide hammer. This puts the upper bound of the retraction force at 124 lbs, shown in **Appendix B, Figure 43**. After implementing the 200 lb. die-springs, the passive retraction from the springs was verified successful, with jamming occurring from operator error and not the press. Optimizing the springs is left open to the client as a future recommendation.

The pressure control was chosen due to its direct influence on force output, making it more manageable than height control. An electronic pressure regulator was added, and a position sensor was added to monitor height for process success, despite the complexity and cost of the required equipment.

To accommodate the additional I/O requirements and need for analog I/O, we opted for a new PLC, choosing the Arduino Portenta Machine Control for its adequate digital and analog I/O capacities, multiple communication ports to connect the HMI, relative cost-effectiveness, and open-source platform.

The current load cell, rated for 10,000 lb., was replaced due to significant inaccuracies in its operational force range. The new cell, rated for 2,000 lb., was chosen due to its ability to operate within the top 10% of a sensor's measurable range. This decision was supported by press testing data. The detailed results of these tests are available in **Appendix A, Figure 39**.

During the project, the control scheme of the PLC switched to being pressure control with the load cell and potentiometer to act as secondary validation. Using the pressure regulator to control forces, brings the press within less than 2% of desired forces for the entire actuation force range. The detailed results of these test can be seen in **Appendix A, Figure 40.**

3.6 - Standards

The design considers ANSI B5.25-1978: the American National Standard for Punch and Die sets in the tolerancing of the die set [2]. The standard is critical for the staking operation due to the tight clearance of the punch in the shell and minimal room for error in the die set.

The software for our PLC was made compliant to IEC 61131-3, the first vendor independent standardized programming language for industrial automation [3].

The PLC cabinet of our machine follows the NFPA 70 National Electrical Code that ensures safeguards are in place for industrial machinery operators, equipment, facilities, and work-in-progress from fire and electrical hazard as outlined in chapter 11 [4].

3.7 - Safety and Reliability

The staking machine is considered the staking machine die-set installed inside of the retrofitted press. The die-set can have physical failure modes, and the press can have both physical and software failure modes. The failure mode and effects analysis (FMEA) can be seen in **Table 8.** Original safety features on the press included a two-hand safety switch and emergency stop button. These features protect the operating user from putting their hand in the press during operation and allow the user to cut all power to the press in case of an unforeseen emergency. Further safety features, including a pinch guard, a pinch skirt, and a safety shield have been also been installed to protect the operator during actuation.

Table 8: FMEA

Function	Failure Mode	Effects	Cause	Control Method	Severity	Occurrence	Control	RPN	Action Plan
Safety switch releases pressure to electronics switch	Fails to actuate press	Operation failed	Loose wire, no air supply, no power	Visual	3	1	4	**12**	Action Not Required
Safety switch releases pressure to electronics switch	Fails to stop press actuation	Damage to machine / work	Short, part failure	Hard stop	7	1	4	**28**	Action Not Required
5-way valve directs pressure	Fails to open	Operation failed	Loose wire, no power	Visual, error code from PLC	3	1	2	**6**	Action Not Required
5-way valve directs pressure	Fails to close	Damage to machine / work	Part failure	Visual	7	1	2	**14**	Action Not Required
Air pressure regulator supplies desired pressure	Incorrect pressure supplied	Damage to machine / work	Part failure	Error code from PLC	7	1	2	**14**	Action Not Required
Position sensor supplied distance reading	Incorrect distance reading supplied	Damage to machine / work	Part failure, loose wire	Error code from PLC	4	1	4	**16**	Action Not Required
Emergency stop button stops press	Emergency stop button does not stop press	Damage to machine / work	Part failure, loose wire	Visual	9	1	1	**9**	Action Not Required

Function	Failure Mode	Effects	Cause	Control Method	Severity	Occurrence	Control	RPN	Action Plan
Load cell supplies force reading	Incorrect force reading supplied	Damage to machine / work	Part failure, loose wire	Error code from PLC	6	1	3	**18**	Action Not Required
Fastener fixes floating housing	Fastener breaks	Damage to machine	Part Failure	Tolerancing, visual	6	1	5	**30**	Action Not Required
Springs retract tooling	Top plate fails to retract	Operation failed, die set is unreliable	Misalignment	Tolerancing, visual	8	2	5	**80**	Backup Retraction Operation
Punch deforms staking ring	Staking ring does not deform correctly	Operation failed	Castellation defects, incorrect force applied	Visual	5	2	6	**60**	Action Not Required
Punch deforms staking ring	Staking ring jams tool punch in connector	Punch not removed from connector	Castellation defects, incorrect force applied	Visual	7	2	6	**84**	Backup Retraction Operation
Tool holder lifted in floating housing	Tool holder does not raise	Shell cannot be removed	Misalignment, jam in housing	Visual	7	2	8	**112**	Backup Retraction Operation and disassembly of the housing to unjam the holder

Function	Failure Mode	Effects	Cause	Control Method	Severity	Occurrence	Control	RPN	Action Plan
Clamp plate fixes connector	Clamp plate does not hold connector during retraction	Punch not removed from connector	Quick release clamp not secured	Visual	5	3	6	**90**	Manual Tool Release and Backup Retraction
Touchscreen Displays GUI	User input misread	Press operation mis-selected and potential staking failure	Loose wire	Error from PLC, Visual	7	3	3	**63**	Action Not Required

With the critical risk priority number (RPN) set to 80, several failure modes come to the forefront. The first failure mode to hit this threshold involves the spring retraction of the tooling and what should happen if the top plate fails to retract after staking a connector. This would indicate an operation failure impacting the reliability of the die-set due to misalignment. Initially, this function of the solution is controlled by tolerancing and visual inspection. In preparation for the event of failure, a backup retraction operation has been designed in which the ram plate is lowered until making contact with the device. The top plate of the mechanism is then physically attached to the ram plate, allowing the force from the press to retract the plate, dislodging the jam.

This backup retraction operation is also involved in enabling the operator to address three other critical failure modes. The first involves the punch function that deforms the staking ring. Should the staking ring jam the tool punch into the connector, the operator will not be able to remove the punch from the connector due to castellation defects or improperly applied forces. The same backup retraction operation can be employed to pull the punch out of the connector using the force from the press.

The backup retraction operation also helps address a potential failure mode in the tool holder, specifically its floating housing. Should the operator be unable to raise the tool holder, first they should engage the backup retraction operation in order to remove the connector from the punch tool. From there, the operator would need to detach the ram plate from the top plate and then remove one half of the floating housing structure by unscrewing the two screws holding it to the other half, and then removing the screw fixing the first half to the top plate. Once the half of the housing is removed, the jam will be dislodged and the housing can be reassembled.

Lastly, in the function of the clamp plate fixing to the connector, a failure mode could arise in which the clamp plate does not hold the connector in place during retraction. If the connector is allowed to move with the retraction force, it will not be removed from the punch tool. This could be caused either by a failed clamping plate or by improperly securing the quick release clamp. In the event of the first scenario, the operator would need to remove to the pin securing the punch tool in its holder and remove the punch tool from the mechanism with the connector still attached. The clamping plate would then need to be replaced, requiring some disassembly. In the latter case in which the quick release clamp was improperly secured, the backup retraction operation would be engaged to apply enough force to the system to return the connector to its lower position in the connector fixture. This will relieve the force angling the clamping plate, allowing the operator to resecure the quick release clamp to proper hold the connector. The backup retraction operation can then be disengaged, allowing the retraction springs to remove the punch tool from the connector.

4 - Design Validation

4.1 - Compliance Matrix

A compliance matrix is a tool used in project management and quality assurance to ensure that all requirements, specifications, standards, or regulations are met. It provides a structured way to track and verify compliance with various elements that are essential for the successful completion of a project or the achievement of a desired outcome. The compliance matrix detailed in **Table 9** pairs the final project specifications with their respective acceptable outcomes and verification methods, as well as space to record their test results, whether the machine passed or failed against the acceptable outcome, and additional notes if needed.

To validate that the final specifications have been successfully met, four commonly used verification methods are employed:

- Inspection (I): This involves visually examining or taking simple measurements to ensure that a specification is met. It also includes checking documentation for compliance.
- Analysis (A): This method uses recognized techniques like computer modeling and simulation to validate that a requirement is met. It involves drawing conclusions based on system design, performance, and extending data to untested conditions.
- Demonstration (D): This is an operational evaluation where visual observation is used to verify that a component meets a specification. It's suitable when quantitative measurements are not necessary for verification.
- Test (T): This method involves verifying that a specification is met by measuring, recording, and evaluating quantitative data obtained during exercises conducted under controlled conditions.

Table 9: Compliance Matrix

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
1	Throughput of 20 connectors a business day (20 connectors per 8 hours minimum)	Connector staking takes less than 24 min.	(T) Sample mean time to conduct 5 staking operations	0:15.2 for touch off, 2:44.78 average for staking	Pass	Can stake 20 connecters per hour
2	Connector shell ID and punch tool OD must be concentric within 0.004" (ideally less than 0.002")	Punch tool can be inserted into connector while installed in machine	(D) Insert punch tool into connector on staking machine	Punch can be inserted into shell on staking machine	Pass	
3	Top and bottom plates of press must be calibrated to be parallel within ±0.005"	Top and bottom press plates measure to be parallel ±0.005"	(I) Measure with dial indicator	Tool plate pitch measures –2 thou pitch in middle, zeros at pins	Pass	
4	Split in connector ring must not be aligned with keyway (Operator instruction, not criteria for machine)	Split in connector ring is not aligned with keyway	(I) Visually check parts are not aligned	Connector ring not aligned with keyway	Pass	Operator must inspect each connector, not function of machine

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
5	Insert key must be aligned with shell keyway to prevent rotation between the shell and insert (Operator Instruction, not criteria for machine)	Keyways on shell and insert are aligned	(I) Visually check parts are aligned	Shell and insert aligned with keyway	Pass	Operator should try to rotate the shell and insert to confirm there is no spinning, not function of machine
6	Must not damage the connector insert or shell within tolerances described by AFSI surface and plating inspection criteria	Exterior of connector is not damaged beyond AFSI inspection criteria	(I) Visually inspect before and after staking	No noticeable marring post staking	Pass	Marring does occur at base due to the connector fixtures provided by client. Client has stated this is not a concern for the project
7	Must be adjustable for at least 2 different ring configuration sizes (Client proposed sizes are 15 and 21) with corresponding press die configurations	Machine can stake size 15 and 21 connectors	(D) Perform staking operation with both sizes	Staking operation successful	Pass	

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
8	PLC used with press to apply loads specified in **Table 1** (300lb - 1200lb) ± 5%	HMI shell selection applies specified load	(T) Measure calibrated forces	Press hits target force for size 15 & 21 within 1%	Pass	
9	Punch must apply loads specified in **Table 1** (300lb -1200lb)	Press can apply at least 1400lb of force	(T) Measure calibrated forces	Press can apply up to 2500 lb	Pass	
10	Punch must be applied at 2 locations on staking ring at a 90 (or a multiple of 30) ± 5 degrees apart	Connector fixture can rotate 90° ± 5°	(I) Measure rotation angle	Connector fixture rotates 90°	Pass	
11	Punch Tooling must be interchangeable and able to be locked into machine	Punch tools can be removed and locked into position	(D) Change punch tools	Punch tool can be changed	Pass	Operator must set locking pin in position to secure tool in place

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
12	Connector holding mechanism must either be interchangeable or allow for multiple connector sizes	Connector fixtures can be removed and held in position	(D) Change connector fixtures	Connector fixtures can be changed	Pass	All connector fixtures fit on same pin in center of bolster plate
13	Prototype must have a safety stop if press operation is automated and not direct manual operation	Prototype has functional safety stop	(D) Initiate safety stop during operation	Safety stop cuts power to system	Pass	
14	Connector holding mechanism must hold connector in place and prevent unintentional rotation of the connector	Connector does not move rotationally or laterally in connector fixture	(D) Show connector secure in fixture	Connector is secure in corresponding fixture	Pass	Client provided connector fixtures satisfy requirements
15	Staking Machine must not be excessively large in horizontal cross-sectional area (less than 10' square area)	Footprint measures less than 10 sqft	(I) Measure footprint	Footprint measures 4.28 sqft	Pass	

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
16	Must require a two-hand safety switch to be engaged in order for the press to operate	Continuous activation of two-finger trigger required to operate	(D) Show effect of releasing trigger	Releasing safety triggercancels actuation	Pass	
17	Must be able to select at least two force set points through user interface that connects to the PLC	Operator can select two force set points (shell sizes) in HMI	(T) Measure forces applied from HMI selection	Operator can select 15R, 15P, 21R, and 21P	Pass	
18	PLC must have at least 6 Digital Input/Output (I/O) points and 4 Analog I/O points	PLC has at least 6 digital and 4 analog I/O points	(A) Review I/O points in Portenta documentatio n	Portenta has 20 digital I/O and 4 analog I/O	Pass	
19	PLC must display active force measurements to the user interface	Active force measurements displayed on HMI	(I) Live reading during staking compared to load cell	Live reading matches calibrated load cell	Pass	

Ref.	Final Specification	Acceptable Outcome	Verification Method	Test Result	Pass/Fail	Notes
20	Insert’s Z-height displacement must be .003” or less after inspection force specified on **Table 2** is applied	Deflection is less than 0.003”	(I) Measure with AFSI inspection tools	Size 21 displaced 0.002” after 100 lb inspection force	Pass	

4.2 - Verification Methods

Each specification in the compliance matrix mentions a brief verification method meant to assess if the acceptable outcome is achieved. The processes for these verification methods are detailed in full in the remainder of this section, ordered by reference number.

4.2.1 – Throughput of Staking Operation

Time and production volume are important factors in the success of the project. A minimum throughput of 20 connectors in a single, 8-hour business day. To accomplish this, the full operation for staking a single connector should take less than 24 minutes.

(T) Sample mean of staking tests

1. Use a stopwatch to record the time required to perform staking operation as detailed in **section 1.3.2** for a single connector
2. Repeat with at least five additional connectors
    a. Additional recordings can be made throughout testing to improve accuracy
3. Calculate sample mean from the recorded times
    a. Sample mean should be less than 24 minutes per connector

4.2.2 – Concentric Tolerance

In order to fit the punch tool between the connector shell and insert, the outer diameter (OD) of the punch tool must be concentric within 0.004" of the inner diameter (ID) of the connector shell. If, while on the staking machine, the punch tool can be lowered into the connector, then the tolerance has been met.

(D) Insert punch tool into connector on staking machine

1. Select the size 21 punch tool, connector fixture, shell, and insert
2. Assemble the connector as defined in **section 1.3.1**, omitting the clamping plate and staking ring
3. Install the punch tool into the tool holder on the staking machine
4. Raise the tool holder and install the connector assembly on the center peg of the bolster plate
5. Lower the tool holder, guiding the punch tool into the connector until it comes to a stop on the ledge of the insert or the castellations are not visible.
    a. If the tool can be lowered into the connector, then the components are concentric within tolerance.

6. Alternatively, the axis centers of the OD of the tool punch can be measured by using calipers and measuring two opposite points of the tool punch and similar points on the connector shell in reference to the vertical guide posts, to derive the center.
    a. Similarly, remove the tool punch and measure the ID of the connector shell in the same manner.
    b. If the center of the OD of tool punch is within 0.004” of the center of the ID of the connector shell, then the concentricity is within tolerance.

4.2.3 – Parallelism

To maintain axial alignment between the punch tool and the connector during the stroke of the staking operation, the top and bottom plates of the die set must be parallel within ±0.005”. To accomplish this, the bottom of the top plate and the top of the bottom plate should be measured and mapped with a dial indicator, with special attention paid to the center half of the plates.

(I) Measure with dial indicator

1. Place the base of the dial indicator on the top of the bolster
2. Position the tip of the dial indicator so that it is touching the bottom of the top plate
    a. Record measurement
3. Slide the base of the dial indicator around on the bolster plate, keeping the tip of the indicator on the bottom of the top plate
    a. Record measurements around the plate
4. Compare the measurements taken
    a. Measurements should not change more than ±0.005”

4.2.4 – Connector Ring Orientation

Before staking a connector, the insert and annealed aluminum ring must be positioned inside the shell. When doing so, the operator should ensure that the split in connector ring is not aligned with keyway in the shell and insert. This is an operator instruction, not criteria for machine.

(I) Visually check parts are not aligned

1. Select the corresponding shell, insert, and punch tool for the desired connector size
2. Take an unformed, annealed aluminum ring and wrap it around the base of the punch tool to form to the appropriate size
3. Position the insert inside the shell by aligning the keyways and pushing into place
4. Position the formed ring inside the shell, being sure that the split in the ring is not aligned with the keyway
5. Once inserted, inspect the location of the split (visible from top of connector) and compare to the location of the keyway (visible from bottom of the connector)

4.2.5 – Shell & Insert Alignment

Before staking a connector, the insert and annealed aluminum ring must be positioned inside the shell. When doing so, the operator should ensure that the keyway in the shell is aligned with the keyway in the insert. The insert will not move into the proper position without the keyways aligned. This is an operator instruction, not criteria for machine.

(I) Visually check parts are aligned

1. Select the corresponding shell and insert for the desired connector size
2. Position the insert inside the shell by aligning the keyways and pushing into place
3. Test completion by attempting to rotate the insert within the shell

4.2.6 – Exterior Damage

In order to be successful, the staking process must not cause excessive damage the connector insert or shell within tolerances described by AFSI surface and plating inspection criteria.

(I) Visually inspect before and after staking

1. Visually inspect the connector shell and insert before beginning the staking operation
    a. Record any preexisting damages
2. Perform the staking operation as defined in **section 1.3.2**
3. Visually inspect the connector shell and insert after completing the staking operation
    a. Record any post-staking damages
4. Compare recordings of visual defects before and after staking to the AFSI surface and plating inspection criteria

4.2.7 – Multiple Configurations

It is the client's hope that the designed machine will be usable to stake any of their connector configurations and sizes. For the scope of this project, the machine only needs to successfully stake two different configuration sizes, specifically the size 15 and the size 21. The team needs to demonstrate a successful staking operation for both sizes

(D) Perform staking operation with both sizes

1. Perform the staking operation as defined in **section 1.3.2** with a size 15 connector shell and insert
2. Perform the staking operation as defined in **section 1.3.2** with a size 21 connector shell and insert
3. Verify that both sizes of shells were staked successfully by using the inspection operation as defined in **section 1.3.3**

a. Inserts should remain in their initial vertical position relative to their shell ±0.003" after the inspection force is applied

4.2.8 – PLC Force Control

PLC used with press to apply loads specified in Table 1 (300lb -1200lb) ± 5% to the staking ring inside the connector. In order to supply this force at the connector, the press must also be able to supply additional force to compensate for the 200 lbs retraction force created by the die springs on the guide rods.

(T) Measure calibrated forces

1. Install the load cell onto the press
2. Select a size 15 configuration in the HMI and initiate the staking operation
    a. Note: for this test, do not follow the staking operation procedure as defined in **section 1.3.2**
3. The press should actuate, continuing the down stroke until the force set point is reached
    a. Load cell should register 700 (500 + 200) lbs ± 5%
4. Repeat steps 2 - 3, selecting a size 21 configuration in the HMI
    a. Load cell should register 1088 (888 + 200) lbs ± 5%
5. Repeat as necessary for results to be significant

4.2.9 – Force Delivery

Punch must apply loads specified in **Table 1** (300lb -1200lb) ± 5% to the staking ring inside the connector. In order to supply this force at the connector, the press must also be able to supply additional force to compensate for the 200 lbs retraction force created by the die springs on the guide rods. With this in mind, the press must be able to supply at least 1450 (1250 + 200) lbs.

(T) Measure calibrated forces

1. Install 3rd party calibrated load cell in pressing area.
2. Actuate press and lowest possible pressure, 10 psi, and record force reading.
3. Actuate press at maximum rated pressure, 100 psi, and record force reading.
4. Confirm maximum and minimum force reading to validate the required force range.

4.2.10 – Distributed Staking Force

In order to ensure a sufficiently deformed staking ring, the punch must be applied at 2 locations on staking ring at a 90° (or a multiple of 30) ± 5° apart. The team selected 90° as the target, and installed pins in the bolster plate to limit the rotation of the connector fixture to that target.

(I) Measure rotation angle

1. Fully assemble the staking machine
2. Using a protractor, measure the angle between the limiting pins from the dowel pin in the center of the bolster plate
    a. The center dowel pin holds the connector fixture, allowing it to be rotated around its center axis
3. Record the results photographically
    a. The angle should measure 90° ± 5°

4.2.11 – Modularity: Punch Tool

For the scope of this project, the machine needs to successfully stake two different configuration sizes, specifically the size 15 and the size 21. Since different connector sizes require different punch tool sizes, the punch tools must be interchangeable.

(D) Change punch tools

1. Remove the detent pin from the tool holder
2. Slide the size 15 punch tool into position within the tool holder
3. Install the detent pin into the tool holder
4. Demonstrate that the punch tool is locked into position
5. Repeat step one
6. Remove the size 15 punch tool from the tool holder
7. Repeat steps 2 - 4 with the size 21 punch tool

4.2.12 – Modularity: Connector Fixture

For the scope of this project, the machine needs to successfully stake two different configuration sizes, specifically the size 15 and the size 21. Since different connector sizes require different connector fixture sizes, the connector fixtures must be interchangeable.

(D) Change connector fixtures

1. Install the size 15 connector fixture onto the dowel pin in the center of the bolster plate
    a. The dowel pin should hold the connector fixture without allowing for lateral movement but still allow the connector fixture to rotate
2. Remove the size 15 connector fixture from the center dowel pin
3. Repeat step one with the size 21 connector fixture

4.2.13 – Safety Stop

For safety reasons, the prototype must have a safety stop installed to halt press operation.

(D) Initiate safety stop during operation

1. Perform the staking operation as defined in **section 1.3.2**
    a. For this demonstration, neither the punch tool nor the connector/fixture needs to be installed
2. While the operation is in progress, have a second operator engage the e-stop
    a. Triggering the e-stop should cut power to the system and vent the pressure in the press, returning it to the upright position

4.2.14 – Connector Holding

To control the position and orientation of the connector, the connector holding mechanism must hold connector in place and prevent unintentional rotation. To accommodate this specification, the team designed the machine to work with the existing connector fixtures from AFSI. The client confirmed that using these fixtures satisfies this requirement.

(D) Show connector secure in fixture

1. Select the size 15 shell and insert
2. Position the insert inside the shell by aligning the keyways and pushing into place
3. Install the unstaked connector on the size 15 connector fixture provided by AFSI
4. Attempt to twist the connector on the fixture to show the acceptable range of motion
5. Repeat steps 1 - 4 for the size 21 connector

4.2.15 – Machine Footprint

The staking machine must not be excessively large in horizontal cross-sectional area (less than 10' square area).

(I) Measure footprint

1. With a tape measure, measure the longest and widest dimensions of the full machine including the staking machine, press guard, press, and PLC cabinet
2. Calculate the maximum footprint of the by multiplying the length and width
    a. Calculated maximum footprint should be less than 10 sqft

4.2.16 – Activation Trigger

For safety, the prototype is required to use a two-hand safety switch in order for the press to operate. Both triggers must remain continuously activated throughout the duration of the staking operation. If either or both triggers are released, the operation should stop.

(D) Show effect of releasing trigger

1. Perform the staking operation as defined in **section 1.3.2**

    a. For this demonstration, neither the punch tool nor the connector/fixture needs to be installed
2. While the operation is in progress, have the operator release the two-hand safety switch
    a. Releasing the trigger should stop the operation and vent the pressure in the press, returning it to the upright position
3. Repeat steps 1-2, but only release the left trigger of the two-hand safety switch
    a. Releasing the left trigger should have the same effect as releasing both triggers
4. Repeat steps 1-2, but only release the right trigger of the two-hand safety switch
    a. Releasing the right trigger should have the same effect as releasing both triggers

4.2.17 – Force Selection

To stake the two different connector sizes, the operator must be able to select the two corresponding force set points through the user interface that connects to the PLC. This is accomplished through the HMI. In the HMI, the operator is able to select the connector configuration desired, and the PLC will apply the corresponding force set point to the staking operation.

(T) Measure forces applied from HMI selection

1. Install the load cell onto the press
2. Select a size 15 configuration in the HMI and initiate the staking operation
    a. Note: for this test, do not follow the staking operation procedure as defined in **section 1.3.2**
3. The press should actuate, continuing the down stroke until the force set point is reached
    a. Load cell should register 700 (500 + 200) lbs ± 5%
4. Repeat steps 2-3, selecting a size 21 configuration in the HMI
    a. Load cell should register 1088 (888 + 200) lbs ± 5%
5. Repeat as necessary for results to be significant

4.2.18 – PLC I/O Availability

To perform the functions required, the PLC must have at least 4 digital I/O points and 4 analog I/O points with 24-volt power output and 0-10 command voltage.

(A) Review I/O points in Portenta documentation

1. Review the documentation for the Arduino Portenta to find the number of digital I/O points included on the board
    a. Should have at least 2 digital in points
    b. Should have at least 2 digital out points

2. Review the documentation for the Arduino Portenta to find the number of digital I/O points included on the board
    a. Should have at least 3 analog in points
    b. Should have at least 1 analog out points
3. Use multimeter to record voltage output of the 3 analog power supplies and command signal pins to verify required voltage levels.

4.2.19 – Active Force Readout

To monitor the status of the staking operation, the PLC must display active force measurements to the user interface. The HMI screen is programmed to display both the active force measurement and the target force the operation is aiming for.

(I) Live reading during staking compared to load cell reading

1. Install the load cell onto the press
2. Select a configuration in the HMI and initiate the staking operation
    a. Note: for this test, do not follow the staking operation procedure as defined in **section 1.3.2**
3. The press should actuate, continuing the down stroke until the force set point is reached
    a. For size 15 configurations, the load cell should register 700 (500 + 200) lbs ± 5%
    b. For size 21 configurations, the load cell should register 1088 (888 + 200) lbs ± 5%
4. Monitor the HMI screen and record the force readout
5. Compare the recorded force readout from the HMI to that of the force measured by the load cell
6. Repeat as necessary for significant results

4.2.20 – Post-Staking Inspection

For a staking to be considered successful, the connector must pass a post-staking inspection. The insert's Z-height displacement must be .003" or less after inspection force specified on **Table 2** is applied. This inspection force is applied by a second machine that is already in the possession of AFSI. Applying the inspection force is not a requirement of the staking machine defined by the scope of this project.

(I) Measure with AFSI inspection tool

1. Perform the staking operation as defined in **section 1.3.2** with a size 15 connector
2. Repeat step one until at least five size 15 connectors are staked
3. Measure and record the distance from the top the shell to the top of the insert
4. Take the staked connectors to the AFSI facility in Allen, TX
5. Perform the inspection operation as defined in **section 1.3.3** for the size 15 connector

    a. The inspection force for size 15 connectors as defined in **Table 2** is 50 lb
6. Remeasure and record the distance from the top the shell to the top of the insert
    a. The measurements from step six should match the measurements from step 3 ±0.003”
7. Repeat steps 1 -7 with size 21 connectors
    a. The inspection force for size 21 connectors as defined in **Table 2** is 100 lb

4.3 - Discussion of Test Results

The tests conducted for the completion of the compliance matrix yield positive results for all specifications included in the project definition. The key performance parameters (KPP) for the project were the alignment tolerances and achieving the specified staking force within ± 5%. See **Appendix A, Figure 40** for the force accuracy graphs.

The implementation of the floating tool housing largely mitigated the concerns about axial alignment by eliminating the risk of catastrophic misalignment between the axis of the punch and the connector. This alignment is further mitigated by the tight machine tolerances provided by the UTD machine shop, which in most cases exceeded the necessary precision. The alignment is maintained throughout the stroke as a result of the parallelism of the top plate with the bolster plate (within ±0.005”) along the length of the guide rods.

Achieving the applied loads defined in **Table 2** within 5% proved initially challenging. There were issues with load cell calibrations and amplifier noise that hindered progress for some time. However, the implementation of the force-from-pressure lookup table allowed the machine to consistently hit the target forces within 1%, exceeding the goal.

5 - Prototype Construction

5.1 - Bill of Materials

Table 10: Bill of Materials

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
1	Bolster Plate (See Dwg No 01_BOLSTER_PLATE-SD_1815) [6"x12"]	Metal Supermarket	01_SD_1815	1	4140 Steel	$68.16	$68.16
2	Clamp Plate (See Dwg No 12_ClampPlate_SD_1815) [6"x6"]	Plastic Craft	13_SD_1815 / 9246K63	4	Delrin	$2.07	$8.28
3	Clamp Plate holder (See Dwg No 11_ClampPlateHolder_SD_1815) [4"x6"]	McMaster	11_SD_1815 / 9246K423	1	Aluminum 6061	13.7	$13.70
4	Puck Holder Cylinder (See Dwg No 07_PuckHolderCylinder_SD_1815) [1.1/4" DIA x 12" L]	McMaster	07_SD_1815 / 8935K42	1	4140 Steel	16.19	$16.19
5	Puck Holder Bottom Plate (See Dwg No 05_PuckHolderBotPlate_SD_1815) [1/4" T , 3"x3"]	McMaster	05_SD_1815 / 4468T24	1	4140 Steel	15.08	$15.08
6	Tool Plate (See Dwg No 02_TOOL_PLATE_SD_1815) [6"x8"]	Metal Supermarket	02_SD_1815 / 4473T45	1	4140 Steel	28.51	$28.51

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
7	Tool Holder Key (See Dwg No 08_ToolHolderKey_SD_1815 [3/4" DIA, 3" L]	Metal Supermarket	08_SD_1815 / 8935K336	1	4140 Steel	8.48	$8.48
8	Tool Housing Keyed (See Dwg No 09_ToolhousingKeyed_SD_1815) [1.1/4 ' T , 3"x6"]	Metal Supermarket	09_SD_1815 / 6554K68	1	4140 Steel	27.65	$27.65
9	Tool Housing (See Dwg No 10_Toolhousing_SD_1815) [1.1/4 ' T , 3"x6"]	Metal Supermarket	10_SD_1815 / 6554K68	1	4140 Steel	27.65	$27.65
10	Ram Plate (See Dwg No 03_RAM_PLATE_SD_1815) [3/4" T , 3"x3"]	Metal Supermarket	03_SD_1815 / 4468T64	1	4140 Steel	28.06	$28.06
11	Dowel Pin Modified (See Dwg No 04_MODIFIED 98381A818 _DOWEL_PIN_SD_1815 & Dwg No 15_MODIFIED 98381A818 _DOWEL_PIN_SD_1815) [3/4" DIA, 6" L]	McMaster	04_SD_1815 / 98381A818	2	4130 Steel	10.74	$21.48
12	Puck Holder top plate (See Dwg No 06_PuckHolderTopPlate_SD_1815) [3"x3"x1/2"]	Metal Supermarket	06_SD_1815 / 4468T54	1	4140 Steel	15.02	$15.02
13	Machine Block (See Dwg No. 16) [2"D - 1.25" Long]	Metal Supermarket	16_SD_1815	1	4140 Steel	25.48	$25.48

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
14	Punch Base (See Dwg No. 19) [1.75"D - 2" Length]	Metal Supermarket	19_X_SD_1815	3	4140 Steel	12.29	$68.16
15	HMI Panel (See Dwg No. 20) [12" x 12" x 0.0625"]	Metal Supermarket	20_SD_1815	1	Aluminum 6061	32.26	$32.26
16	Tool Holder Sandwich Plate (See Dwg No. 21) [3" x 3" x 0.06"]	Metal Supermarket	21_SD_1815	1	Mild Steel Sheet Cold Rolled	19.22	$19.22
17	POT Bracket (See Dwg No. 18) [0.75" x 0.75" x 5"]	Metal Supermarket	18_SD_1815	1	Aluminum 6061	5.31	$5.31
18	3D Printed Drip Bolts for Air Filters	UTDesign	22_SD_1815	3	Anycubic UV Tough Resin	0.08	$0.23
19	3D Printed Bracket - Auto Oiler	UTDesign	23_SD_1815	1	Anycubic UV Tough Resin	0.82	$0.82
20	3D Printed Sleeve - Auto Oiler	UTDesign	24_SD_1815	1	Resione F39 Flexible Resin	1.32	$1.32
21	3D Printed PLC Cabinet Key	UTDesign	25_SD_1815	1	Anycubic UV Tough Resin	0.15	$0.15
22	3D Printed 80/20 Extrusion Cap	UTDesign	26_SD_1815	1	Resione F39 Flexible Resin	0.28	$0.28
23	3D Printed Fan Bracket	UTDesign	27_SD_1815	1	Anycubic UV Tough Resin	0.33	$0.33

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
24	3D Printed Anti-marring Cap - Inspection Tool	UTDesign	28_SD_1815	1	Resione F39 Flexible Resin	0.13	$0.13
25	3D Printed Spacer - POT	UTDesign	29_SD_1815	1	Anycubic UV Tough Resin	0.26	$0.26
26	3D Printed Staking Ring Insert Tool - Size 21	UTDesign	30_SD_1815	1	Anycubic UV Tough Resin	0.96	$0.96
27	3D Printed Staking Ring Insert Tool - Size 15	UTDesign	31_SD_1815	1	Anycubic UV Tough Resin	0.53	$0.53
28	3D Printed Bracket - USB Splitter	UTDesign	32_SD_1815	1	Anycubic UV Tough Resin	0.39	$0.39
29	3D Printed Sleeve - USB Splitter	UTDesign	33_SD_1815	1	Resione F39 Flexible Resin	0.37	$0.37
30	3D Printed Bracket - USB-to-RS Connection	UTDesign	34_SD_1815	1	Anycubic UV Tough Resin	0.75	$0.75
31	Red Chrome-Silicon Steel Die Spring for 1-1/2" Hole Diameter, 2" Long	McMaster	9584K81	2	Chrome-Silicon Steel	15.02	$30.04
32	Dowel Pin, 3/16" Diameter, 3" Long	McMaster	90145A523	1	Alloy steel.	4.54	$4.54

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
33	Dowel Pin [0.75 DIA - 1.75 L]	McMaster	98381A807	1	416 Stainless Steel	5.59	$5.59
34	Dowel Pin [0.5 DIA 7/8 L]	McMaster	98381A504	1	4037 Alloy Steel, 4140 Alloy Steel	6.35	$6.35
35	External Retaining Ring	McMaster	97633A250	4	1060-1090 Spring Steel	0.16	$0.64
36	Bushing Bracket (See Dwg No 14_BUSHING_BRACKET_SD _1815) [2" DIA]	Metal Supermarket	14_SD_1815 / 8974K71	2	Aluminum 6061	5.73	$11.46
37	Dowel Pin, 1/16" Diameter, 3/4" Long	McMaster	98381A422	1	4037 Alloy Steel, 4140 Alloy Steel	0.25	$0.25
38	Spacer [1.1/2" DIA, 12" L] (See Dwg SD1815_13_Rec21_Spacer)	Plastic Craft	12_SD_1815 / 8974K18	2	Delrin	3.77	$7.54
39	18-8 Stainless Steel Low-Profile Socket Head Screw 6-32 Thread Size, 3/8" Long	McMaster	93615A215	6	18-8 Stainless Steel	0.2956	$1.77
40	18-8 Stainless Steel Low-Profile Socket Head Screw 10-24 Thread Size, 3/4" Long	McMaster	93615A355	4	18-8 Stainless Steel	0.528	$2.11
41	18-8 Stainless Steel Washer, 11/16" Screw Size, 0.750" ID, 1.500" OD	McMaster	92141A233	6	18-8 Stainless Steel	0.95	$5.70

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
42	18-8 Stainless Steel Low-Profile Socket Head Screw 1/4"-20 Thread Size, 1-1/2" Long	McMaster	93615A425	2	18-8 Stainless Steel	1.042	$2.08
43	Black-Oxide Alloy Steel Socket Head Screw, 1/4"-20 Thread Size, 2-1/4" Long, Fully Threaded	McMaster	90044A126	2	Black-Oxide Alloy Steel	0.62	$1.24
44	Oil-Embedded Flanged Sleeve Bearing, 3/4" Shaft, 7/8" Housing ID, 1/2" Long, 1-1/8" Flange OD	McMaster	6338K429	3	Oil-Impregnated Bronze	3.99	$11.97
45	18-8 Stainless Steel Hairpin Cotter Pin, 5/8"- 1" Pin Diameter, 11/64" Wire Diameter, 7/8" Eye Diameter	McMaster	92391A066	1	18-8 Stainless Steel	2.28	$2.28
46	Dowel Pin for Angle Pins, 3/16" Dia. - 0.5in L	McMaster	98381A505	2	Alloy steel.	0.19	$0.38
47	Aluminum Unthreaded Spacer, 10 mm OD, 11 mm Long, for M5 Screw Size	McMaster	94669A336	2	Aluminum 6061	1.94	$3.88
48	Same-Size Thread 18-8 Stainless Steel Shoulder Screw, 5 mm Shoulder Diameter, 18 mm Shoulder Length, M5 x 0.80 mm Thread	McMaster	91273A391	2	18-8 Stainless Steel	7.64	$15.28

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
49	Saginaw enclosure, NEMA 1, 12 x 12 x 8in (HxWxD), wall mount, carbon steel, ANSI 61 gray, powder coat finish, single-door, 1/4-turn semi-flush latch.	Automation Direct	SCE-12N1208LP	1	Carbon Steel	101	$101.00
50	Saginaw subpanel, perforated, carbon steel, white, powder coat finish. For use with SCE-12N1204LP, 12N1206LP and SCE-12N1208LP enclosures.	Automation Direct	SCE-12N12MPP	1	Carbon Steel	24	$24.00
51	Integra DIN rail, slotted, 35mm, 7mm height, 10.8in length, plated steel. Package of 2. For use with 12in wide Premium series polycarbonate enclosures.	Automation Direct	DIN12-P10	1	Plated Steel	32	$32.00
52	Iboco T1 series open slot wide finger wire duct, 1in width, 1in height, 6.5ft/2m length, gray. Cover included.	Automation Direct	T1-1010G-1	1	N/A	18	$18.00
53	Konnect-It screw single-level feedthrough terminal block, accepts wire size 26-12 AWG, gray, 20A, 35mm DIN rail mount, 100kA SCCR. Package of 25. For use with jumpers KN-2J12, KN-3J12, KN-4J12 and KN-10J12.	Automation Direct	KN-T12GRY-25	1	N/A	9	$9.00

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
54	Konnect-It screw-down end bracket, 10mm wide. Package of 10. For use with 35mm DIN rail.	Automation Direct	KN-EB7-10	1	N/A	9.75	$9.75
55	Konnect-It terminal block jumper, screw-down type, 4-pole, 24A, 750V. Package of 15. For use with KN-T12 or KN-D12 series block.	Automation Direct	KN-4J12	1	N/A	18	$18.00
56	Ardiuno Portenta Machine Control PLC	Amazon	AKX00032	1	N/A	356.35	$356.35
57	PLC key Portenta Machine Control	Arduino	AVX00070	1	N/A	17.6	$17.60
58	Micro Center 32GB microSDHC	Micro Center	294397	1	N/A	2.99	$2.99
59	Magedok 9 Inch Touch Screen Display for Raspberry Pi	Amazon	B0C2ZJY8KR	1	N/A	89	$89.00
60	Mean Well 10V Power Supply	DigiKey	MDR-20-12	1	N/A	19.19	$19.19
61	Enfield TR Pressure Regulator	Enfield Technologies	TR-010-g10-s	1	N/A	926	$926.00
62	M8, 4 POLE, FEMALE, 2M CABLE	Enfield Technologies	A-CBL-M8-04P-F-0200	1	N/A	39	$39.00
63	Load Cell Amplifier	DigiKey	APD-4059	1	N/A	469	$469.00
64	Linear Potentiometer Position Sensor	HGSI	LPPS-22-150	1	N/A	210	$210.00
65	18 Gauge Silicone Wire Kit	Amazon	B01AAX64WO	1	N/A	9.98	$9.98

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
66	transkoot 2pcs 3/8" to 3/8" NPT Male Thread Brass Straight Hex Nipple Fast Coupler Pipe Hose Fitting 3/8 inch x 3/8 inch Straight Fitting	Amazon	B075LMX4GD	1	N/A	8.99	$8.99
67	3/8 Air Fittings Push to Connect Fittings,CEKER 3/8 Inch Tubing Od x 3/8" NPT Thread Male Pneumatic Fittings Air Line Fittings Quick Connect Push in Connectors 5Packs	Amazon	B07Y1C6T6K	4	N/A	2.798	$11.19
68	Legines Brass Pipe Fitting Hex Bushing, 3/8" NPT Male to 1/4" NPT Female 1200psi (2pcs)	Amazon	B0747LL11P	1	N/A	3.745	$3.75
69	PL 3/8" Tubing Od x 1/4" Npt Thread Pneumatic Push In Connectors	Amazon	B09MD9SRG5	1	N/A	13.99	$13.99
70	1/4" NPT Male Air Silencer Fitting	Amazon	B07MQYKH54	1	N/A	5.49	$5.49
71	Raspberry Pi 4 Model B	Amazon	RAS-4-4G	1	N/A	61.78	$61.78
72	UART to RS486 Converter	Amazon	B081MB6PN2	1	N/A	14.99	$14.99
73	DC Power Cable 5.5 x 2.1mm / 2.5mm Male to 5.5 2.1/2.5mm Male Plug Cable Right Angled 90 Degree 24AWG, 2ft / 60cm	Amazon	B0BG15KZJH	1	N/A	6.99	$6.99
74	Particulate Air Filter	Pneumatic Plus	PPF3-N03B	1	N/A	19.49	$19.49

ITEM NO.	ITEM DESCRIPTION	VENDOR	Model/Part No	QTY.	MATERIAL	Unit Cost	Total Cost
75	Three Stage Air Drying System	Pneumatic Plus	PPC3C-N03G	1	N/A	134.99	$134.99
76	SMC AKH11-00 check valve	SMC Pneumatics	AKH11-00	1	N/A	22.75	$22.75
	Grand Total						$3,488.04

5.2 - Fabrication Processes

5.2.1 - Machined parts

Our project makes use of some very tight tolerances throughout to ensure that the top and bottom plates are within 0.005” parallelism, which presents difficulty due to the tolerance stack-up of the bottom plate, top plate, guide posts, bushings, connector fixture, floating housing, and tool holder. These tolerances are shown in the engineering drawings found in Appendix C. Our on-campus machine shop was able to easily hit the tolerances required for the assembly’s function.

To assemble the tooling, press fits were preferred due to their ability to simultaneously fasten and precisely locate. Press fits require tight tolerances with precise reaming and grinding operations. The guide posts were shrink-fit into the bottom plate using liquid nitrogen with .0007” - .0017” interference at room temperature. The bushings were press-fit into the top plate and required careful tolerancing for interference as too much interference could cause the bushing to bind to the dowel pins. With an OD tolerance of 0” - 0.001” for the bushing, our engineering drawings required the machine shop to use a micrometer on the OD of the provided bushing, and cut the mating parts with 0.003” - 0.007” interference.

5.2.2 - Modified COTS

The two unique parts that were bought from McMaster Carr and modified were the guide posts, which had grooves machined in them (as per SD1815-15) and the bushing bracket (as per SD1815-14), the two of which were chosen from McMaster for ease of purchase and tolerances. Both parts were modified and involved in press-fits or shrink-fits.

5.2.3 - 3D Printed Components

The project utilizes 3D printing for a variety of small components such as brackets, spacers, and operator assistance tools. All parts were printed using an Anycubic Photon Mono liquid crystal display masked stereolithography (LCD mSLA) printer. Two resins were used to take advantage of their different material properties on a case-by-case basis. Anycubic UV Tough Resin was used for most parts, as it is less brittle than Anycubic UV Standard Resin. Resione F39 Flexible Resin, with a shore hardness of 60-75A, was used for softer components that could take advantage of the additional strain. Unless otherwise stated in **Table 11**, all prints received a 5-minute post-print wash in 99% isopropyl alcohol (IPA) and a 5-minute UV post-cure.

Table 11: 3D Printed Parts

Part	Part #	Material	Function	Notes
Air Filter Plug Bolts	SD1815-22	Anycubic UV Tough Resin	Drain plug for air filtration water collection bowls.	~5% print failure rate from bed adhesion, could improve with mouse-ear brim
Auto Oiler Mount Bracker	SD1815-23	Anycubic UV Tough Resin	Connects SD1815-24 to electrical cabinet.	No supports or special instructions
Auto Oiler Mount Sleeve	SD1815-24	Resione F39 Resin	Connects Auto Oiler to SD1815-23	No supports or special instructions
Electrical Cabinet Key	SD1815-25	Anycubic UV Tough Resin	Opens the electrical cabinet.	No supports or special instructions
80/20 Cap	SD1815-26	Resione F39 Resin	Encloses 80/20 extrusion used to mount the PRO-Safe 12” Lathe Guard.	No supports or special instructions
Cooling Fan Bracket	SD1815-27	Anycubic UV Tough Resin	Mounts 24V DC Fan to HMI frame.	Requires mouse-ear brim. Low tolerance part, FDM viable
Inspection Tool Cover	SD1815-28	Resione F39 Resin	Covers inspection tool to prevent damage to connectors.	No supports or special instructions
Pot Bracket Spacer	SD1815-29	Anycubic UV Tough Resin	Acts as spacer for part SD1815-17.	No supports. Spacer can be removed if part SD1815-17 is machined to longer length
Staking Ring Pre-insert Tool	SD1815-30-X	50% Anycubic UV Tough Resin, 50% Anycubic UV Standard Resin	Used to position staking rings for shell size 15 (SD1815-30-1) and shell size 21 (SD1815-30-2).	Wash twice as long in IPA. Two 5-minute UV post-cures (in upright and upside-down positions). Can benefit from optional thermal post-cure for 1 hour at 80°C

Part	Part #	Material	Function	Notes
USB Splitter Mount Bracket	SD1815-31	Anycubic UV Tough Resin	Connects SD1815-32 to Electrical Cabinet Door.	No supports or special instructions
USB Splitter Mount Sleeve	SD1815-32	Resione F39 Resin	Connects the USB Splitter to SD1815-31.	No supports or special instructions
USB to RS485 Bracket	SD1815-33	Anycubic UV Tough Resin	Locks the usb male to female connection between the USB to RS485 connector and the Raspberry Pi.	No Supports. Wash twice as long in IPA. Two 5-minute UV post-cures (in upright and upside-down positions)

6 - Cost Summary

The costs shown in **Table 12** reflect the actual costs of materials and services, while labor is based on hypothetical fully loaded rates for the various personnel involved in the project. **Table 13** provides a breakdown of the non-labor subtotal from the cost summary.

Table 12: Cost Summary Table

Category				**Totals**
		Materials	$4,888.96	
		Services	$2,374.00	
		Non-Labor Subtotal		$7,262.96
Labor Classifications	*Loaded Rate*	*Hours*	*Cost*	
Engineer	$100/hr.	1993.75	$199,375	
Team Mentor	$175/hr.	60	$10,500	
Engineering Director	$250/hr.	15	$3,750	
Staff	$60/hr.	30	$1,800	
		Labor Subtotal		$215,425.00
Grand Total				**$222,687.96**

Table 13: Project Budget Breakdown

Part No	ITEM	Provider	Qty	Unit Cost	Total
FSTF10810	ARINC Receptable Press Fixture - [Shell 21]	Amphenol FSI	1	$100.00	$- *
FSTF10821 -8	Swage Punch Stake Base - [Shell 15] and [Shell 21]	Amhpenol FSI	1	$100.00	$- *
FSTF10824 -21-3	ARINC Swage Punch - [Shell 21]	Amhpenol FSI	1	$100.00	$- *
	Press (Direct Aire 400T)	Amphenol FSI	1	$4,250.00	$- *
10-525996-10A	Swage ring	Amhpenol FSI	1	$10.00	$- *
SG2-ULINK	TECO SG2 Programming Cable	FactoryMation	1	$37.90	$37.90
LCWD-2K	Load cell replacment	Omega	1	$610.98	$610.98
	Press Guard	McMaster	1	$250.29	$- **
	BOM	Various	1	$3,488.04	$3,488.04
SD1815-01	Bolster Plate	UTD Machine Shop	1	$112.00	$112.00
SD1815-02	Tool Plate	UTD Machine Shop	1	$168.00	$168.00
SD1815-03	Ram Plate	UTD Machine Shop	1	$56.00	$56.00
SD1815-04	Guide Post	UTD Machine Shop	1	$28.00	$28.00
SD1815-05	Puck Holder Bottom Plate	UTD Machine Shop	1	$168.00	$168.00
SD1815-06	Puck Holder Top Plate	UTD Machine Shop	1	$112.00	$112.00
SD1815-07	Puck Holder Cylinder	UTD Machine Shop	1	$84.00	$84.00
SD1815-08	Tool Holder Key	UTD Machine Shop	1	$28.00	$28.00
SD1815-09	Tool Housing (Keyed)	UTD Machine Shop	1	$168.00	$168.00
SD1815-10	Tool Housing	UTD Machine Shop	1	$168.00	$168.00
SD1815-11	Clamp Arm	UTD Machine Shop	1	$140.00	$140.00
SD1815-12	R21 - Clamp Plate	UTD Machine Shop	1	$56.00	$56.00
SD1815-12	P21 - Clamp Plate	UTD Machine Shop	1	$56.00	$56.00

Part No	ITEM	Provider	Qty	Unit Cost	Total
SD1815-12	R15 - Clamp Plate	UTD Machine Shop	1	$56.00	$56.00
SD1815-12	P15 - Clamp Plate	UTD Machine Shop	1	$56.00	$56.00
SD1815-13	Plug Spacer	UTD Machine Shop	1	$42.00	$42.00
SD1815-13	Receptacle Spacer	UTD Machine Shop	1	$42.00	$42.00
SD1815-14	Bushing Bracket	UTD Machine Shop	2	$28.00	$56.00
SD1815-15	Guide Post, Clamp Plate	UTD Machine Shop	1	$28.00	$28.00
SD1815-16	Machine Block	UTD Machine Shop	1	$56.00	$56.00
SD1815-17	POT Bracket, to Cylinder	UTD Machine Shop	1	$65.81	$65.81
SD1815-18	POT Bracket, to Piston	UTD Machine Shop	1	$84.00	$84.00
SD1815-19	Punch Base	UTD Machine Shop	3	$98.00	$294.00
SD1815-20	HMI Panel	UTD Machine Shop	1	$56.00	$56.00
SD1815-21	Tool Holder Sandwich Plate	UTD Machine Shop	1	$56.00	$56.00
	Shipping Costs	Various	1	$242.73	$242.73
	Pretotyping	Various	1	$976.84	$597.50
				Total	**$7,262.96**

* Components provided by client

** Components salvaged from UTDesign scrap yard

6.1 - Materials

The material cost listed in the Cost Summary, **Table 12,** is $1,760.11 higher than that listed in the BOM, **Table 10**. This is due to the addition of costs associated with pretotyping and the sum of all shipping costs accrued throughout the course of the project.

6.2 - Services

The machining of designed parts was the only external service used by the team during the project. The majority of machining was provided by the machine shop at the University of Texas at Dallas (UTD), who fabricated all parts except for SD1815-17 and the 3D printed components (SD1815-22 to SD1815-33). SD1815-17 was made by Xometry, who provided the materials and machining. Xometry was chosen for the fabrication of SD1815-17 for considerations of cost. While Xometry was more cost effective for machining SD1815-17, this was not generally true and the UTD machine shop provided the best cost for all other machined parts.

7 - Conclusions and Recommendations

7.1 - Conclusions

The proposed design meets project specifications, supplying necessary forces for connector staking and transferring force through the punch to the staking ring while maintaining alignment. The HMI provides an intuitive approach to operational steps, allowing AFSI to bring staking in-house, saving time and money with each connector. The design simplifies operator interaction and ensures safe punch removal. The client has approved the final prototype and has plans to incorporate the project into their assembly line.

7.2 - Recommendations

Several items that were outside the specifications and achievable scope for the allotted time and budget were identified during the project. While not present in the delivered prototype, the team recommends that these changes be implemented by AFSI to improve the machine's performance.

7.2.1 - Light Curtain/Interlocking Press Guard

During the secondary safety inspection, it was strongly recommended by the UTD safety manager that an interlocking press guard be implemented so that the press cannot be operated with the press guard open, and the press guard cannot be opened while the press is in operation. The staking machine at AAO uses a light curtain that prevents operation of the machine if the threshold is broken. The current design uses a non-interlocked lathe guard and a simple pinch skirt for operator protection. For improved safety, we recommend that AFSI implements either an interlocked press guard or a light curtain similar to AAO.

7.2.2 - Replacing Load Cell and Amplifier

The load cell purchased from Omega is out of calibration. While the return window has closed, it is still under warranty and Omega has offered to fix it. However, the lead time for recalibrating the load cell extended beyond the project timeline. To accomplish the project goal, a work around was devised to hit the target force using the readings from the pressure regulator. We recommend AFSI has Omega recalibrate the load cell while it is still under warranty, so the live force can be read more directly.

Associated, the amplifier for the load cell requires a warm-up period of at least one hour in order to reach the appropriate operating temperature for accurate readings. The current amplifier also produces a considerable amount of electrical noise. To improve the accuracy of the readings, it is recommended that AFSI replace the amplifier for the load cell with an Omega DRC-4710 or equivalent. However, the team recommends calling Omega to verify the compatibility and warm up time.

7.2.3 - Updated Tool Holder Pin

The current design uses a cotter pin to secure the punch tooling inside the tool holder. For improved ergonomics and to prevent loss, it is recommended that this pin is replaced with a T-Handle Locking Quick-Release Pin with Lanyard (3/16" Diameter, 3" Usable Length) from McMaster-Carr.

7.2.4 - Bushing Selection

A minor oversight on this project were the oil-impregnated bushings that were chosen. The bushings in question were too short in length for their diameter, resulting in a mechanical failure of the press fit. To resolve the error, green Loctite was used on the bushing bearings, and the bushing bearings were re-press-fit. In the future, it is best practice to choose bushings whose length is greater than or equal to one diameter of the post. That was not the case with these parts, and while there is no problem with the machine operation currently, there is some difficulty in the initial locating of the posts and attempting to manipulate the top plate by hand.

7.2.5 - Surface Treatments

Several components of the tooling are raw 6061 T6 aluminum which risks corrosion, creep, and fatigue over extended use. It is recommended that these components go through anodization before going into regular factory use in order to improve wear and corrosion resistance.

7.2.6 - Heat Treatments

Several components of the tooling are cold drawn annealed 4140 steel which risks creep and fatigue over extended use. As these components are critical for the precision and repeatability of the machine, it is recommended that these steel components go through heat treatment to improve strength and hardness. For the reference block in particular, it is strongly recommended to heat treat because the touch-off function applies concentrated load which has already been seen to leave indents in the material which can offset the reference and interfere with staking accuracy over extended use.

7.2.7 - Clamp Arm Redesign

In our development of the clamp arm, we initially considered using a separate clamping shaft collar, though we could not find one with a high enough thrust load. It was then requested by the Client that the clamping mechanism be integrated into the clamp arm, and the design on the press is the result. It may be desirable to re-design the part so that it is removable without taking the die-set apart, or so that the required torque the user has to exert is lowered. The current design was achieved by copying much of the geometry from the considered McMaster part – some future considerations may be to texture the surface of the guide post or inside surface of the clamp plate holder for increased friction, or to select a larger diameter screw for lower torque.

7.2.8 - Thermal Cycling Test for Raspberry Pi

During testing, the original Raspberry PI for the HMI thermally failed due to overheating, by running the HMI for an extended period. A fan and heatsink were added for thermal regulation and the onboard temperature sensor was set to shut down the Raspberry Pi if dangerous temperatures are reached. It is recommended that a thermal cycling test is conducted to assess exactly how long the system can run before thermal limits are reached for the Raspberry Pi so additional thermal regulation can be implemented as needed.

7.2.9 - Exhaust Valve Instead of Check Valve

The current design utilizes a check valve to prevent dirty air from returning to the system. However, during an emergency situation where the e-stop is triggered, the press will hold pressure and continue moving until reaching an equilibrium position. To improve operator safety, the check valve should be replaced with an exhaust valve that vents pressure during power loss.

7.2.10 - Air Filtration Drip Pan

The air filters chosen to clean the air supply to the press drip water that they filter from the supplied air. This water currently collects in a series of bowls that are plugged with 3D printed bolts (SD1815-22). These collection bowls need to be manually relieved. Replacing the bolts with a drip pan can decrease the labor associated with the air filtration system.

7.2.11 - Replacing 3D-Printed Parts

As mentioned in **Section 5.2.3**, the current design requires a 3D printed spacer (SD1815-29) to secure the POT to the cylinder of the press. While this solution is satisfactory, if the machine were reproduced, the spacer could be eliminated by increasing the length of the POT bracket (SD1815-17) 1.60 inches (new total length: 3.60 inches).

The section also mentions the staking ring insert tools (SD1815-30-X). The leading edge on the outer component that drive the staking ring in between the connector shell and insert is made of very thin walls, the same thickness as the punch tool. UV Tough resin was used to increase the allowable strain, and their inward deformation is intrinsically limited by the inner component. However, the walls of this leading edge are not immune to breaking. New insert tools can be printed for less than $1.00 of material cost provided a mSLA printer is available. For the sake of longevity, AFSI may consider having replacements machined out of aluminum. However, the tools cannot be machined with traditional methods as drawn, and would need to be redesigned into three parts that can be assembled after machining.

7.2.12 - Optimizing the Retraction Springs

As mentioned in section 3.5, the retraction springs currently apply a 200 lb retraction force. This 200 lb. value was based off of calculations of a slide hammer discussed in the design justification. The team recommends that AFSI uses the existing tool holding rig provided by the client to manually stake a connector and measure the necessary retraction force. The measured retraction force can then be used to optimize the spring constant of the die-springs in the staking machine.

7.2.13 - Waterjet the Cabinet Door

If the HMI panel is unsatisfactory or if the use of epoxy is not desired. The electrical cabinet door can be replaced with an identical door. Due to the detachable hinges, the cabinet door can be laid flat on a waterjet. It is recommended for future doors to use the HMI panel design as the foundation for a waterjet sequence to precision cut the holes in the cabinet door. Please note that if switching to this manufacturing method, the position of the lock will need to be modified to match its dimension specifications.

7.2.14 - Sensors & Electronics Data Collection

It is recommended to switch all sensors and electronics data collection to operate on 4-20 mA. This will reduce noise and provide more accurate data.

References

[1] MMPDS-10: Metallic Materials Properties Development and Standardization (MMPDS). [Washington, D.C.]: [Columbus, Ohio]: Federal Aviation Administration; Battelle Memorial Institute, 2015.

[2] "ANSI B5.25-1978 American National Standard for Punch and Die sets." American Society of Mechanical engineers, 1978.

[3] "IEC." IEC 61131-3:2013 | IEC Webstore | Water Automation, Water Management, Smart City, webstore.iec.ch/publication/4552.

[4] "NFPA 79: Electrical Standard for Industrial Machinery." NFPA Link®, link.nfpa.org/publications/79/2021.

Appendices

Appendix A – PLC

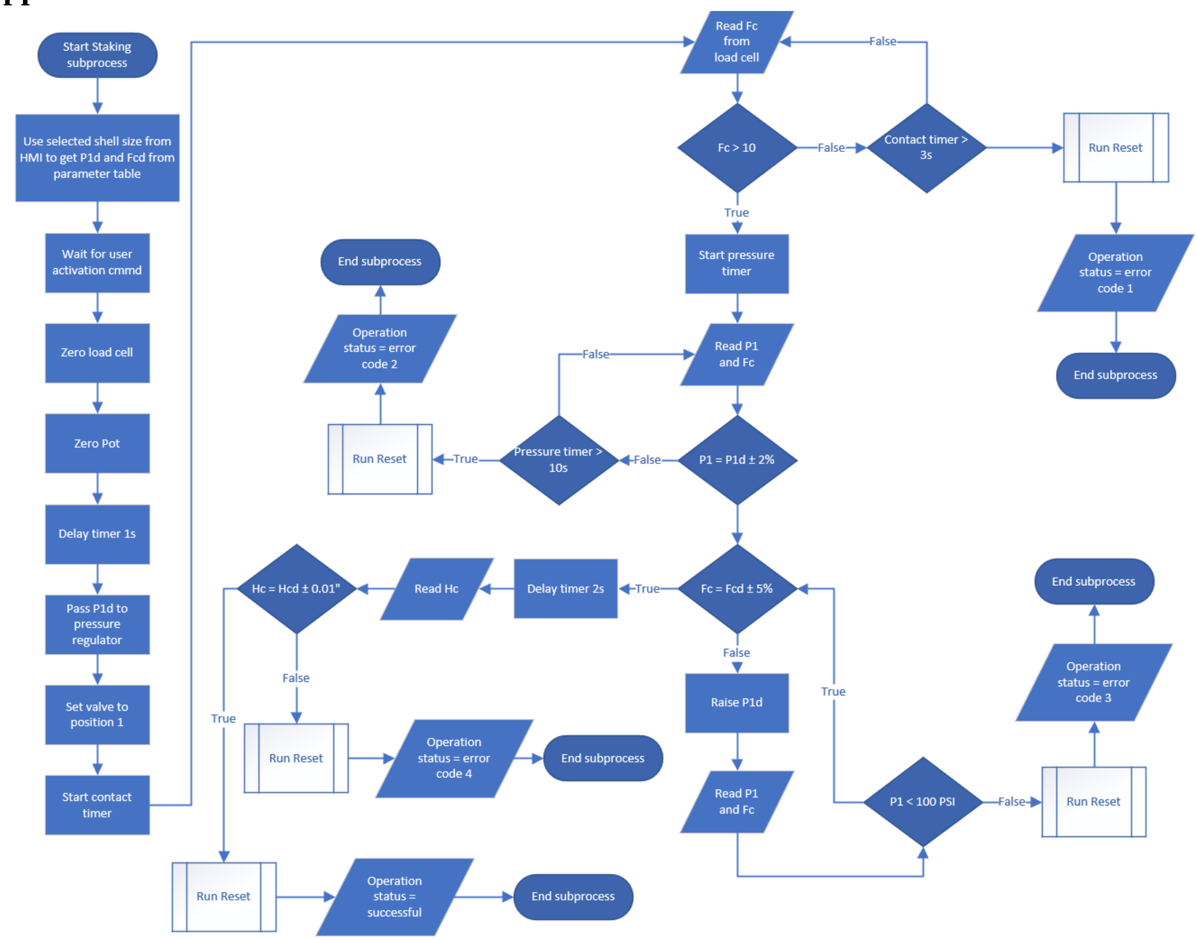


Figure 33: Staking Operation

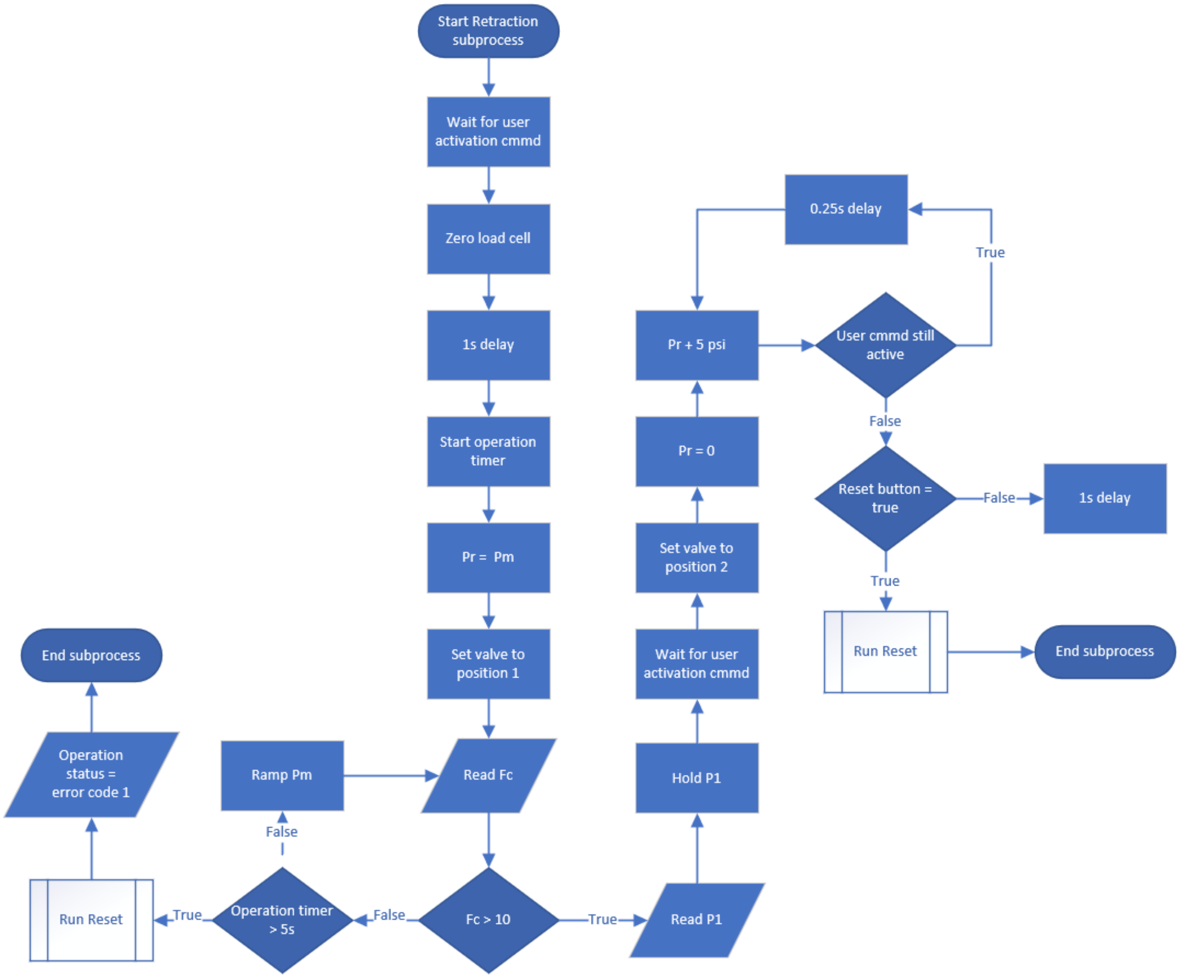


Figure 34: Retraction Process

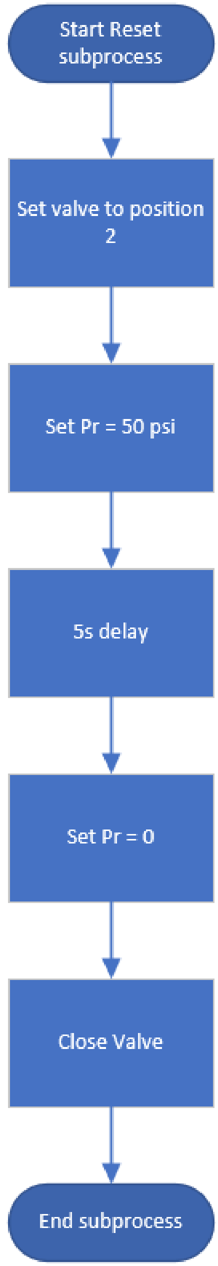


Figure 35: Reset Process

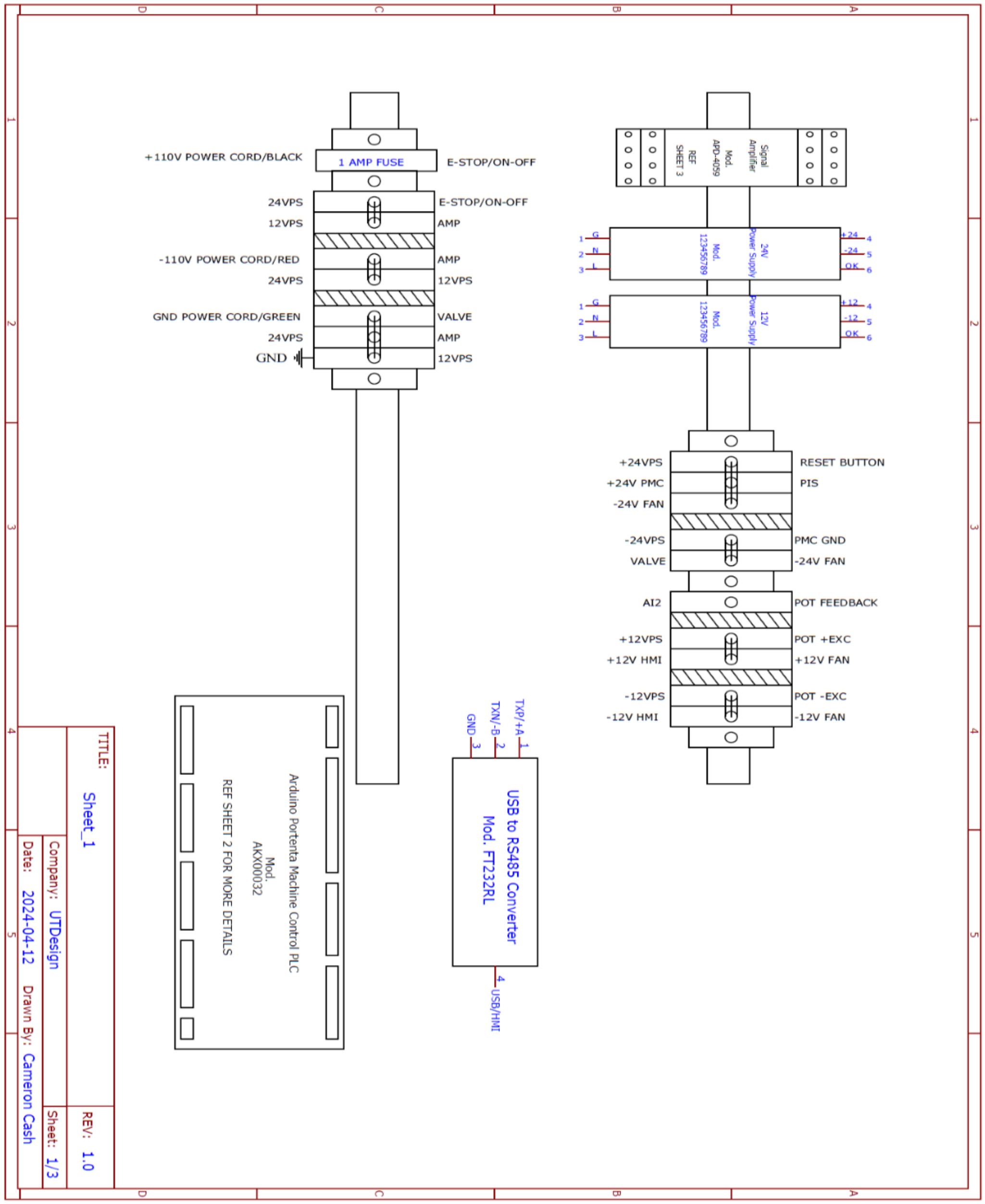


Figure 36: Electrical Cabinet Panel Wire Diagram

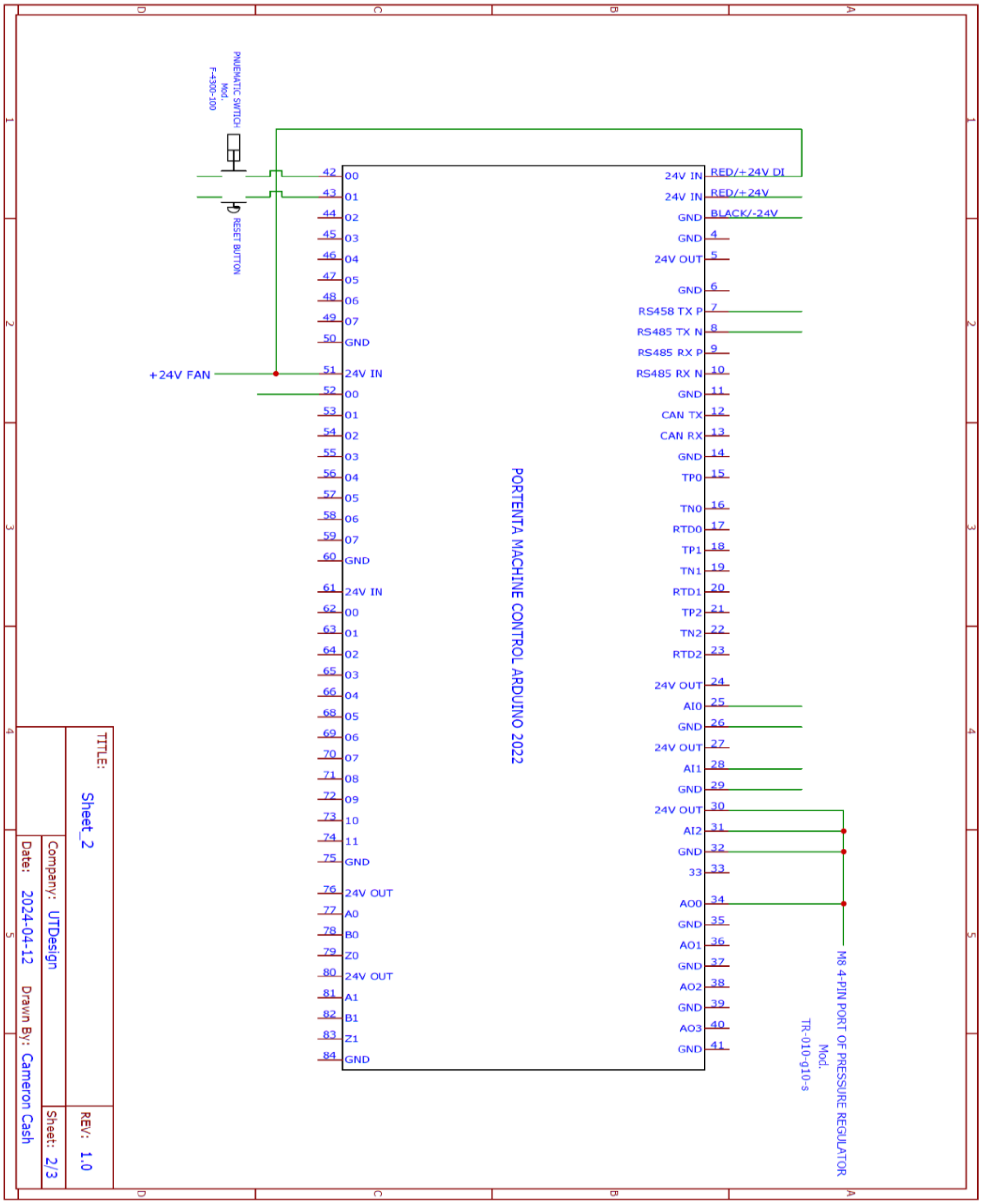


Figure 37: Portenta Machine Control Wire Diagram

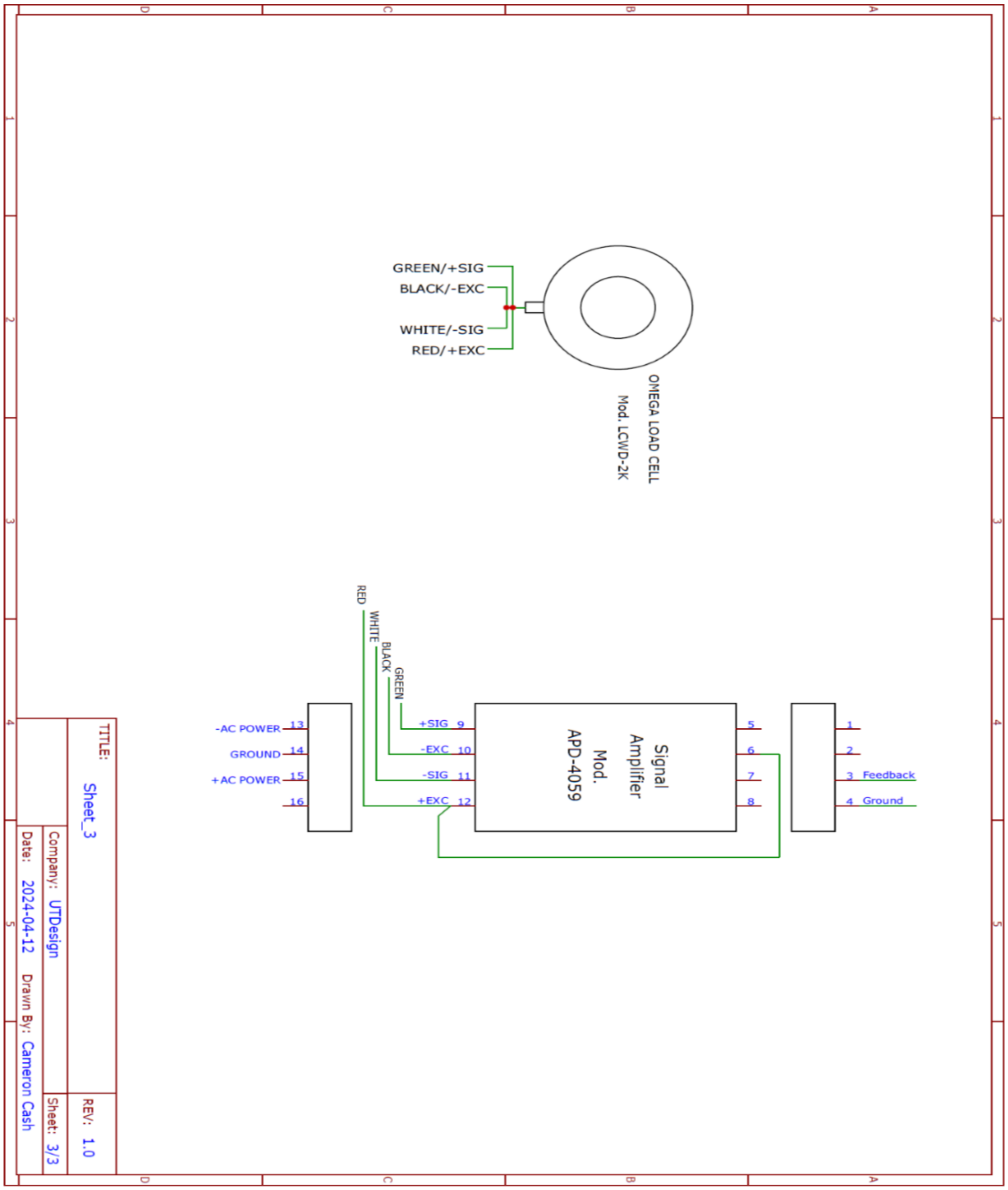


Figure 38: Load Cell Amplifier Wire Diagram

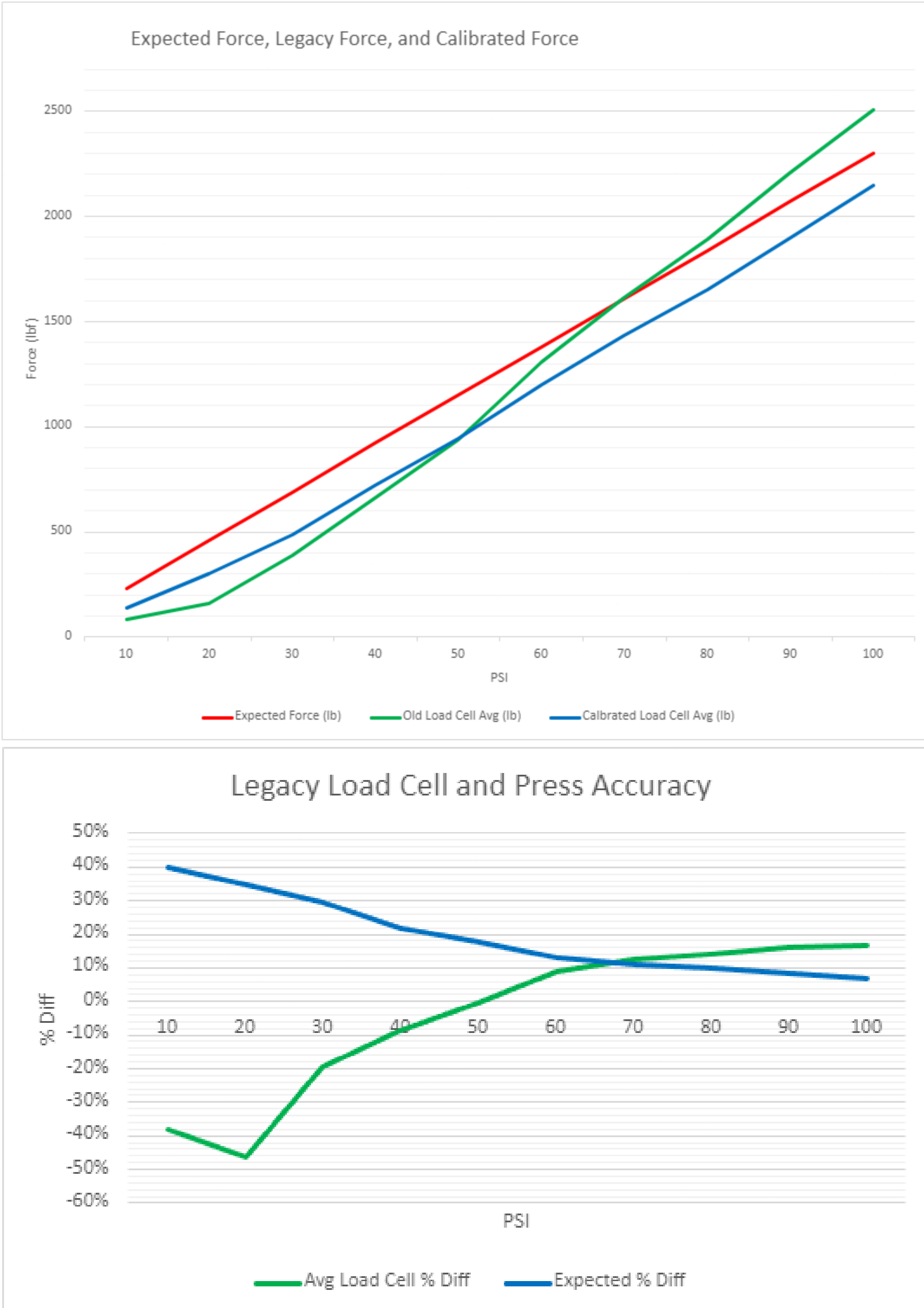


Figure 39: Press Testing Data

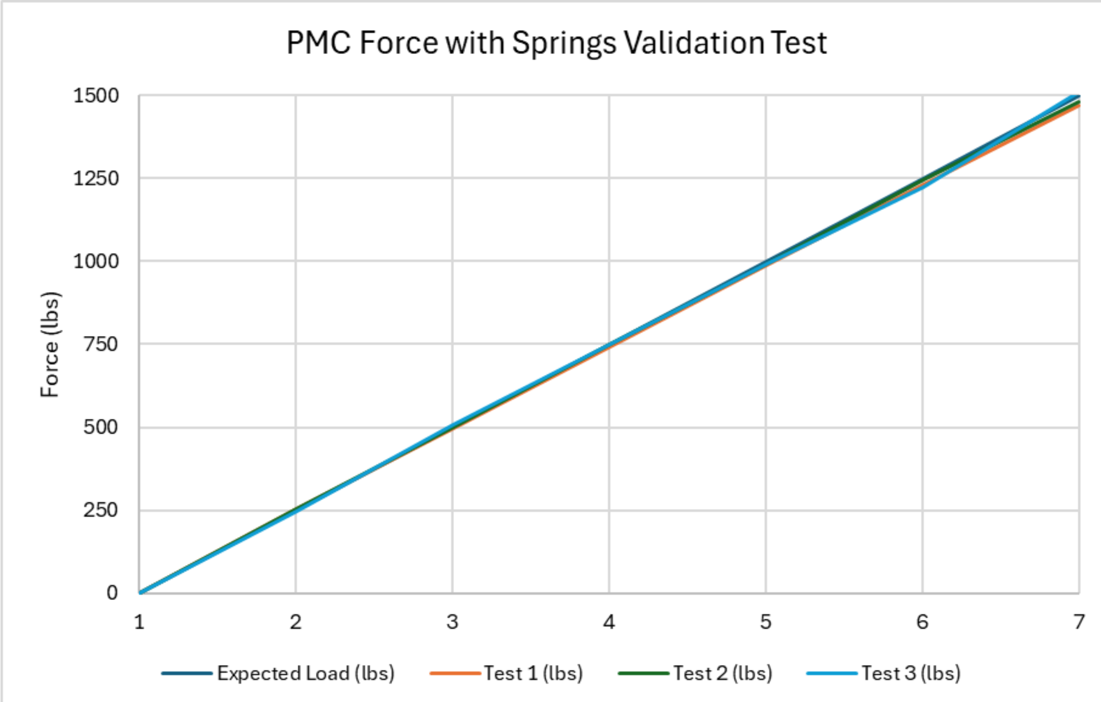


Figure 40: Pressure Regulator Force Control Tests

Appendix B – Design Analysis

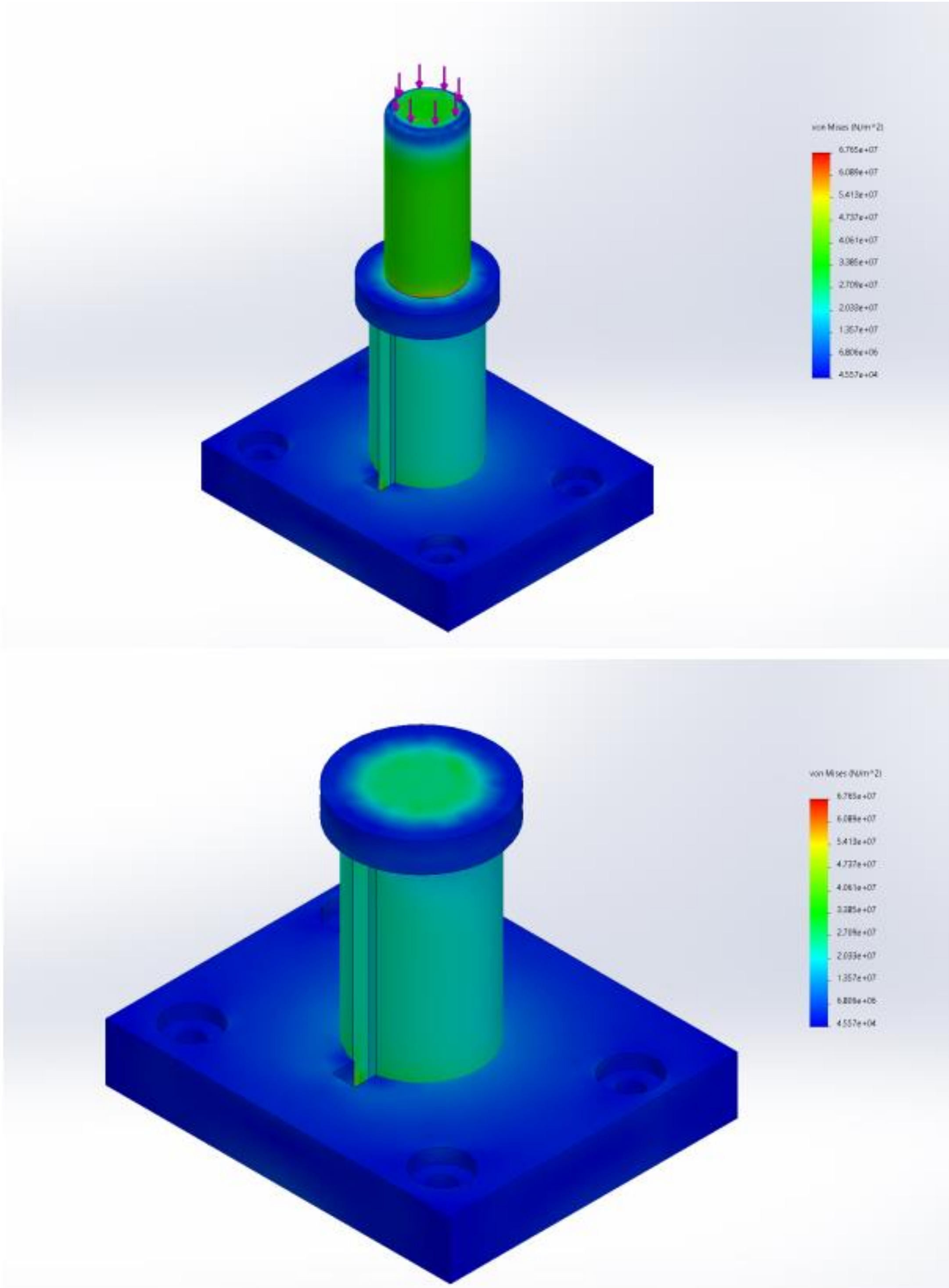


Figure 41: FEA of tool holder subassembly

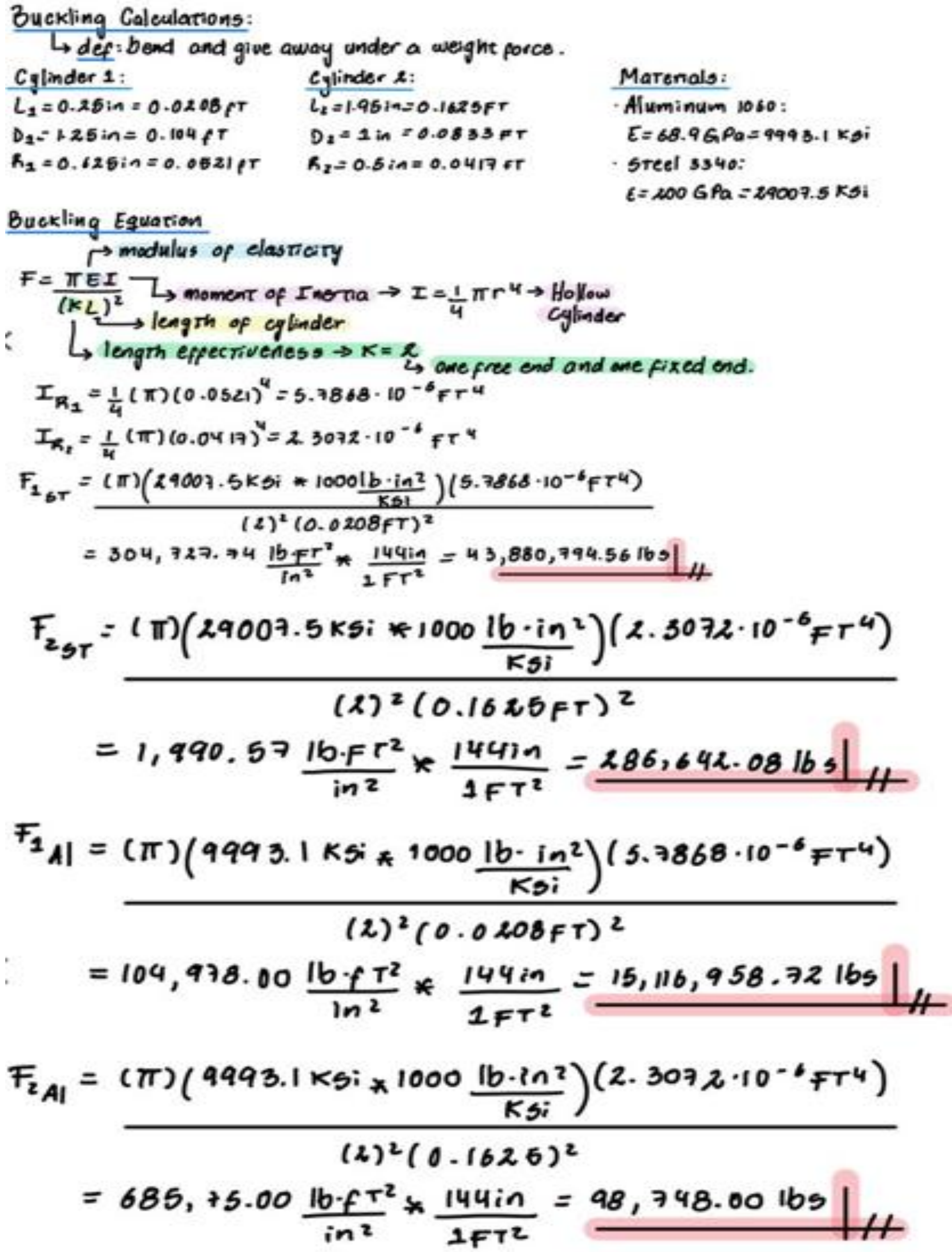


Figure 42: Puck holder cylinder buckling calculations

Slide Hammer Retraction Force Calculation:

Given:

Mass = 2lb = 0.0621 slugs

Velocity = 0.5 – 2 ft/s

Time Interval = 0.001 seconds

Impulse Momentum Equation:

$$\mathrm{Ft} = \mathrm{mv}$$

Rearrange for F:

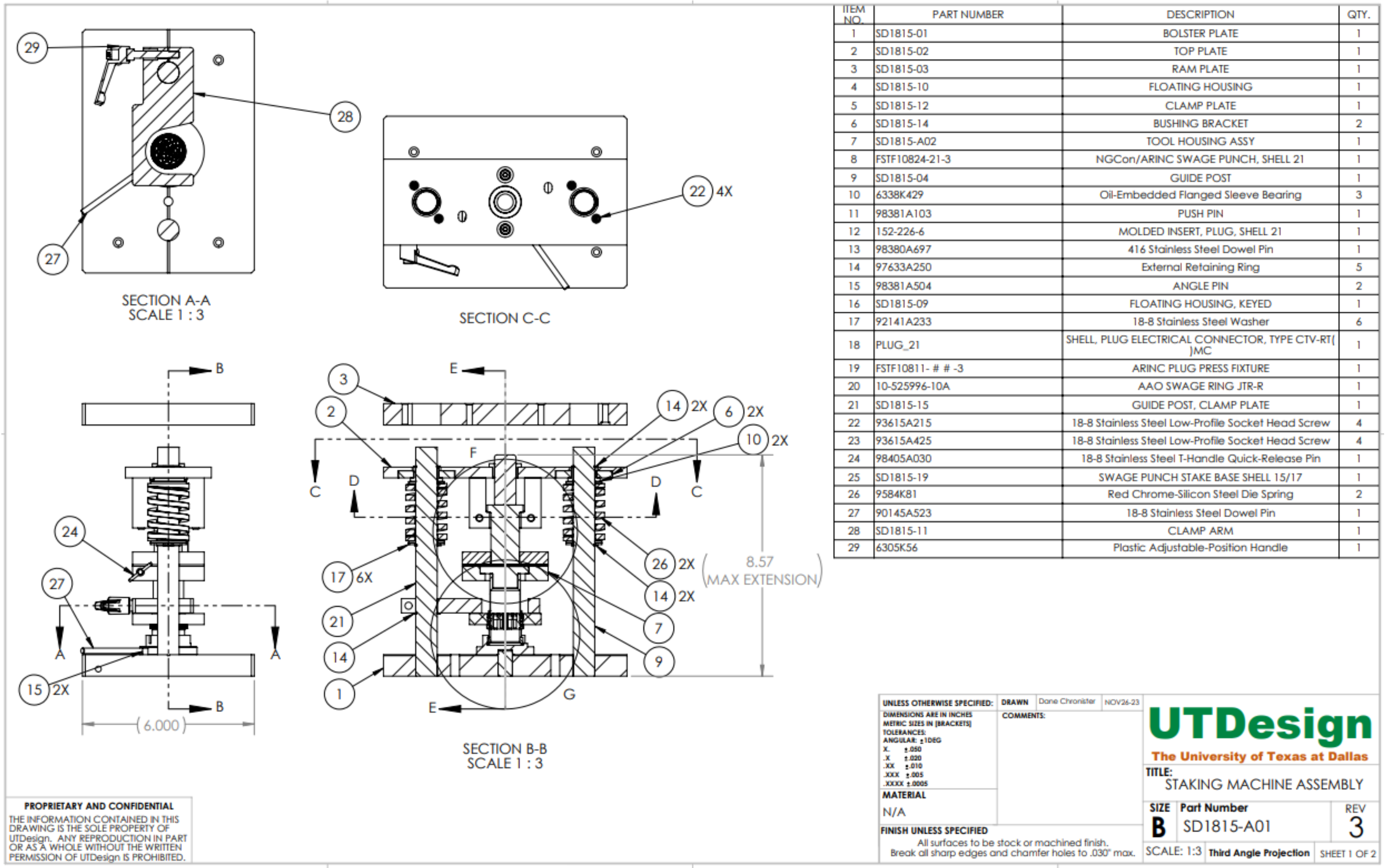
$$\mathrm{F} = \frac{\mathrm{mv}}{\mathrm{t}}$$

Assume maximum velocity of 24 m/s and solve:

$$\mathrm{F} = \frac{0.0621 * 2}{0.001} = 124.2\ lb$$

Figure 43: Slide hammer retraction force calculation

Appendix C – Engineering Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SD1815-01	BOLSTER PLATE	1
2	SD1815-02	TOP PLATE	1
3	SD1815-03	RAM PLATE	1
4	SD1815-10	FLOATING HOUSING	1
5	SD1815-12	CLAMP PLATE	1
6	SD1815-14	BUSHING BRACKET	2
7	SD1815-A02	TOOL HOUSING ASSY	1
8	FSTF10824-21-3	NGCon/ARINC SWAGE PUNCH, SHELL 21	1
9	SD1815-04	GUIDE POST	1
10	6338K429	Oil-Embedded Flanged Sleeve Bearing	3
11	98381A103	PUSH PIN	1
12	152-226-6	MOLDED INSERT, PLUG, SHELL 21	1
13	98380A697	416 Stainless Steel Dowel Pin	1
14	97633A250	External Retaining Ring	5
15	98381A504	ANGLE PIN	2
16	SD1815-09	FLOATING HOUSING, KEYED	1
17	92141A233	18-8 Stainless Steel Washer	6
18	PLUG_21	SHELL, PLUG ELECTRICAL CONNECTOR, TYPE CTV-RT( )MC	1
19	FSTF10811- # # -3	ARINC PLUG PRESS FIXTURE	1
20	10-525996-10A	AAO SWAGE RING JTR-R	1
21	SD1815-15	GUIDE POST, CLAMP PLATE	1
22	93615A215	18-8 Stainless Steel Low-Profile Socket Head Screw	4
23	93615A425	18-8 Stainless Steel Low-Profile Socket Head Screw	4
24	98405A030	18-8 Stainless Steel T-Handle Quick-Release Pin	1
25	SD1815-19	SWAGE PUNCH STAKE BASE SHELL 15/17	1
26	9584K81	Red Chrome-Silicon Steel Die Spring	2
27	90145A523	18-8 Stainless Steel Dowel Pin	1
28	SD1815-11	CLAMP ARM	1
29	6305K56	Plastic Adjustable-Position Handle	1

Figure 44a: Staking Machine Assembly Drawing (1/2)

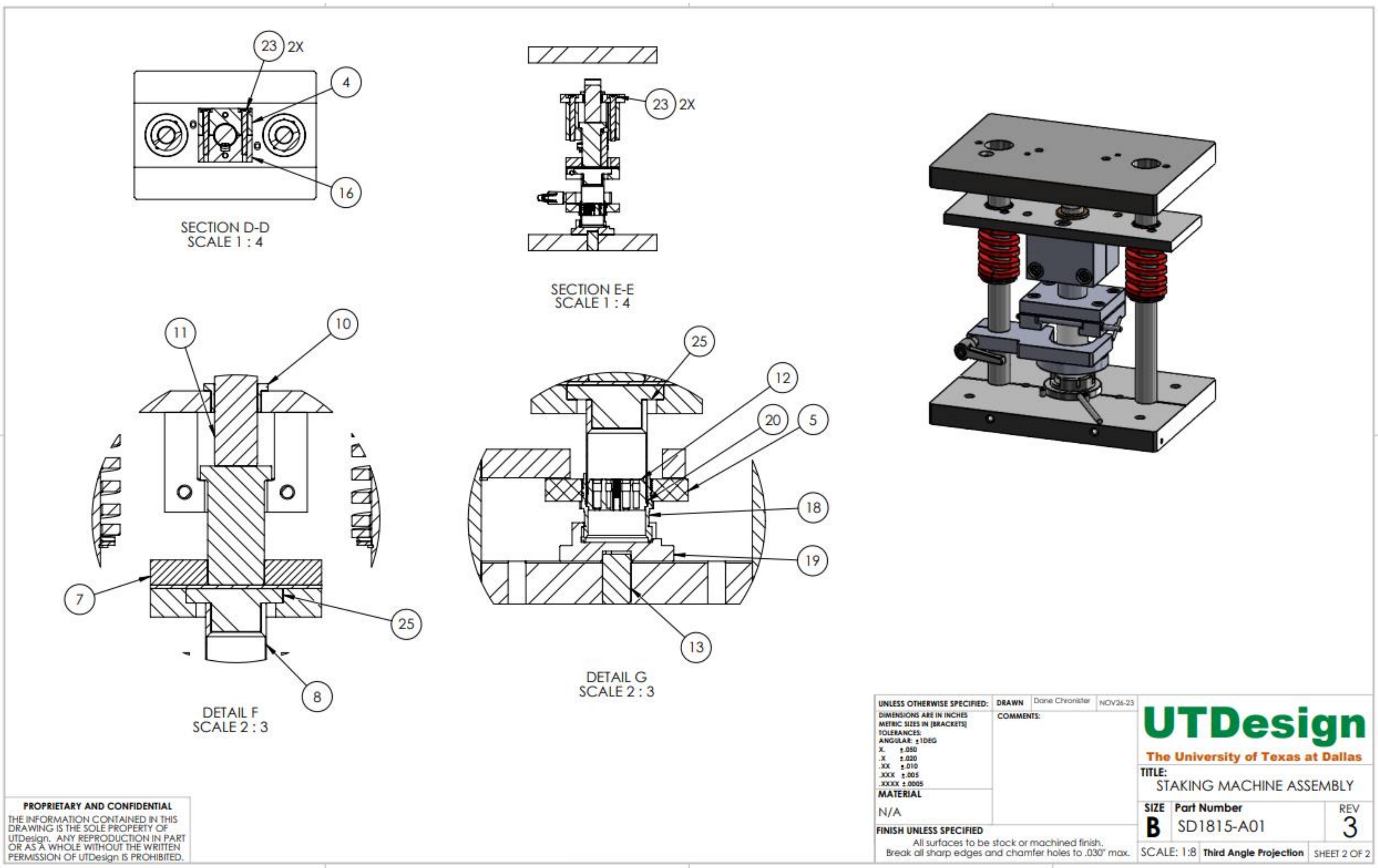


Figure 44b: Staking Machine Assembly Drawing (2/2)

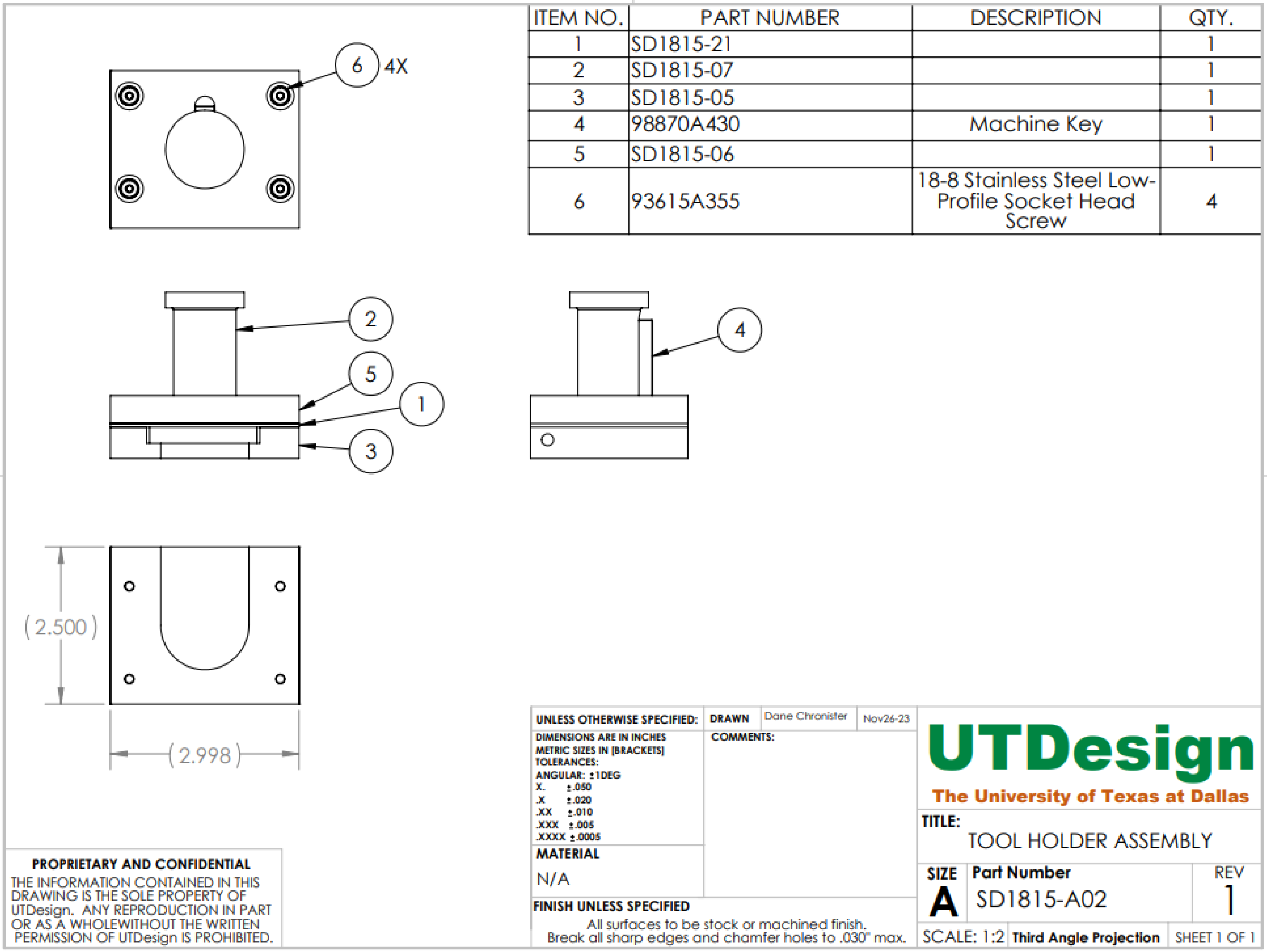


Figure 45: Tool Holder Assembly Drawing

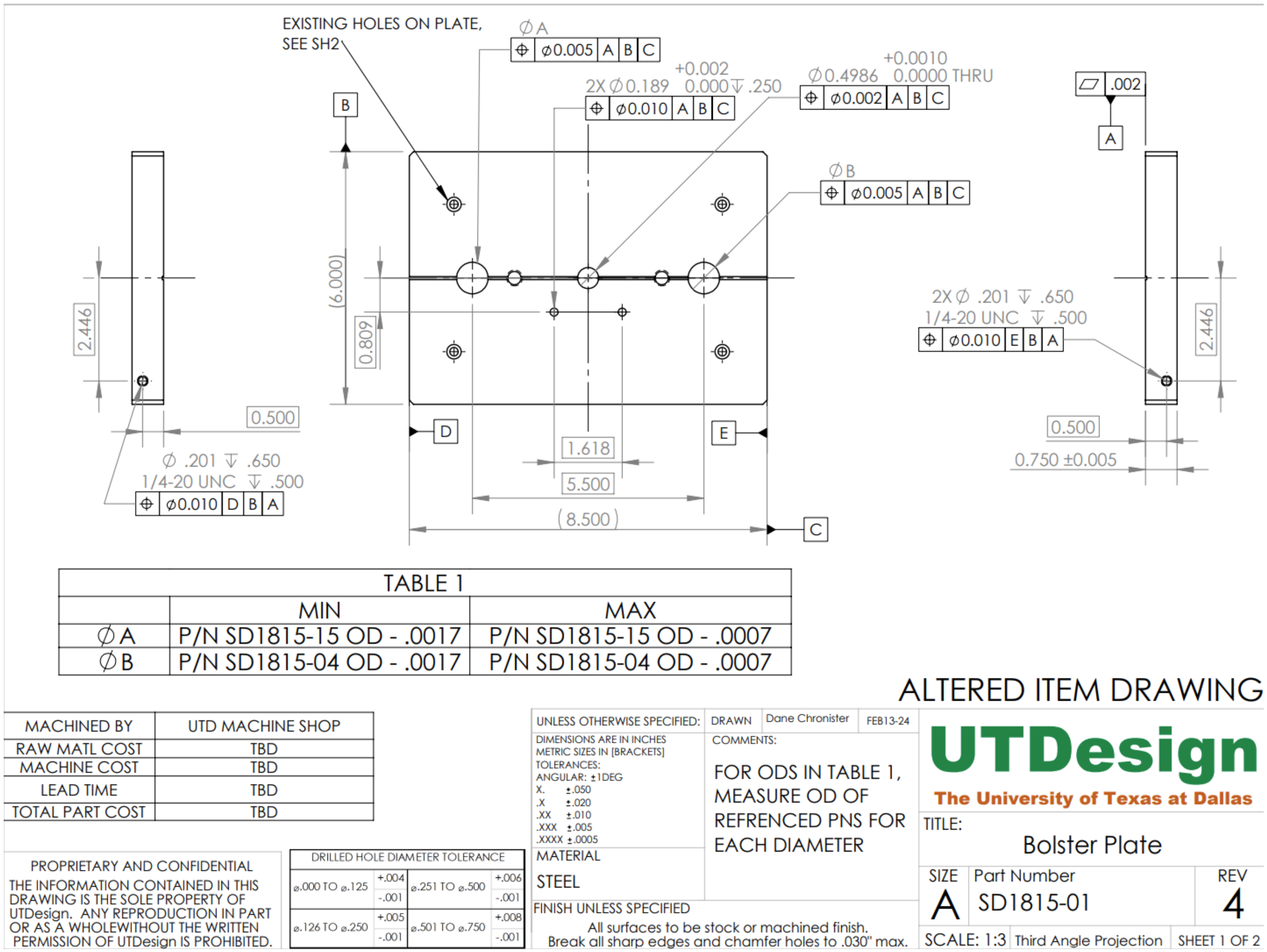


Figure 46: Bolster plate drawing

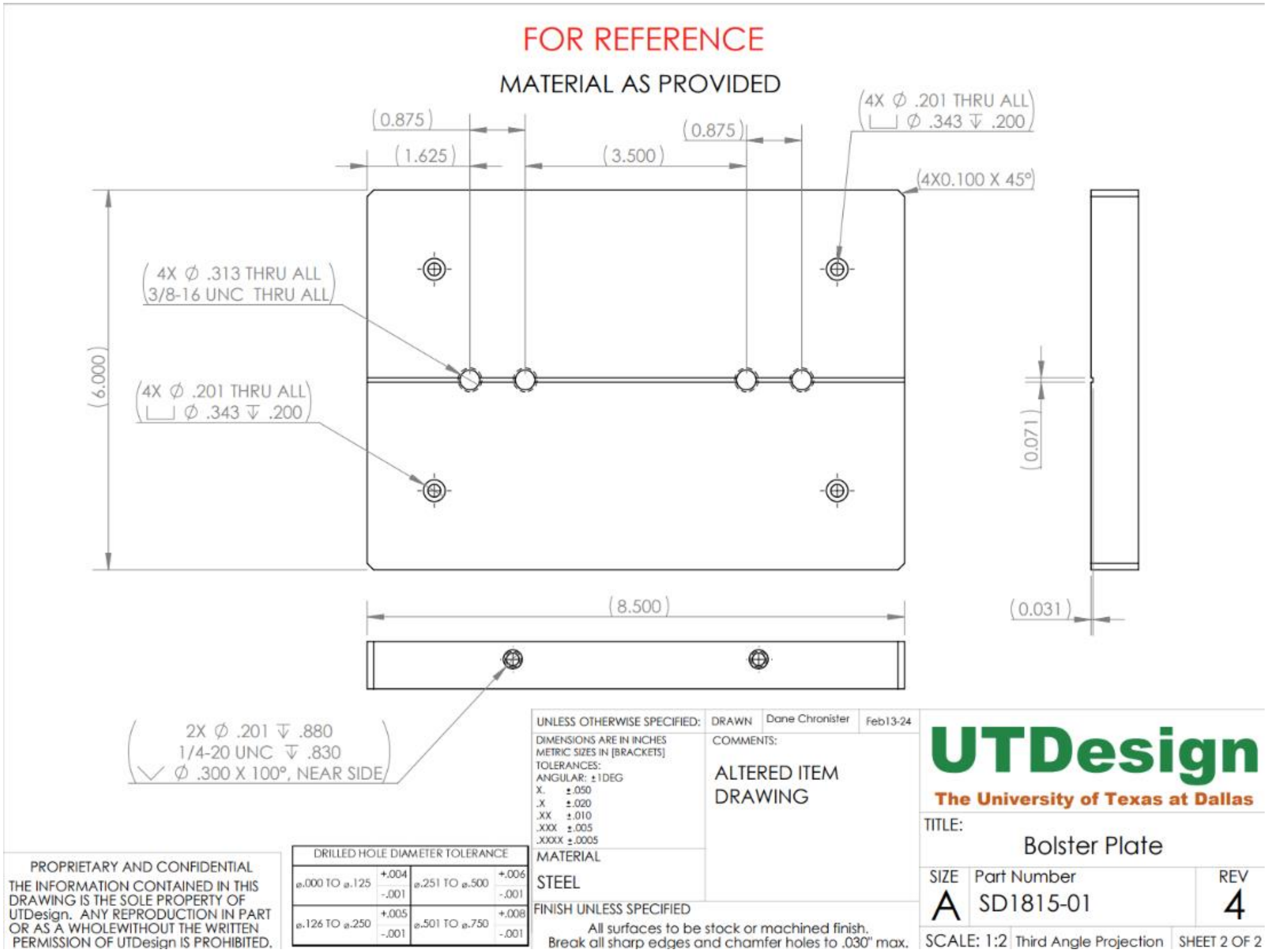


Figure 47: Bolster plate, reference of existing part

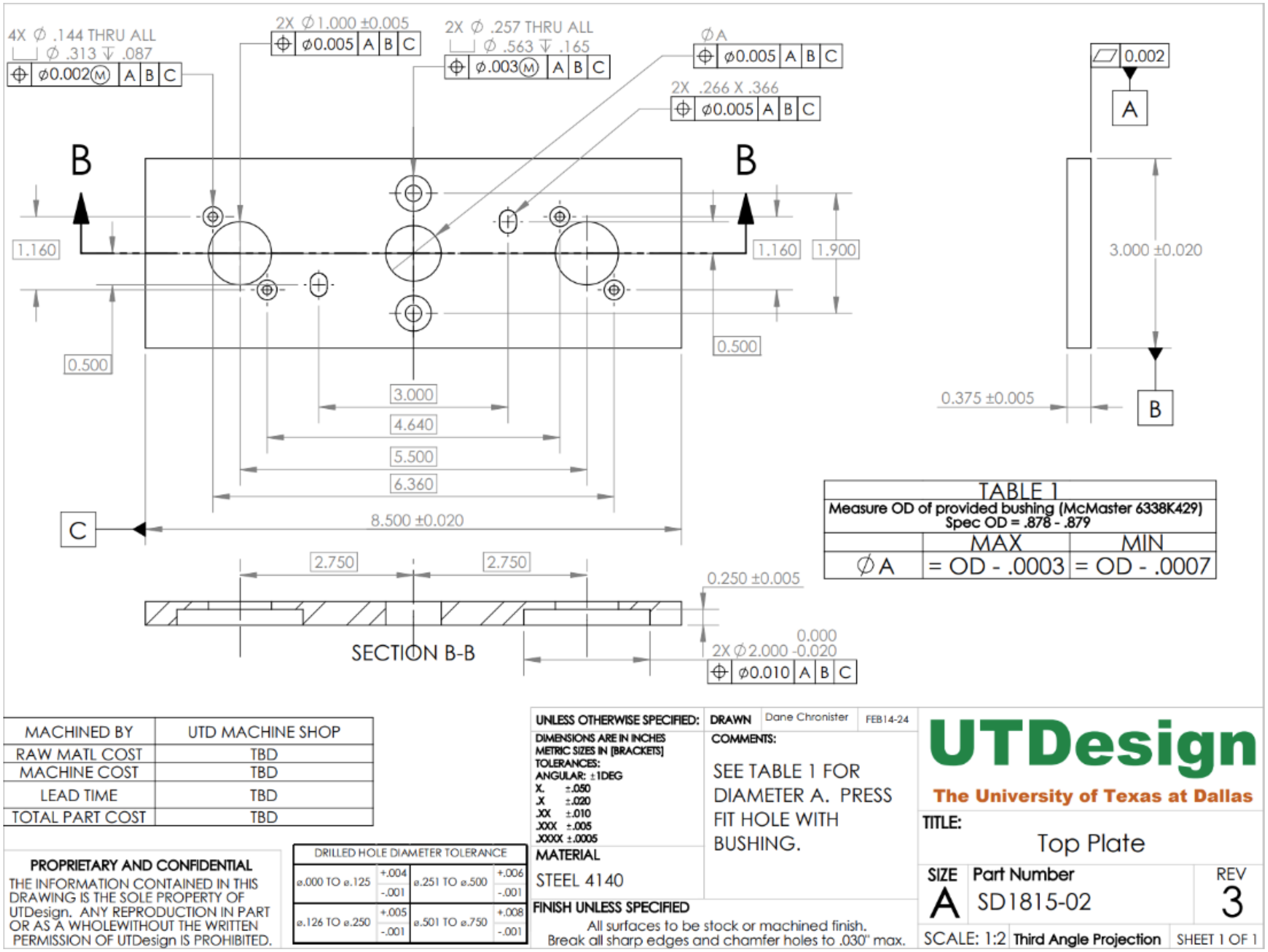


Figure 48: Top plate drawing

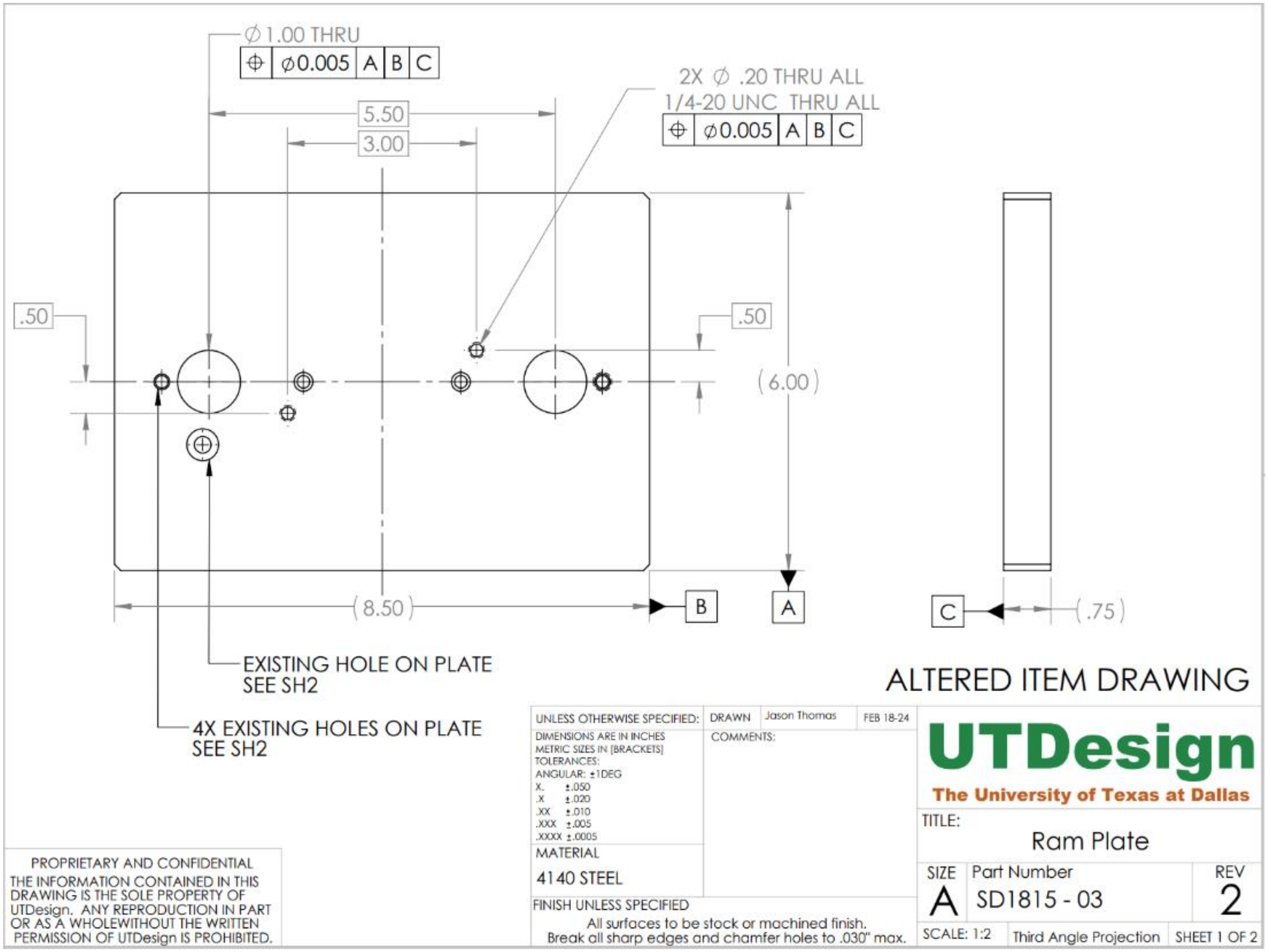


Figure 49: Ram plate drawing

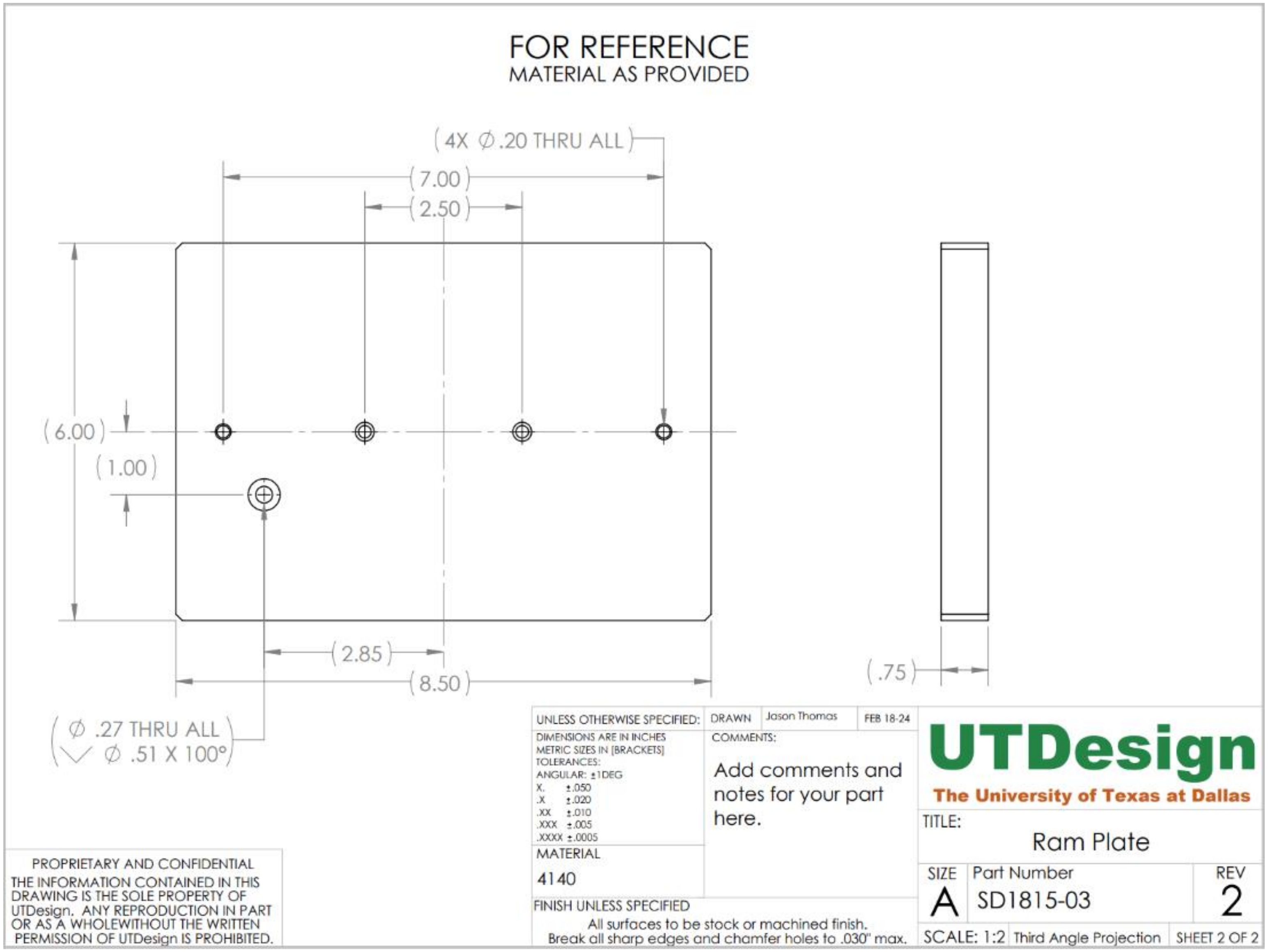


Figure 50: Ram plate, reference of existing part

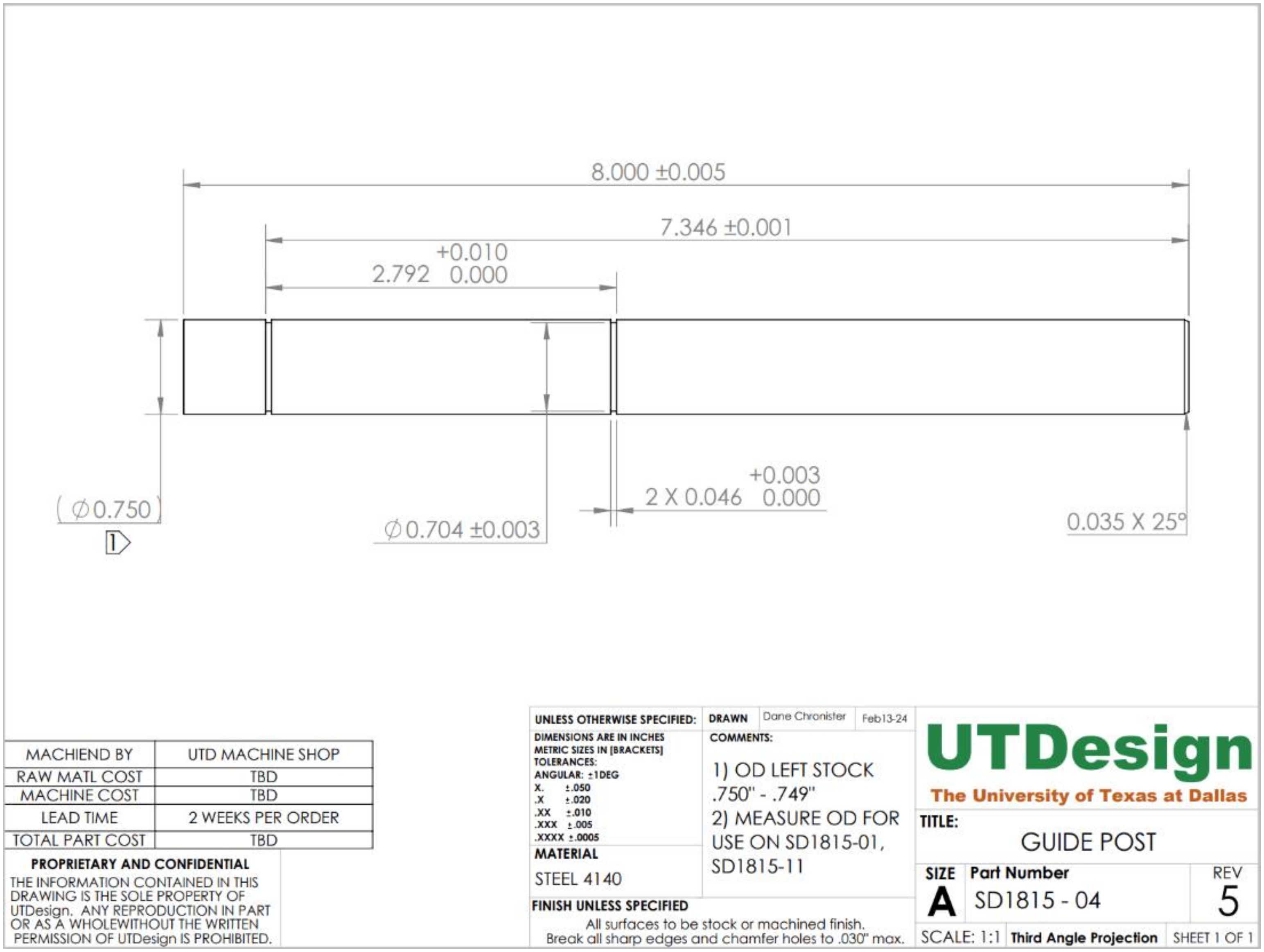


Figure 51: Right guide post drawing

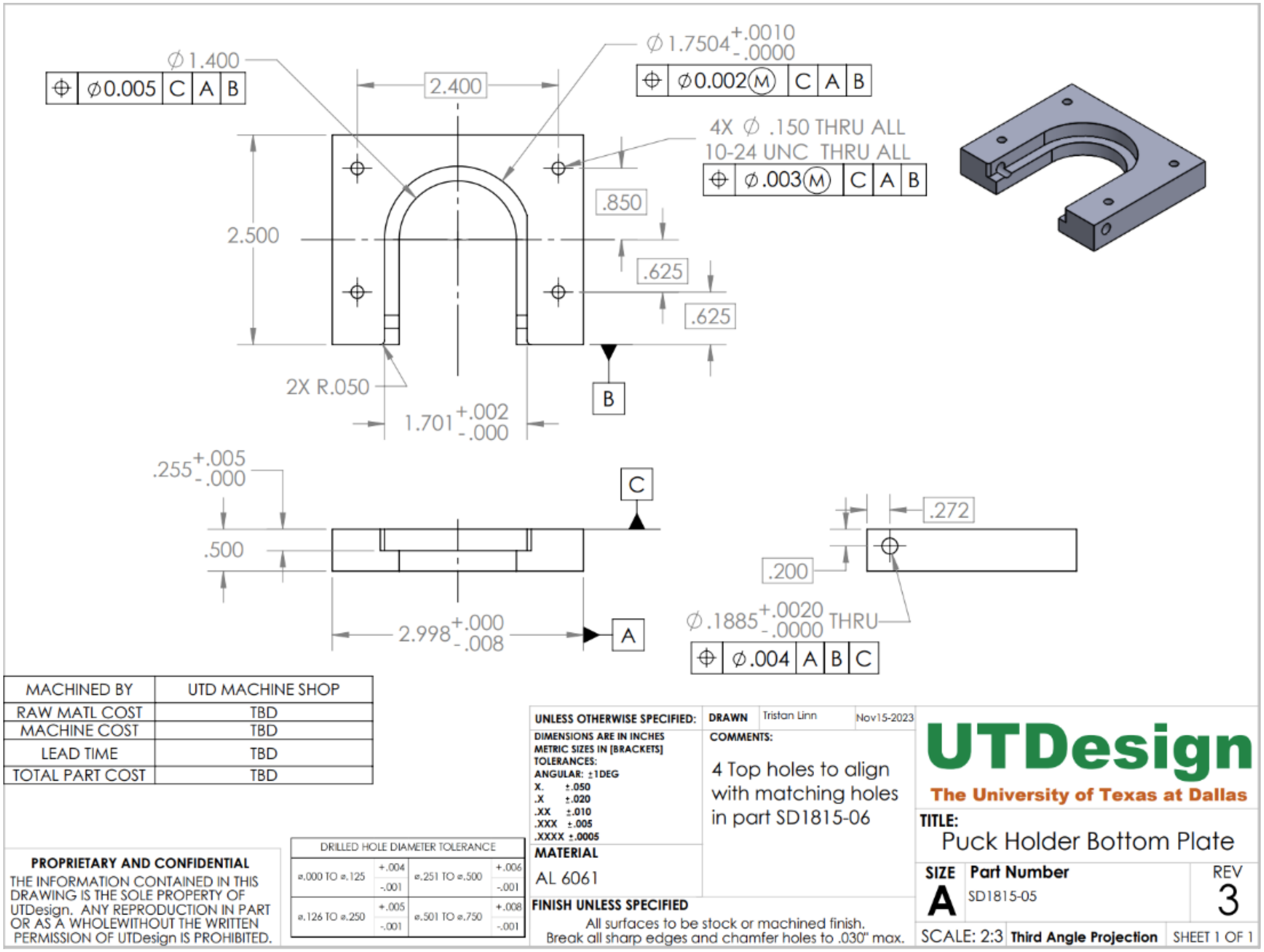


Figure 52: Puck Holder, Bottom Plate drawing

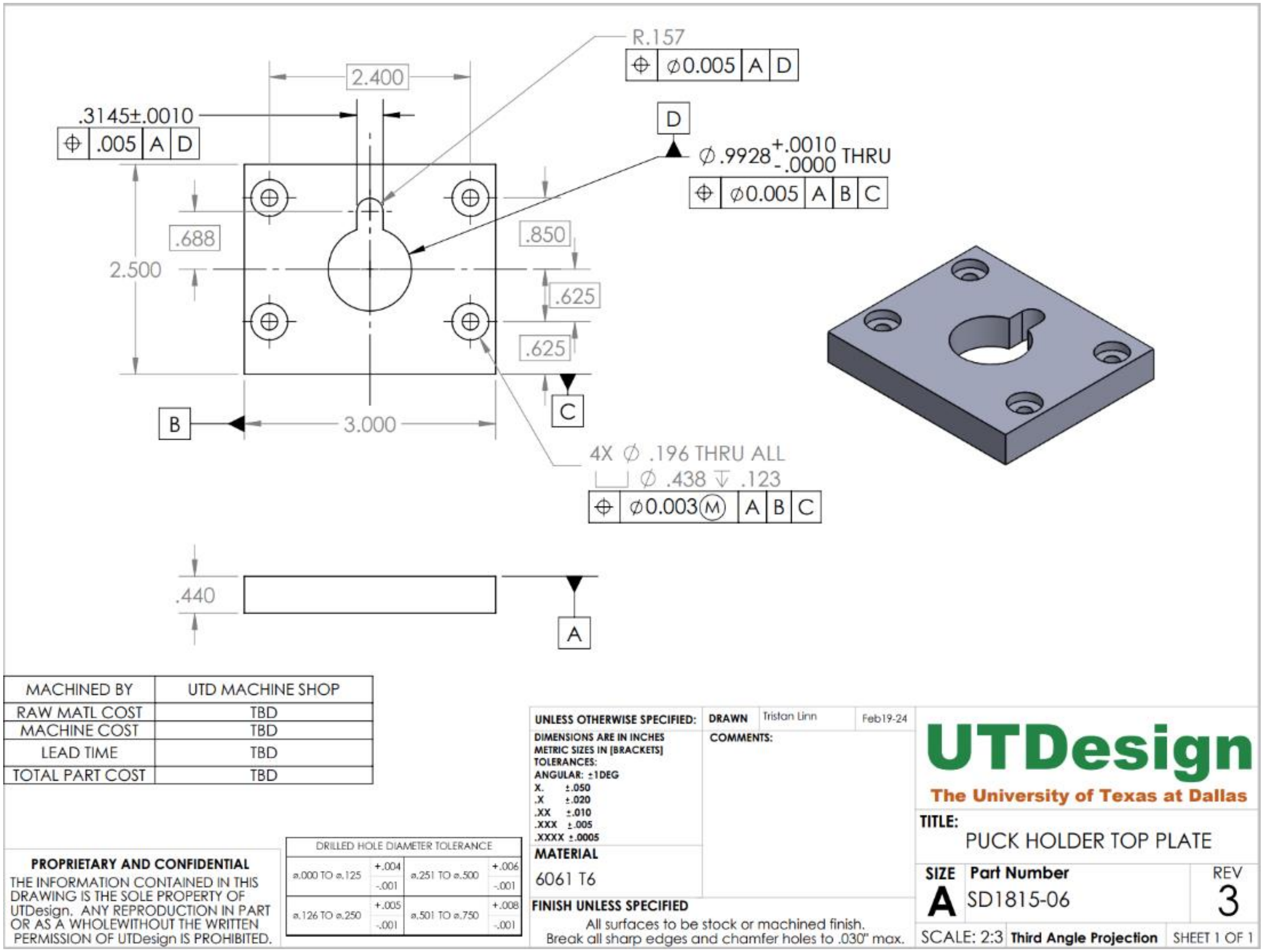


Figure 53: Puck Holder, Top Plate drawing

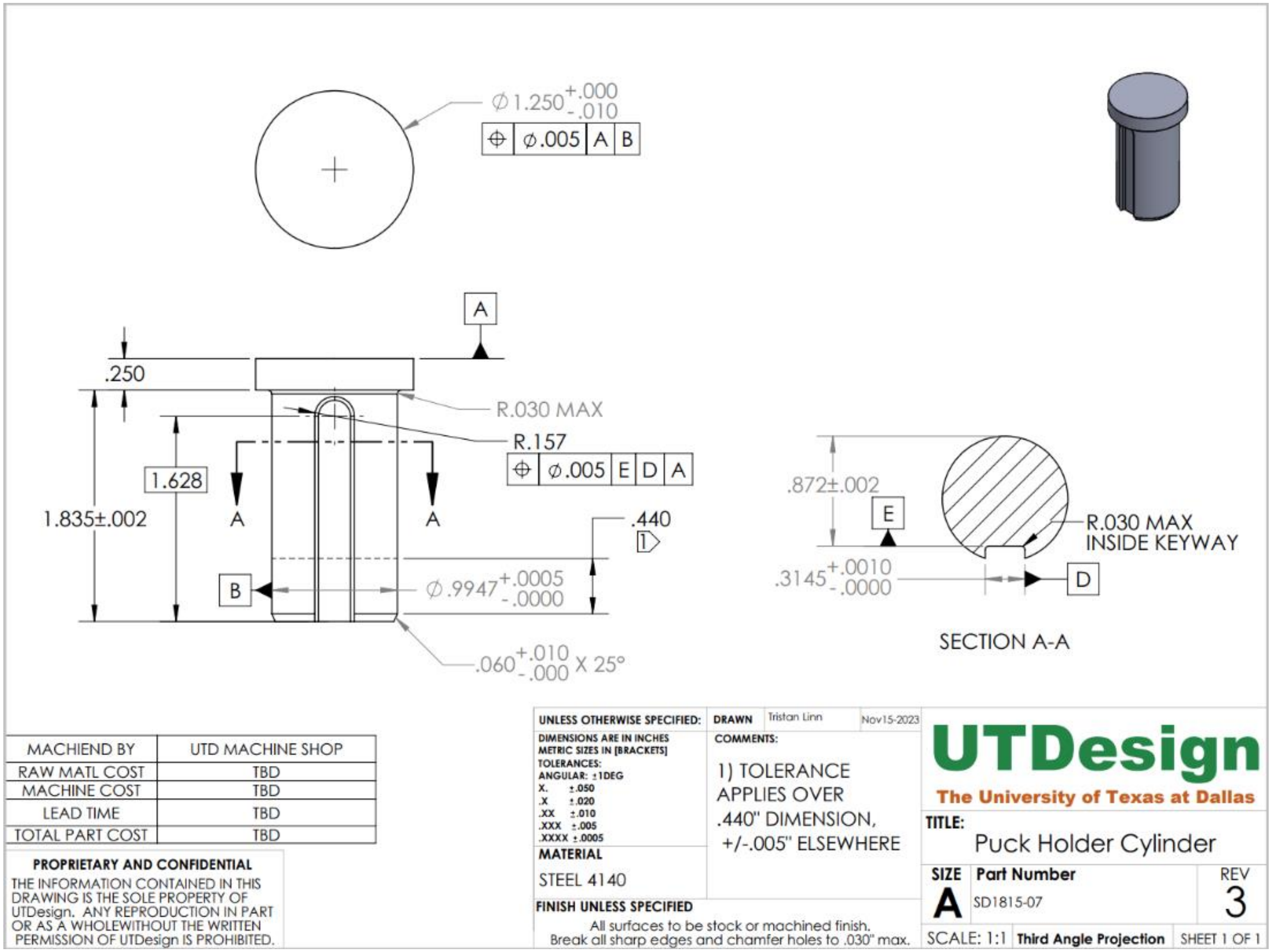


Figure 54: Puck Holder, Cylinder drawing

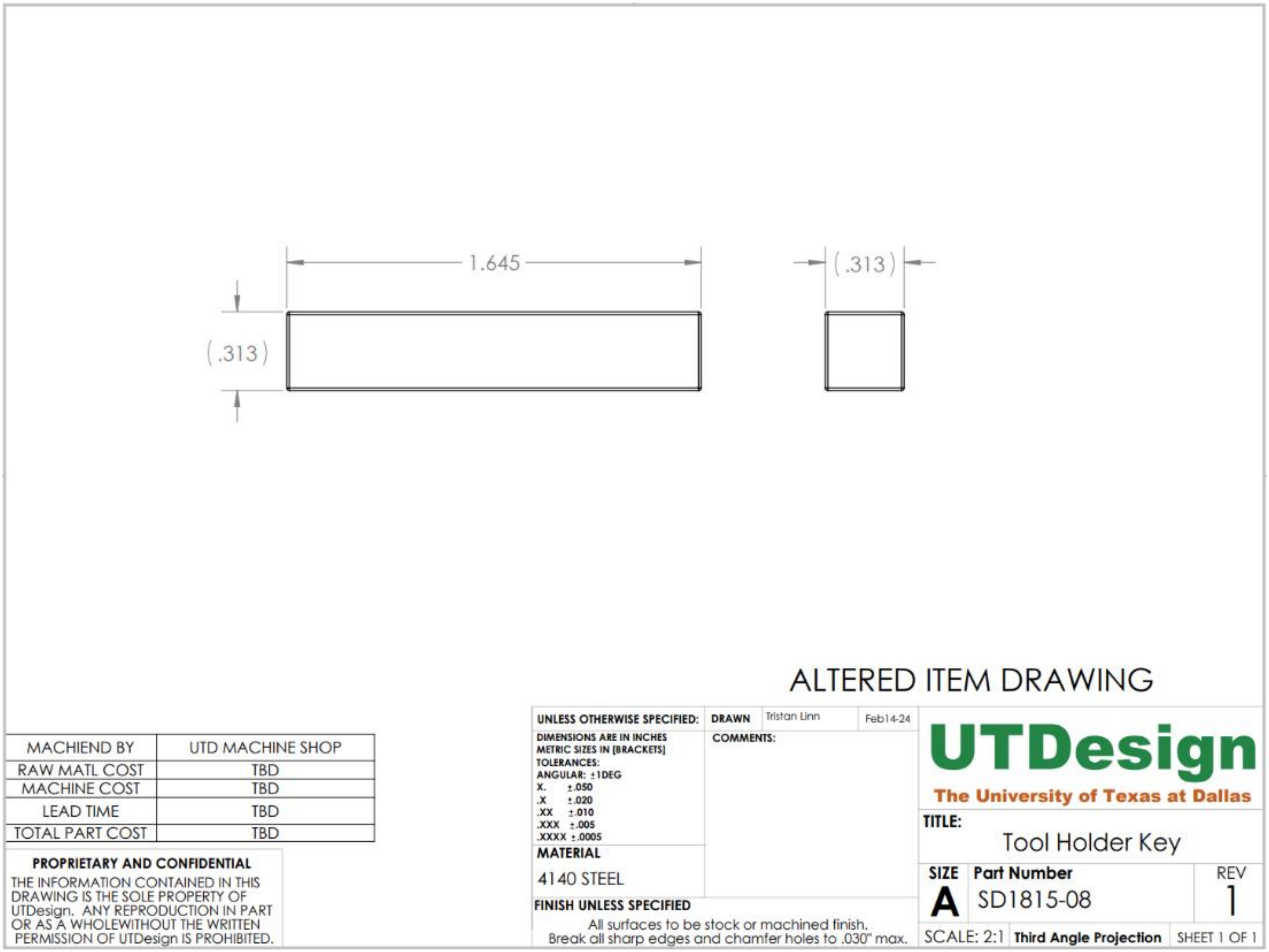


Figure 55: Tool Holder, Key drawing

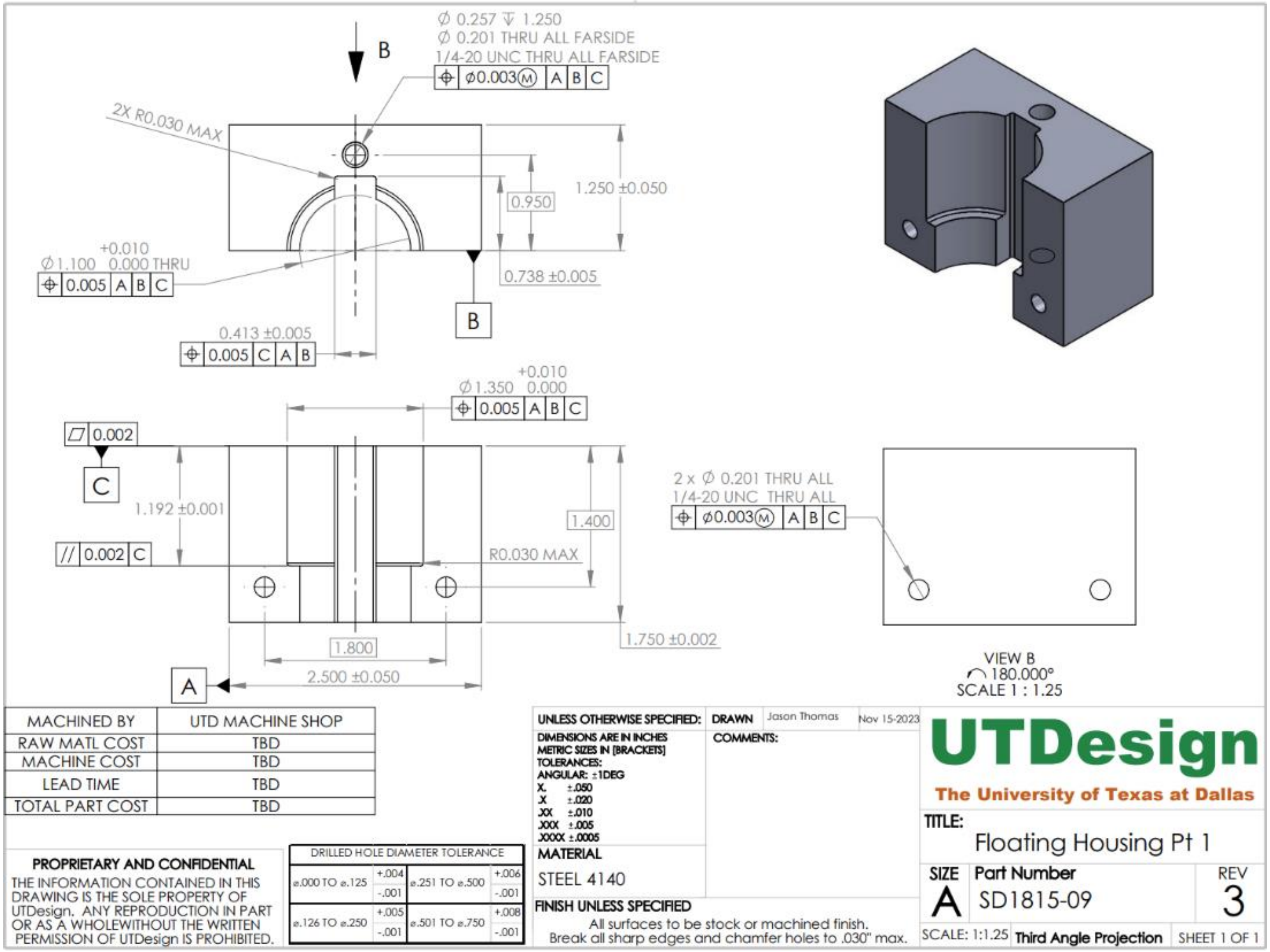


Figure 56: Floating Housing, PT 1 drawing

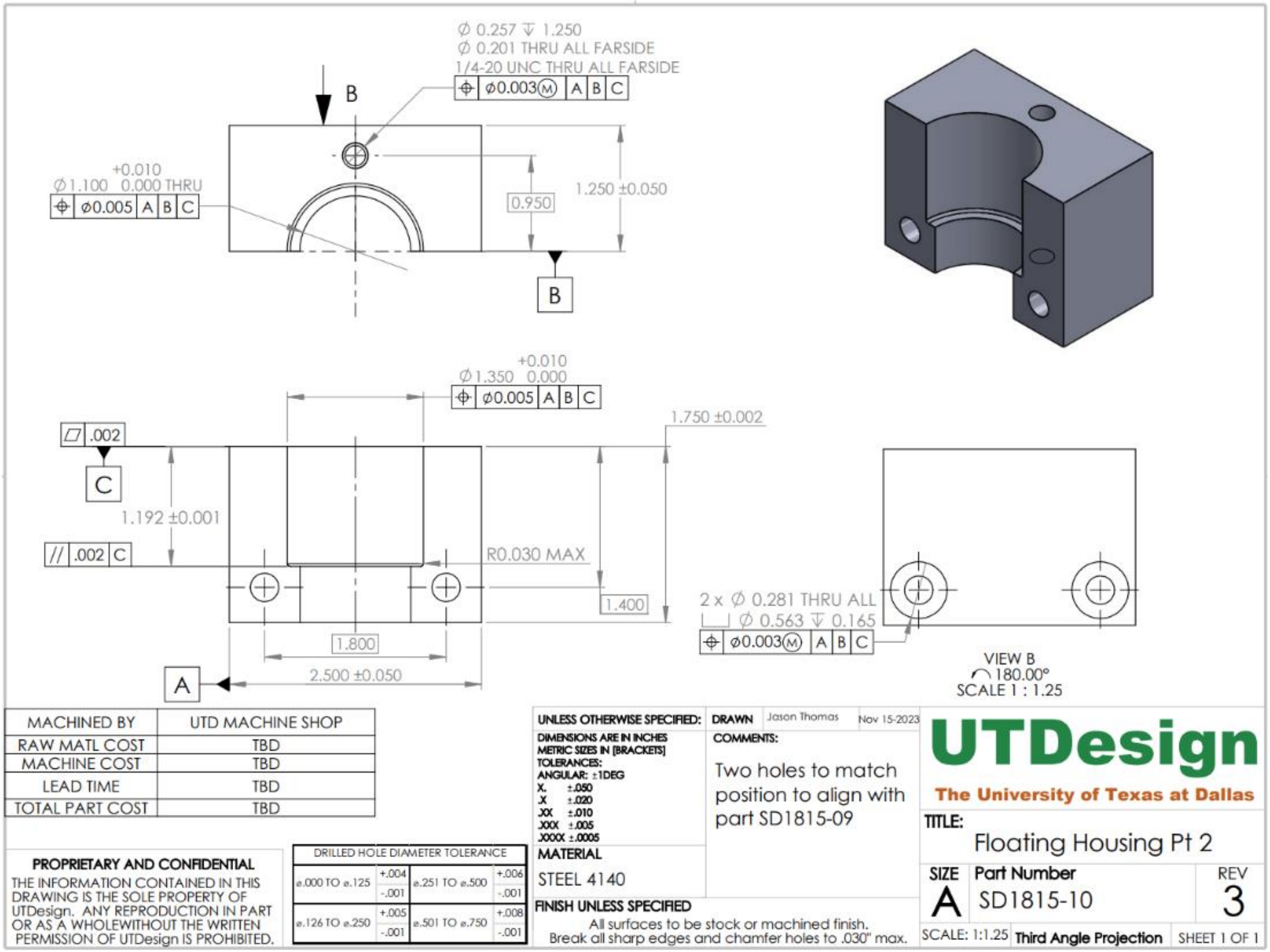


Figure 57: Floating Housing, PT 2 drawing

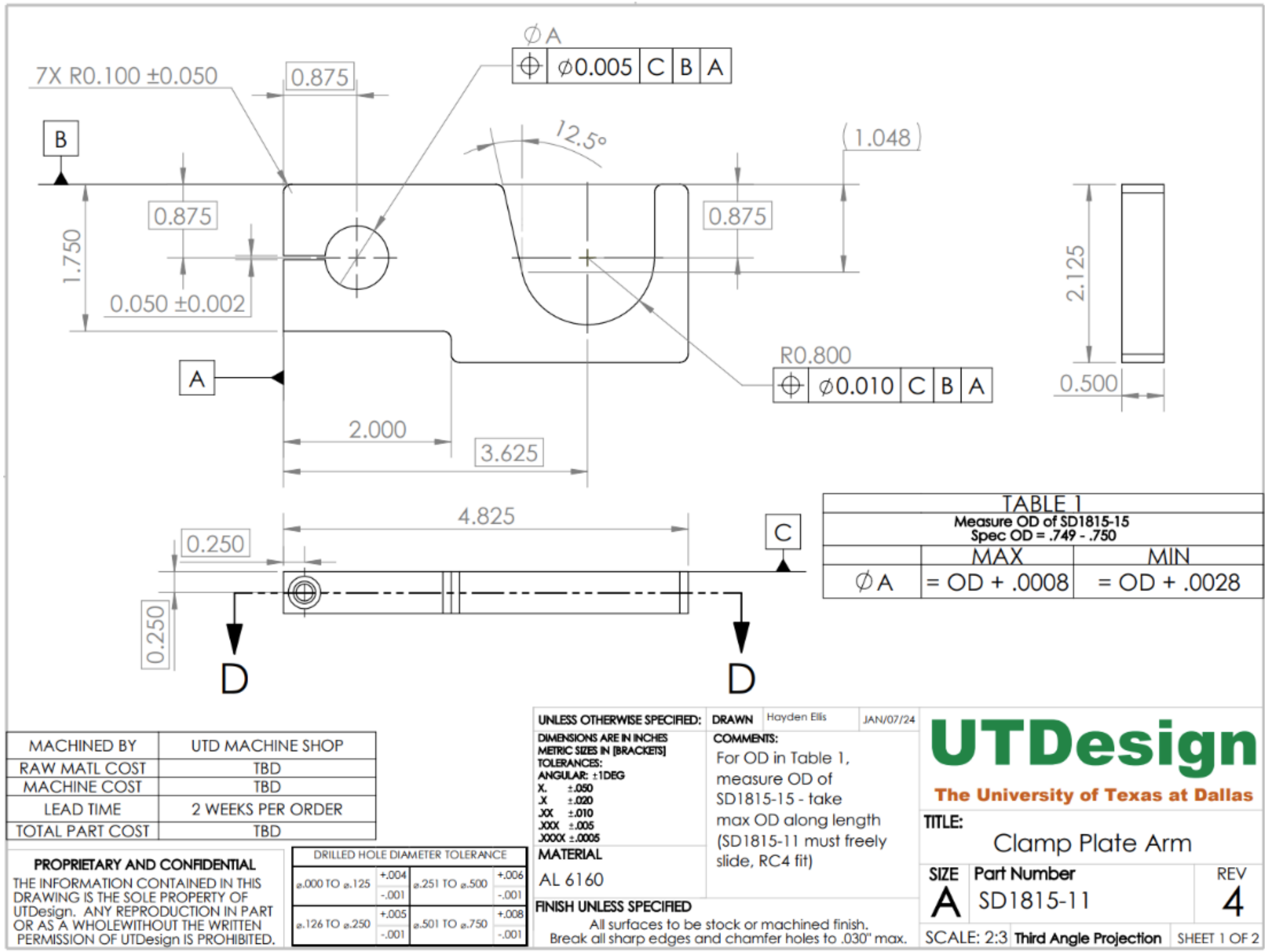


Figure 58: Clamp Plate Arm drawing, sheet 1

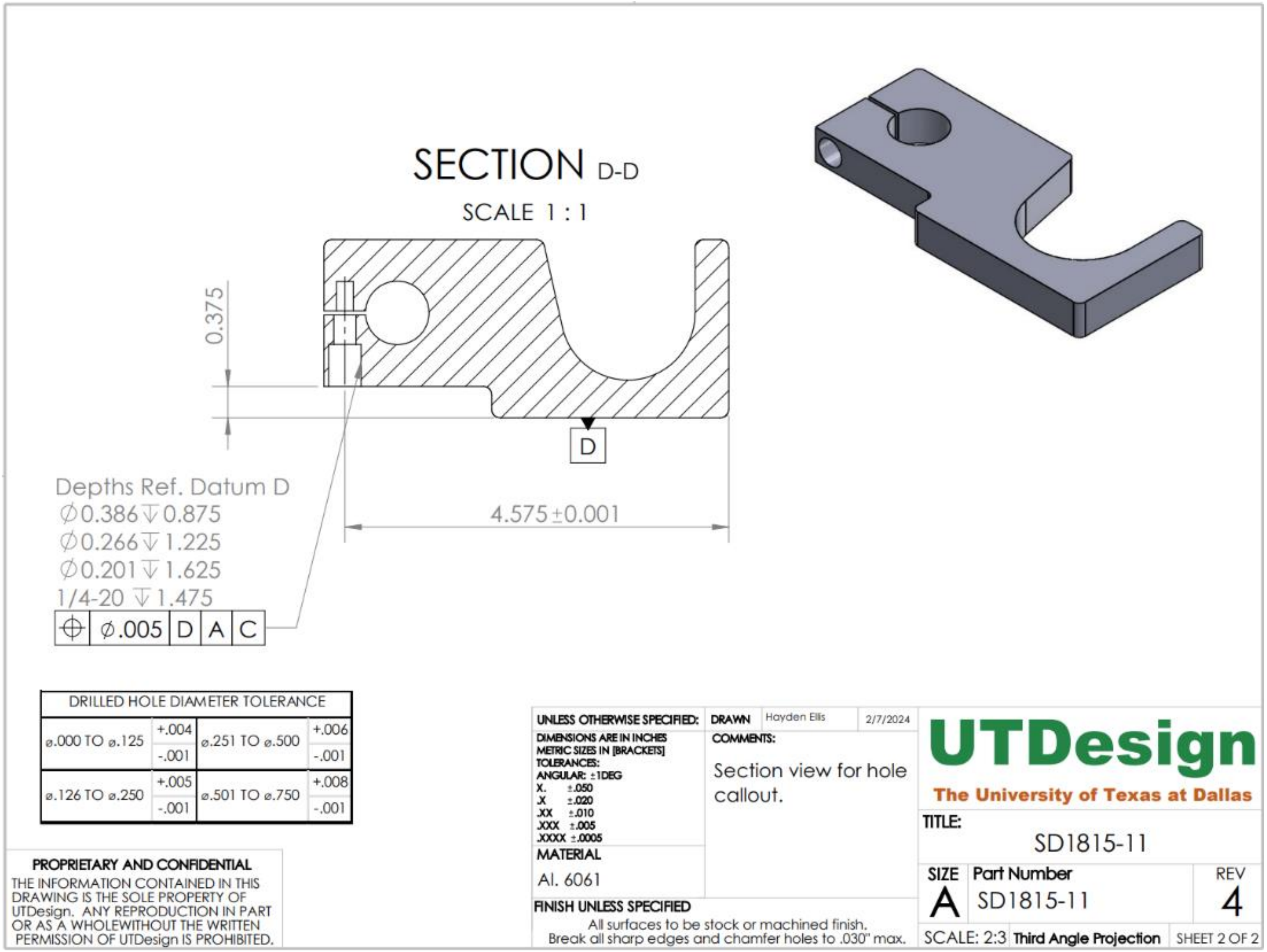
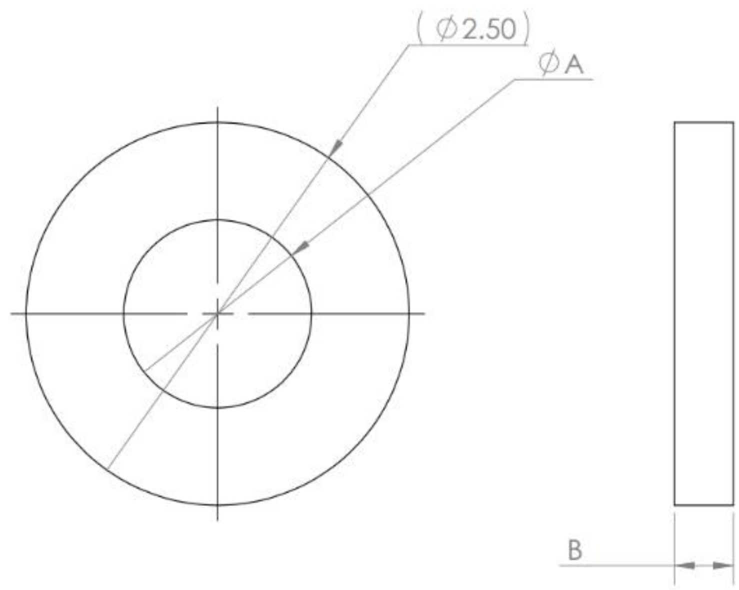


Figure 59: Clamp Plate Arm drawing, sheet 2



PART NUMBER	DESCRIPTION	øA +.005 -.000	B +.005 -.005
SD1815-12-1	PLUG SHELL 15	0.871	0.387
SD1815-12-2	PLUG SHELL 21	1.226	0.387
SD1815-12-3	INLINE REC SHELL 15	0.871	0.234
SD1815-12-4	INLINE REC SHELL 21	1.226	0.234

MACHINED BY	UTD MACHINE SHOP
RAW MATL COST	TBD
MACHINE COST	TBD
LEAD TIME	2 WEEKS PER ORDER
TOTAL PART COST	TBD

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES METRIC SIZES IN [BRACKETS] TOLERANCES: ANGULAR: ±1DEG X. ±.050 .X ±.020 .XX ±.010 .XXX ±.005 .XXXX ±.0005

DRAWN Dane Chronister Feb13-24

COMMENTS:

MATERIAL Delrin

FINISH UNLESS SPECIFIED All surfaces to be stock or machined finish. Break all sharp edges and chamfer holes to .030" max.

UTDesign

The University of Texas at Dallas

TITLE: Clamp Plate

SIZE A | Part Number SD1815-12 | REV 3

SCALE: 1:1 | Third Angle Projection | SHEET 1 OF 1

Figure 60: Clamp Plate drawing

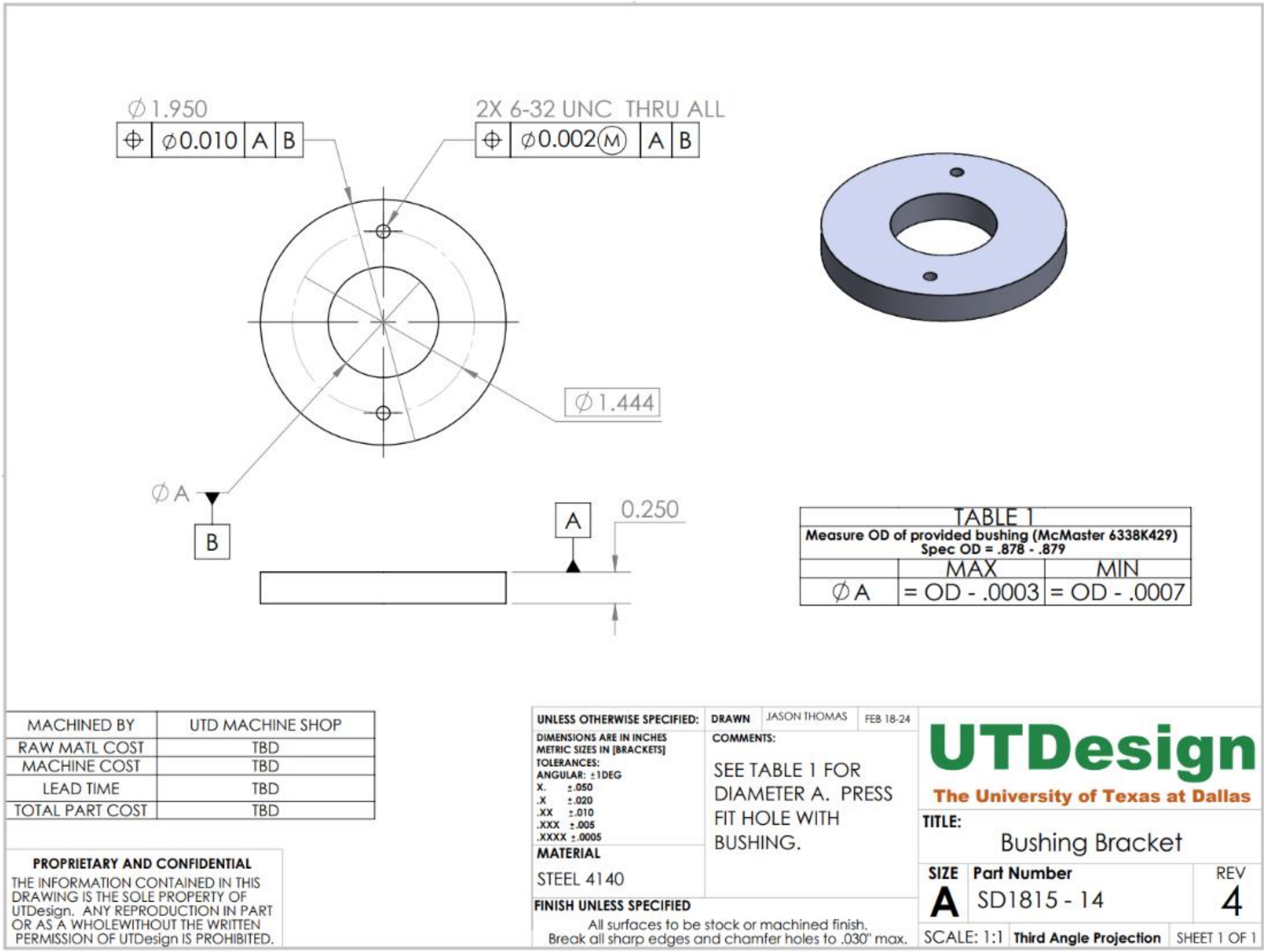


Figure 61: Bushing Bracket drawing

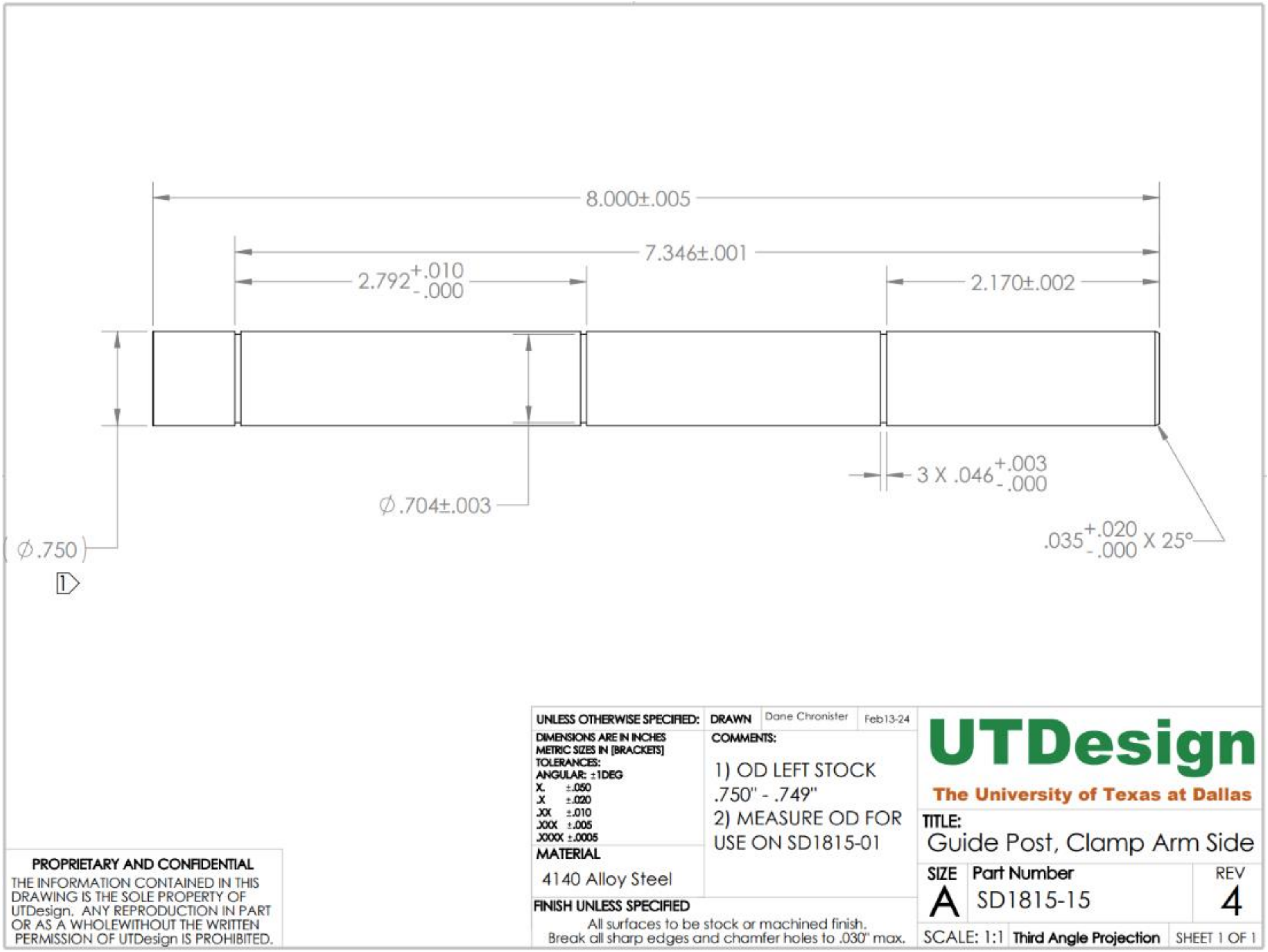


Figure 62: Left Guide Post, Clamp Arm Side drawing

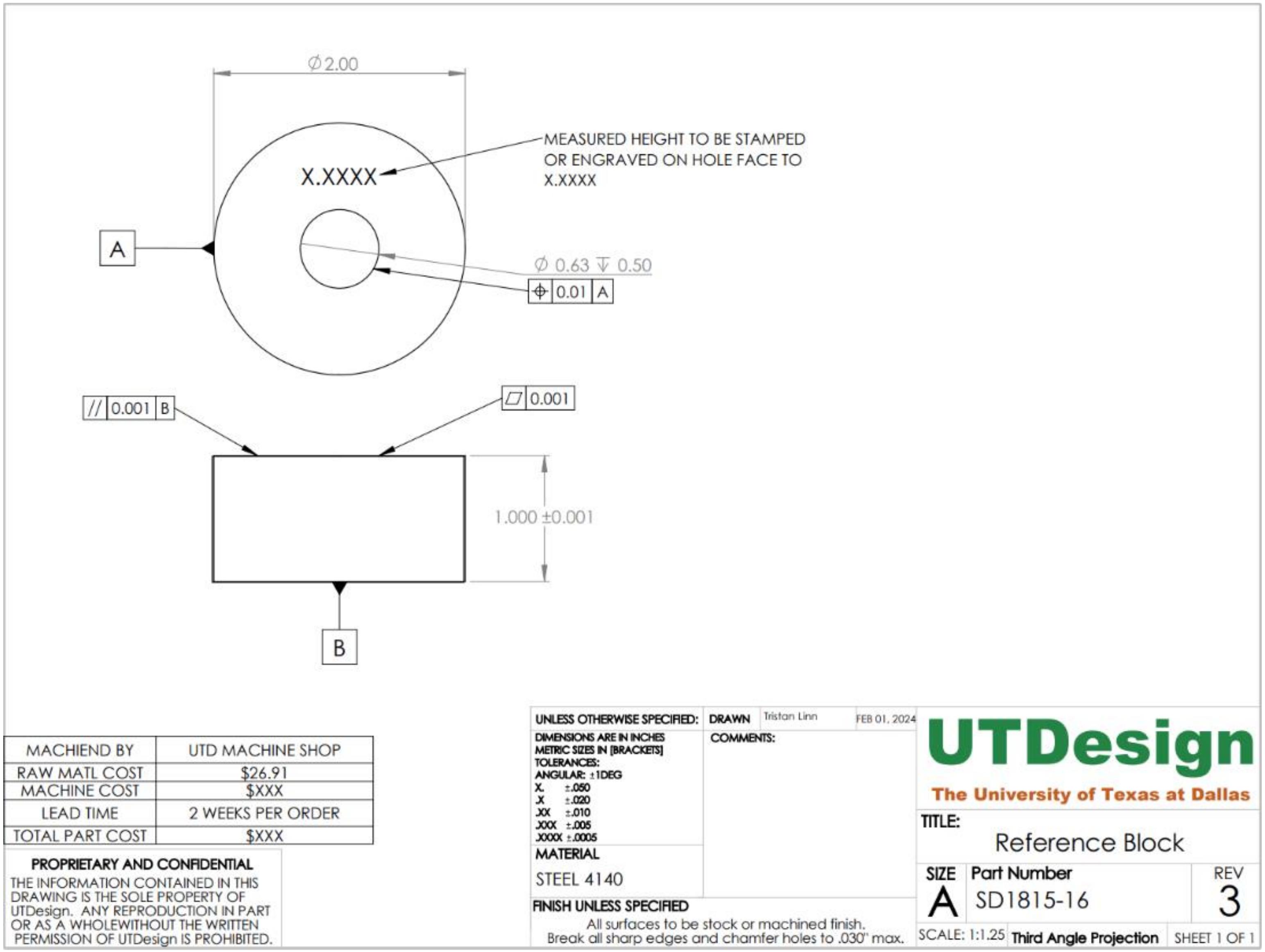


Figure 63: Reference Block drawing

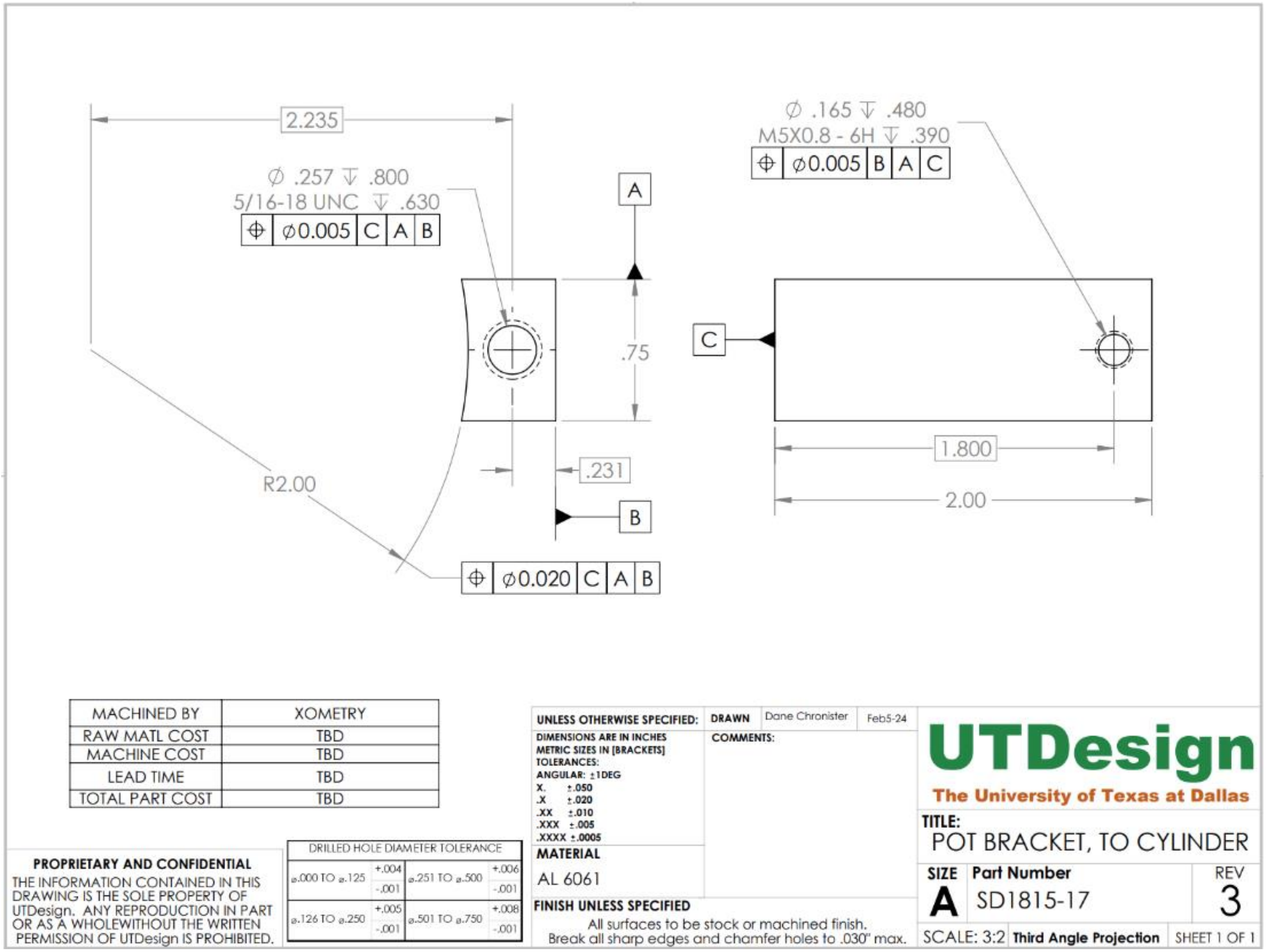


Figure 64: POT Bracket, to Cylinder drawing

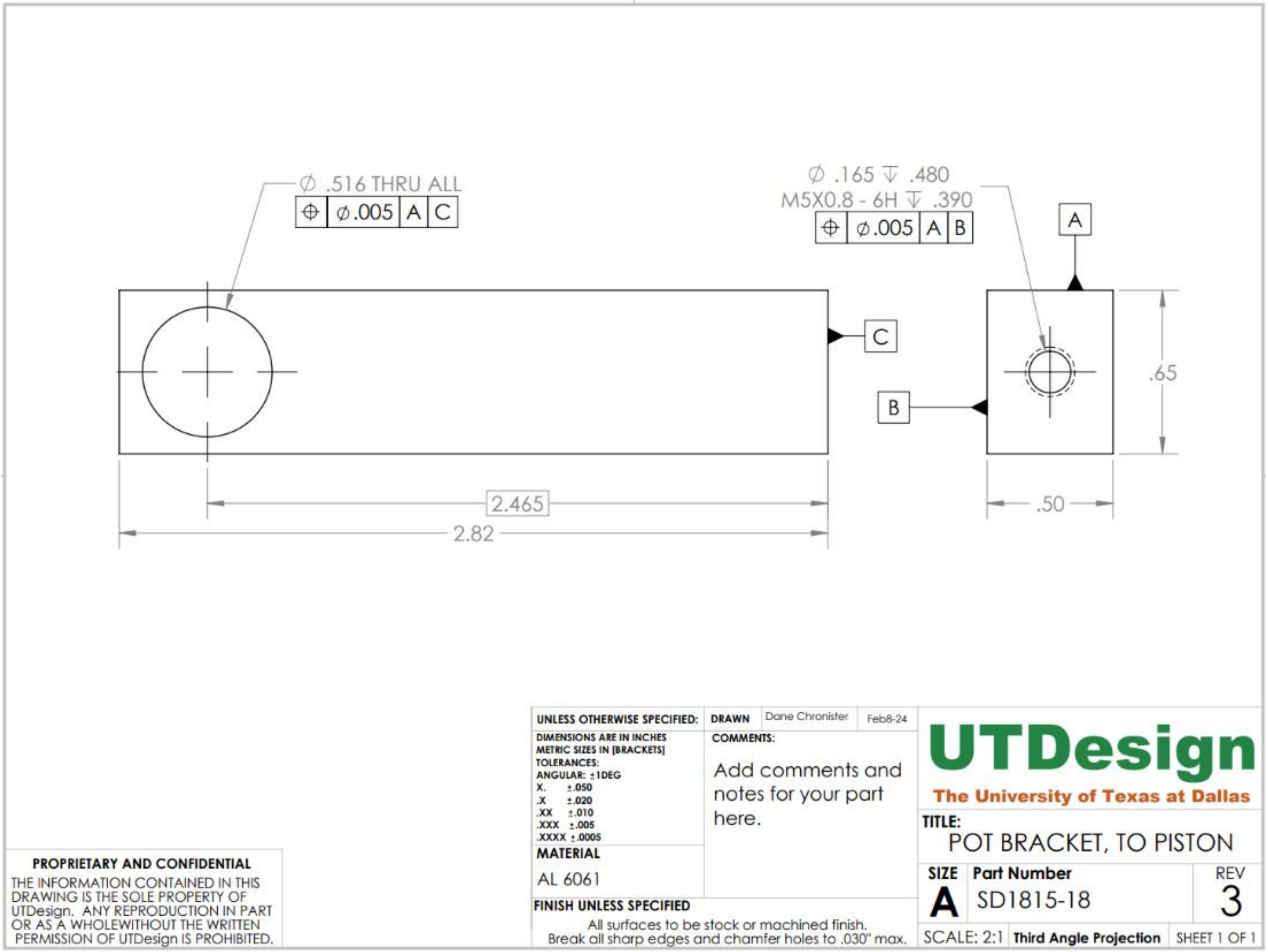


Figure 65: POT Bracket, to Piston drawing

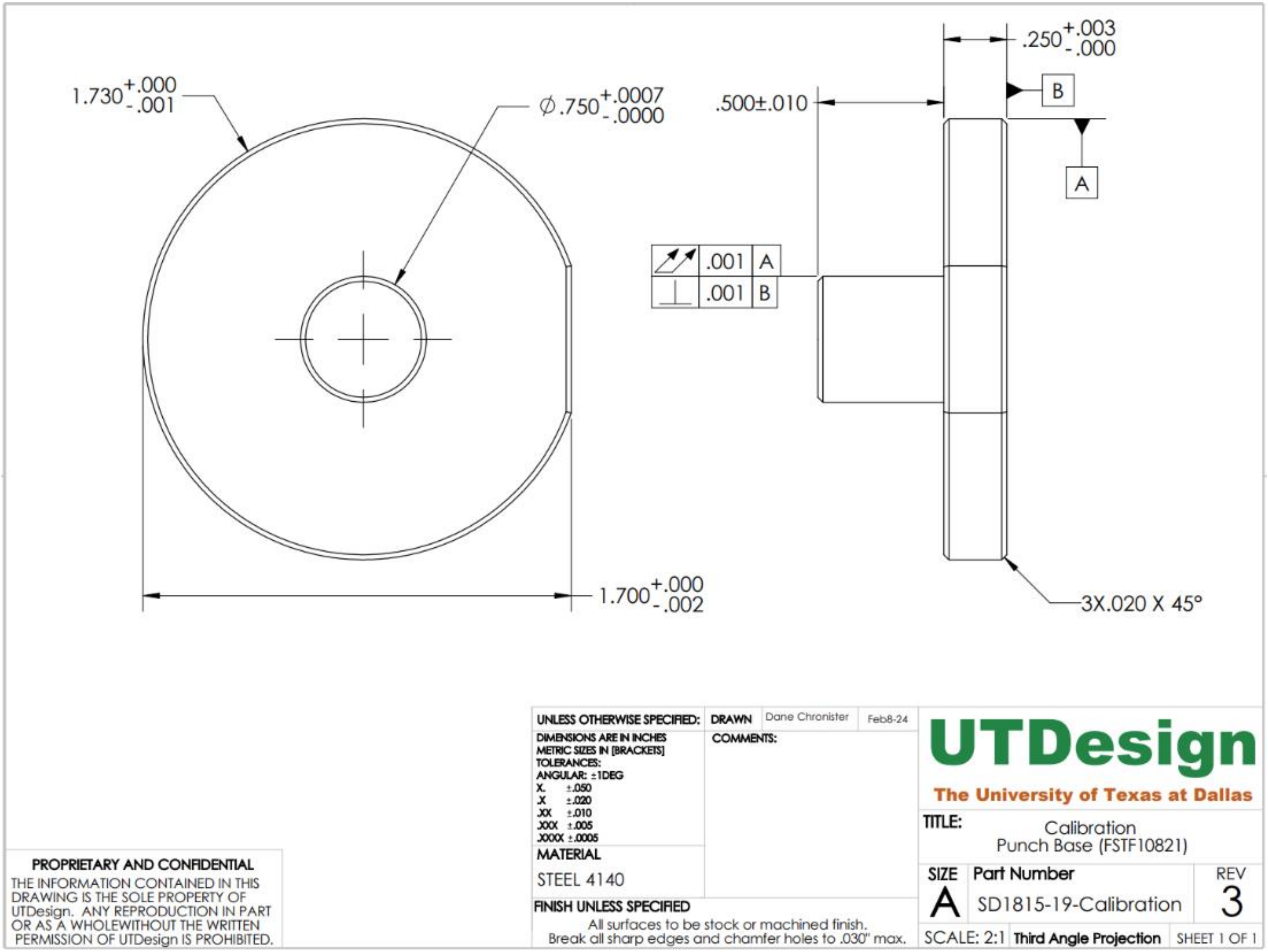


Figure 67: Load Cell Calibration Punch Base drawing

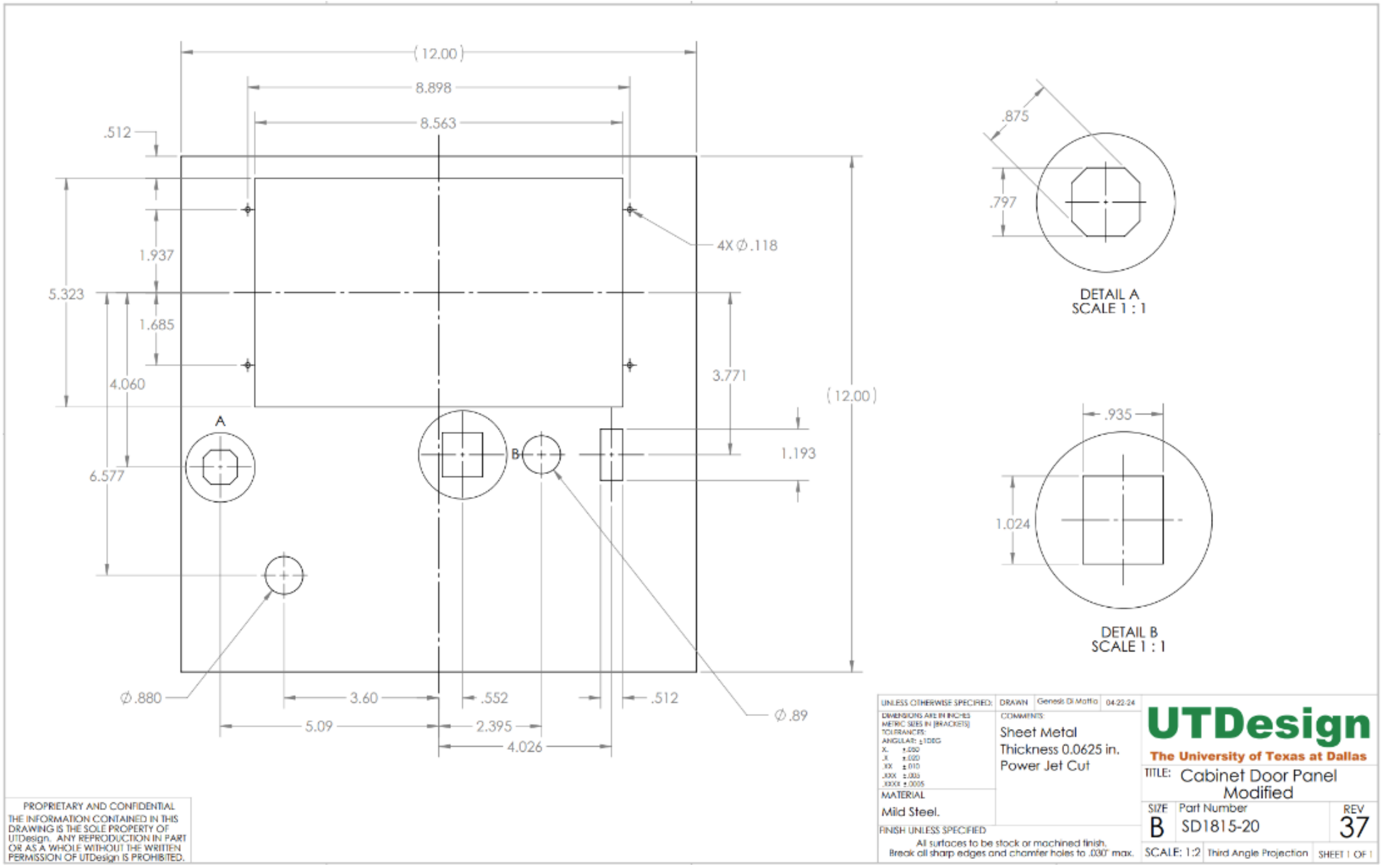


Figure 68: Cabinet Door Panel drawing

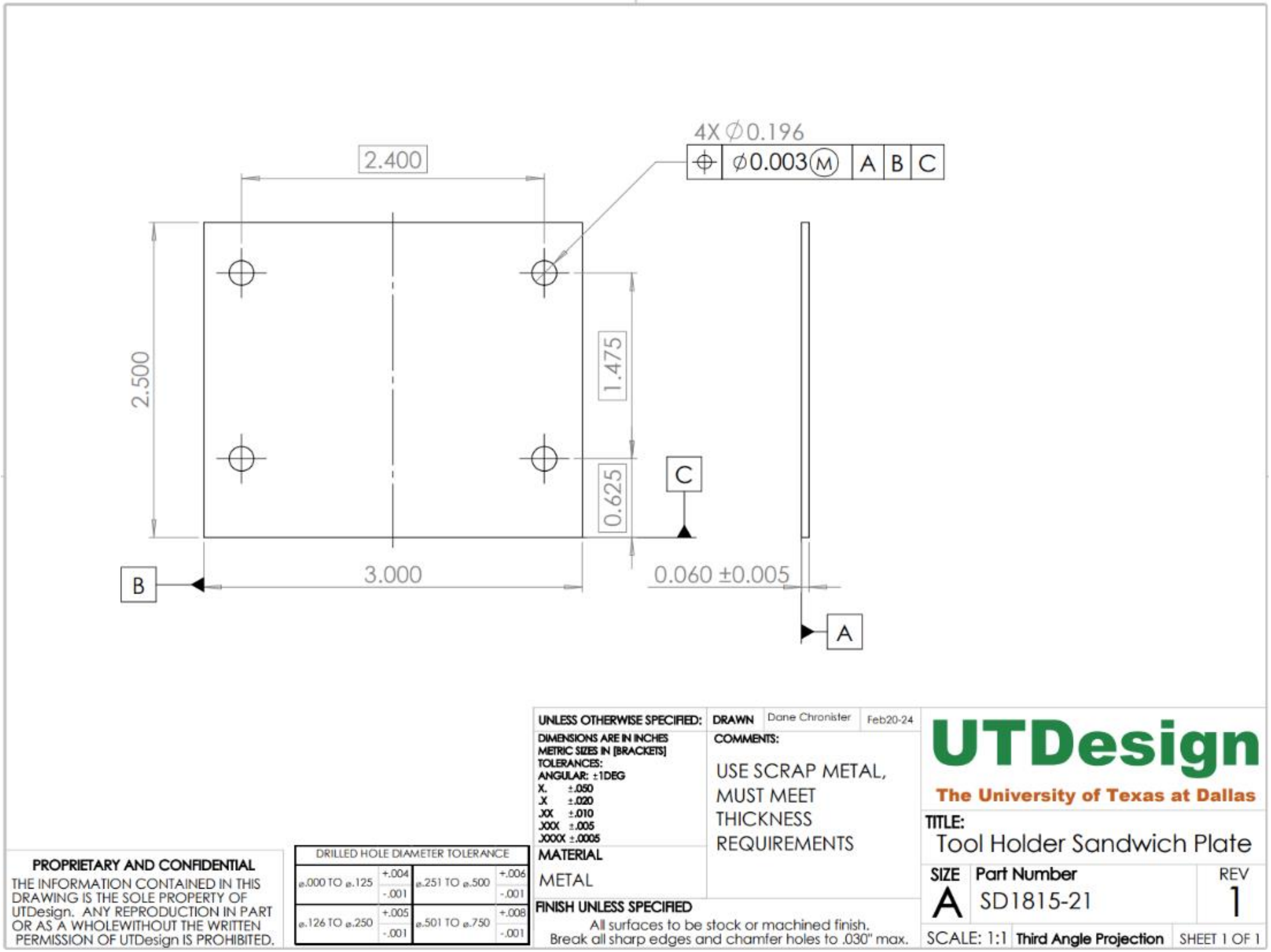


Figure 69: Tool Holder Sandwich Plate drawing

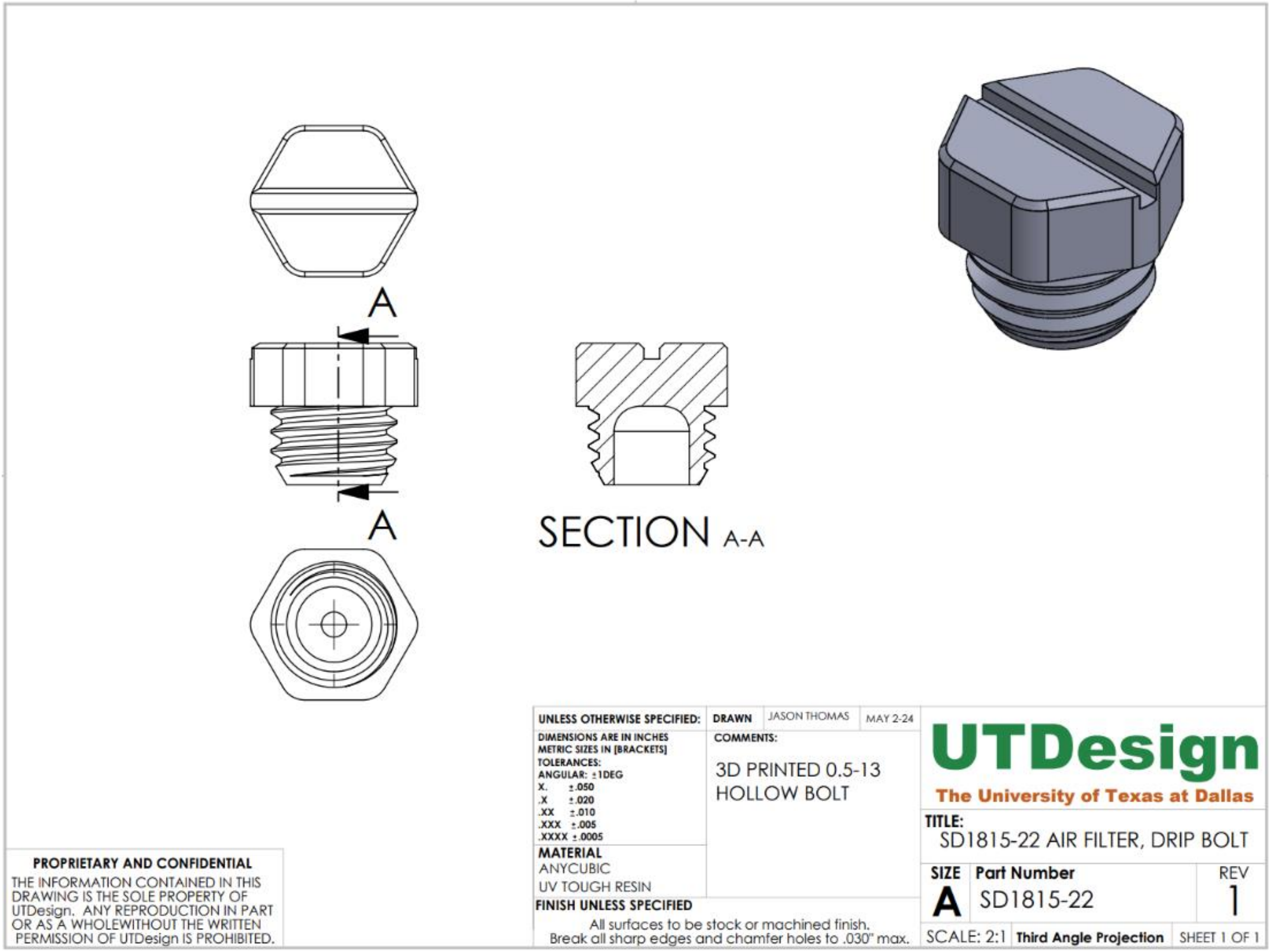


Figure 70: Air Filter, Drip Bolt drawing

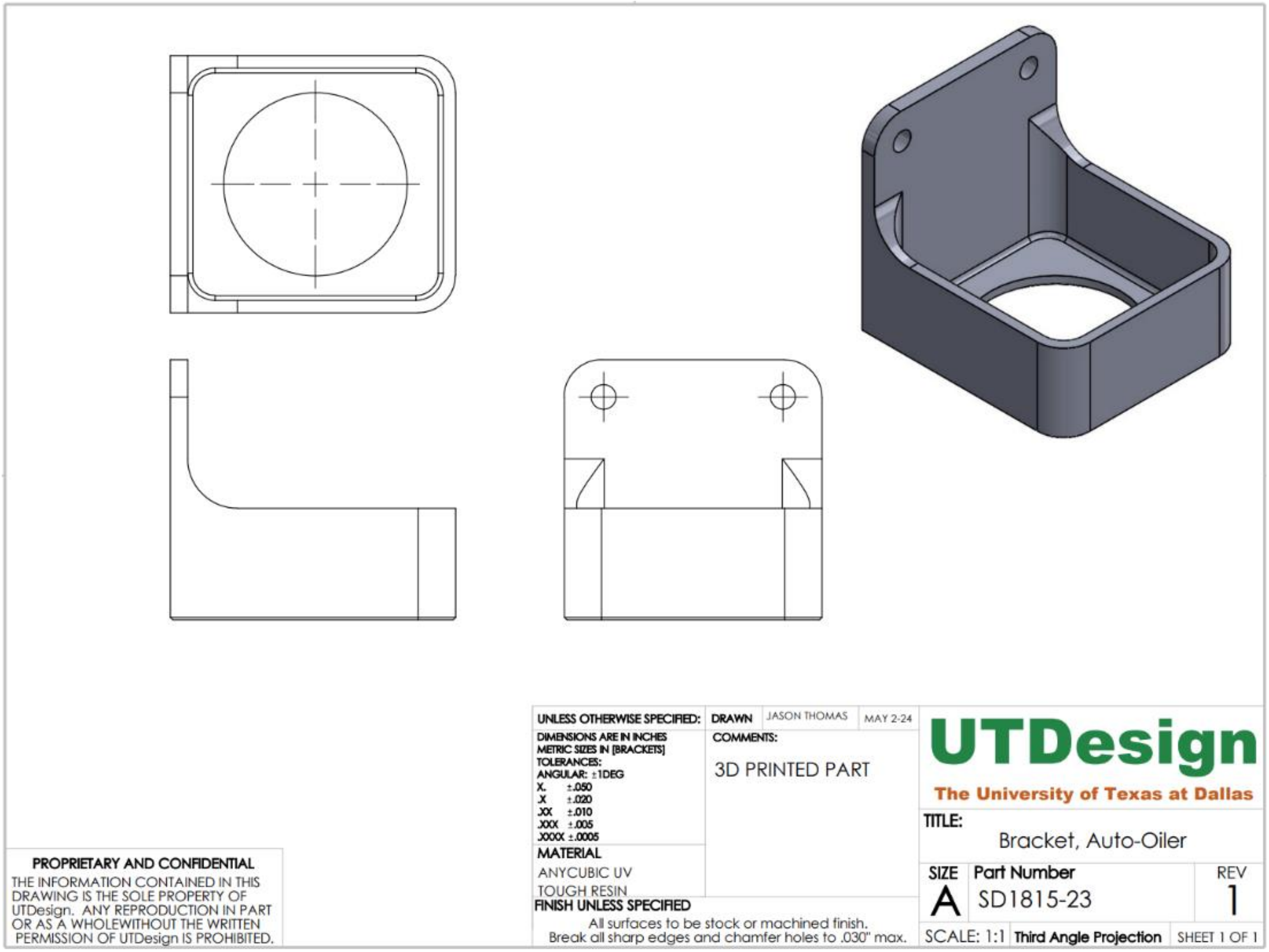


Figure 71: Bracket, Auto-Oiler drawing

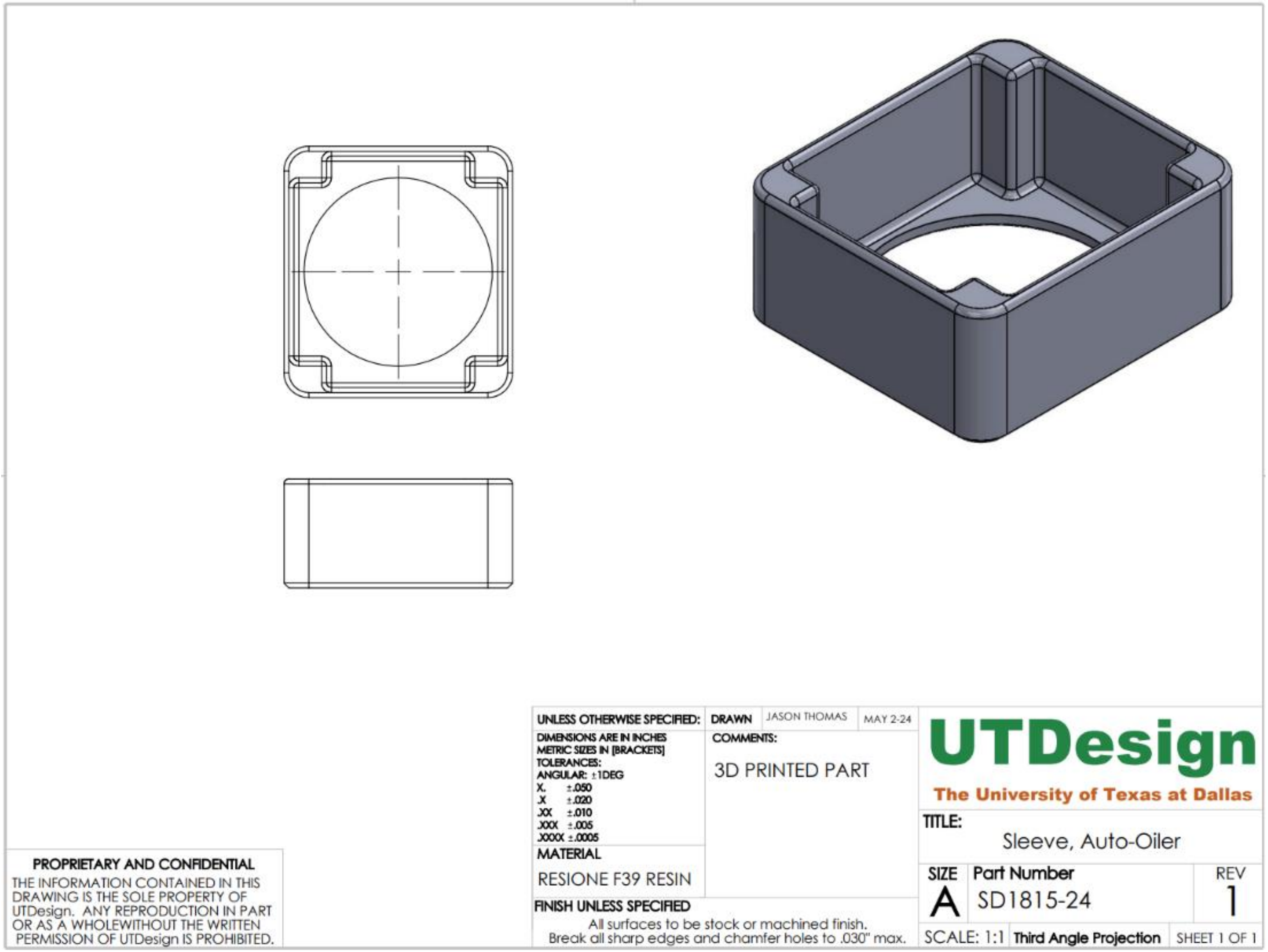


Figure 72: Sleeve, Auto-Oiler

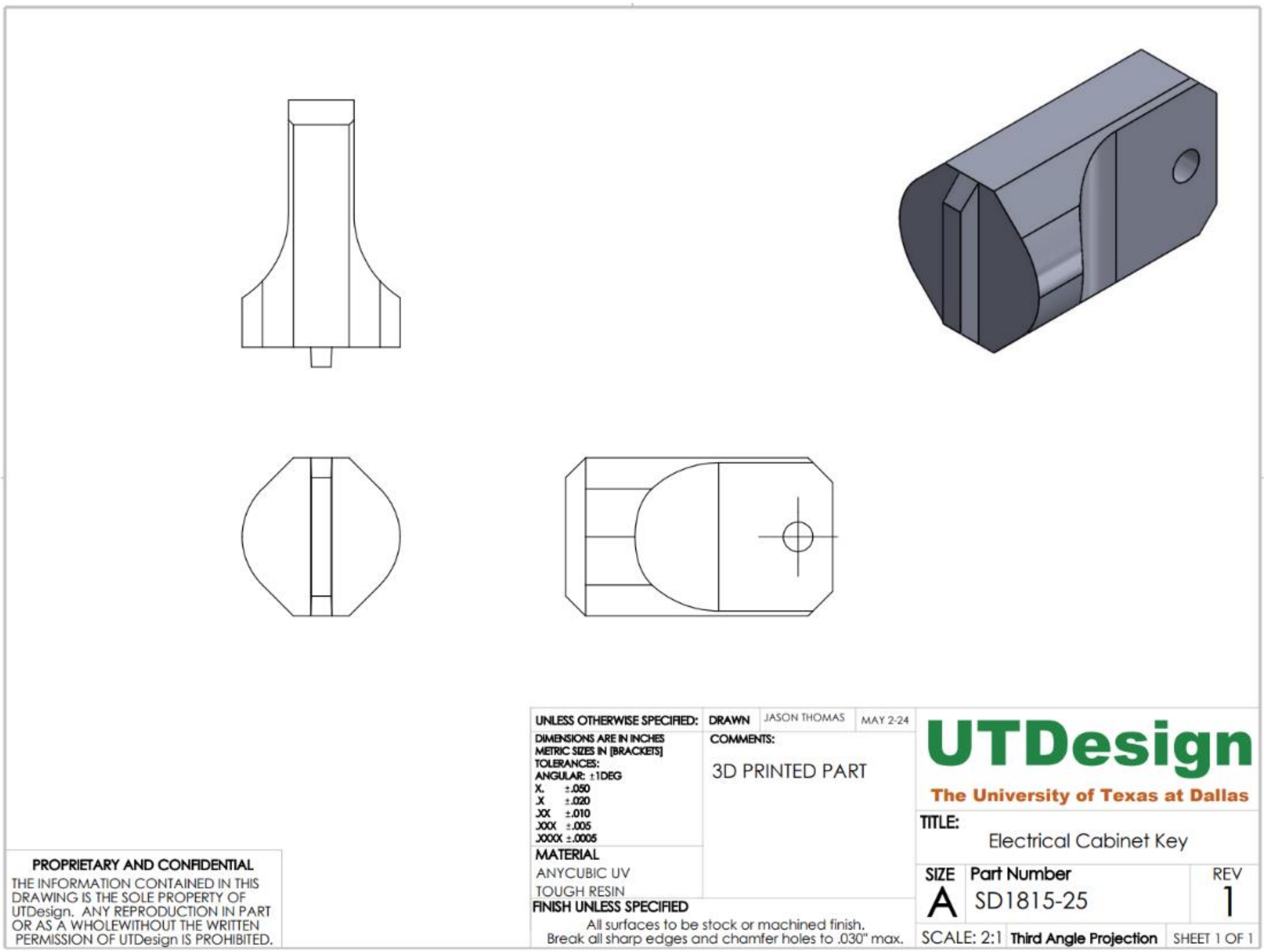


Figure 73: Electrical Cabinet Key drawing

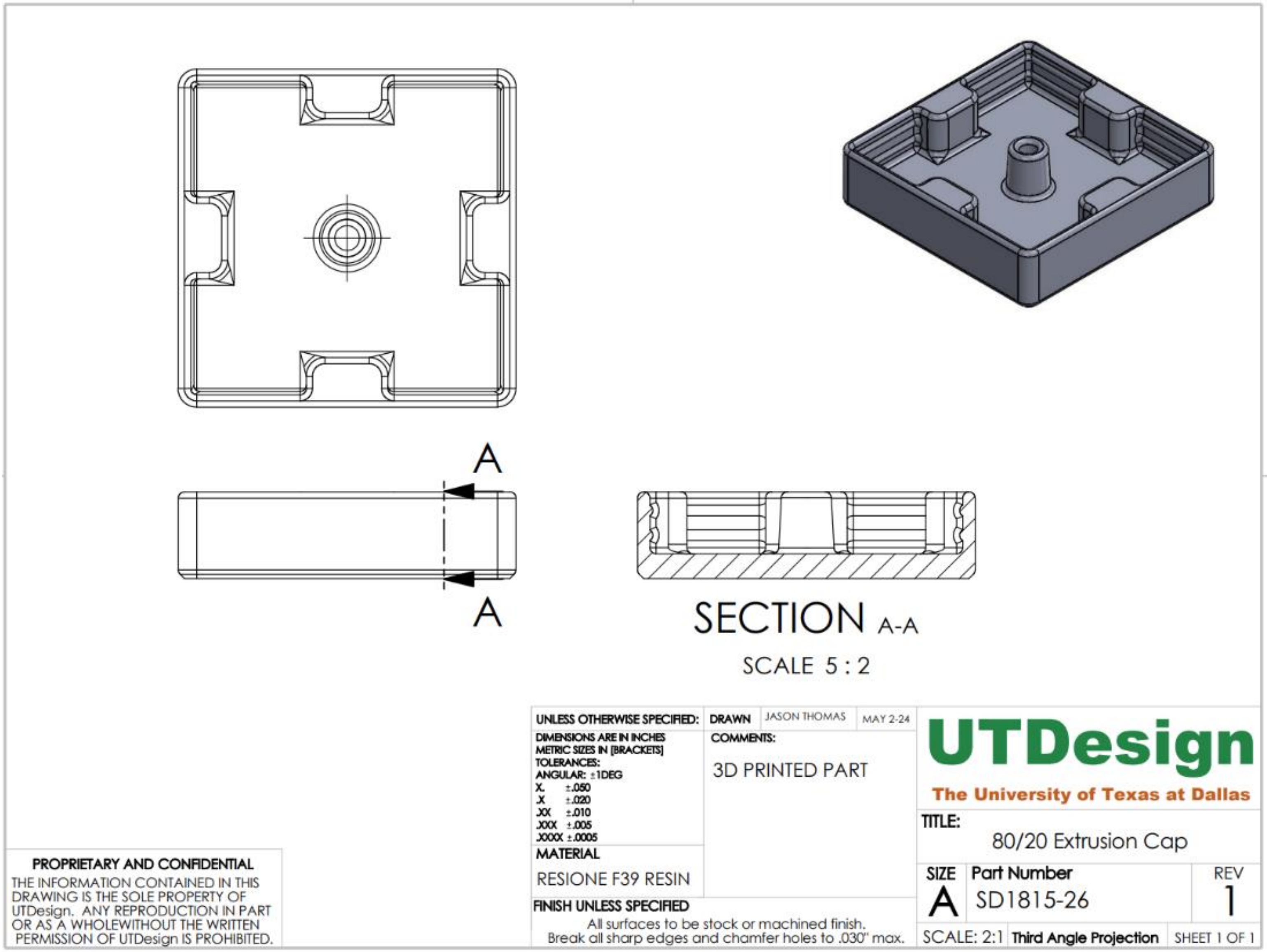


Figure 74: 80/20 Extrusion Cap drawing

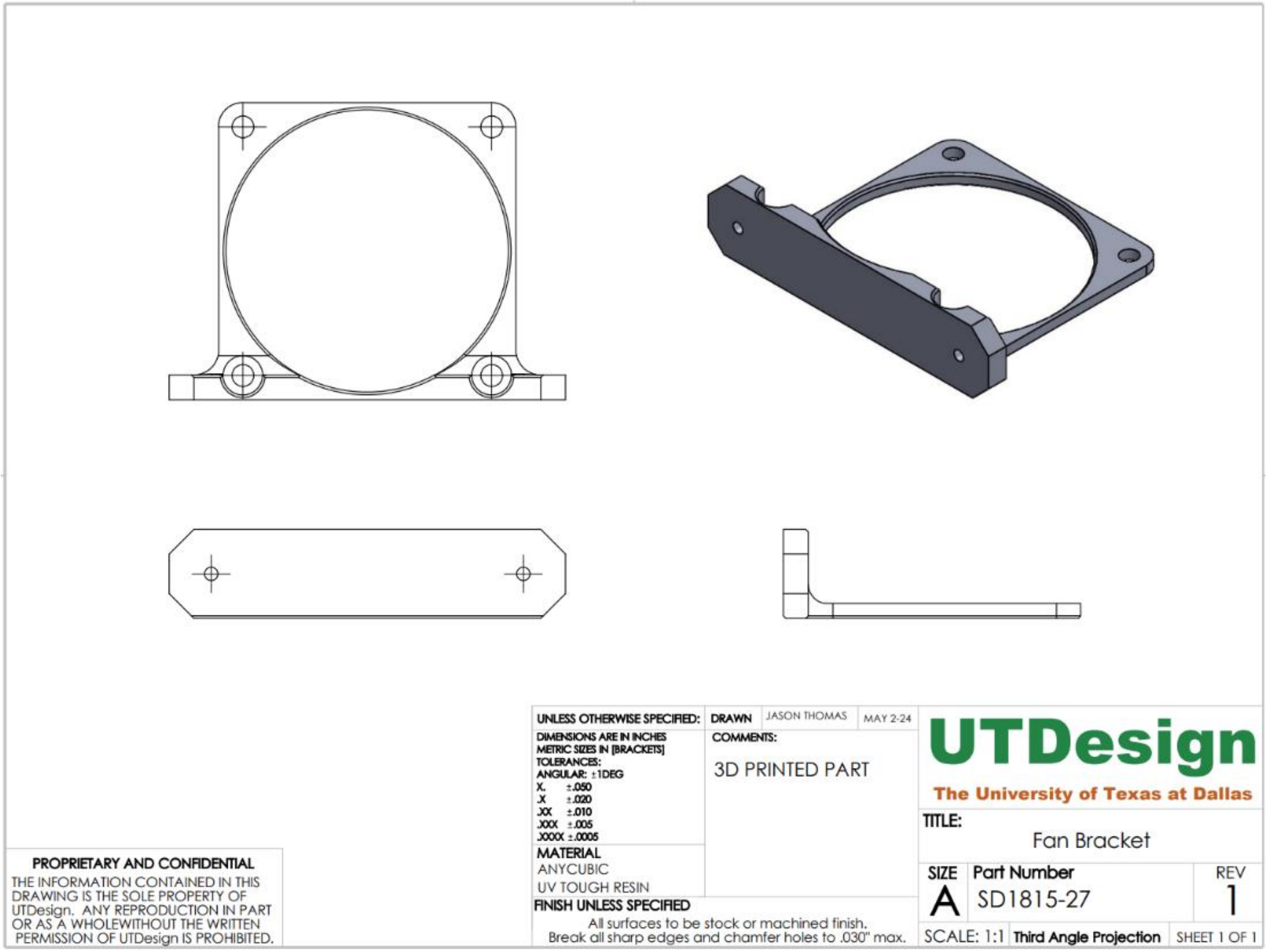


Figure 75: Fan Bracket Drawing

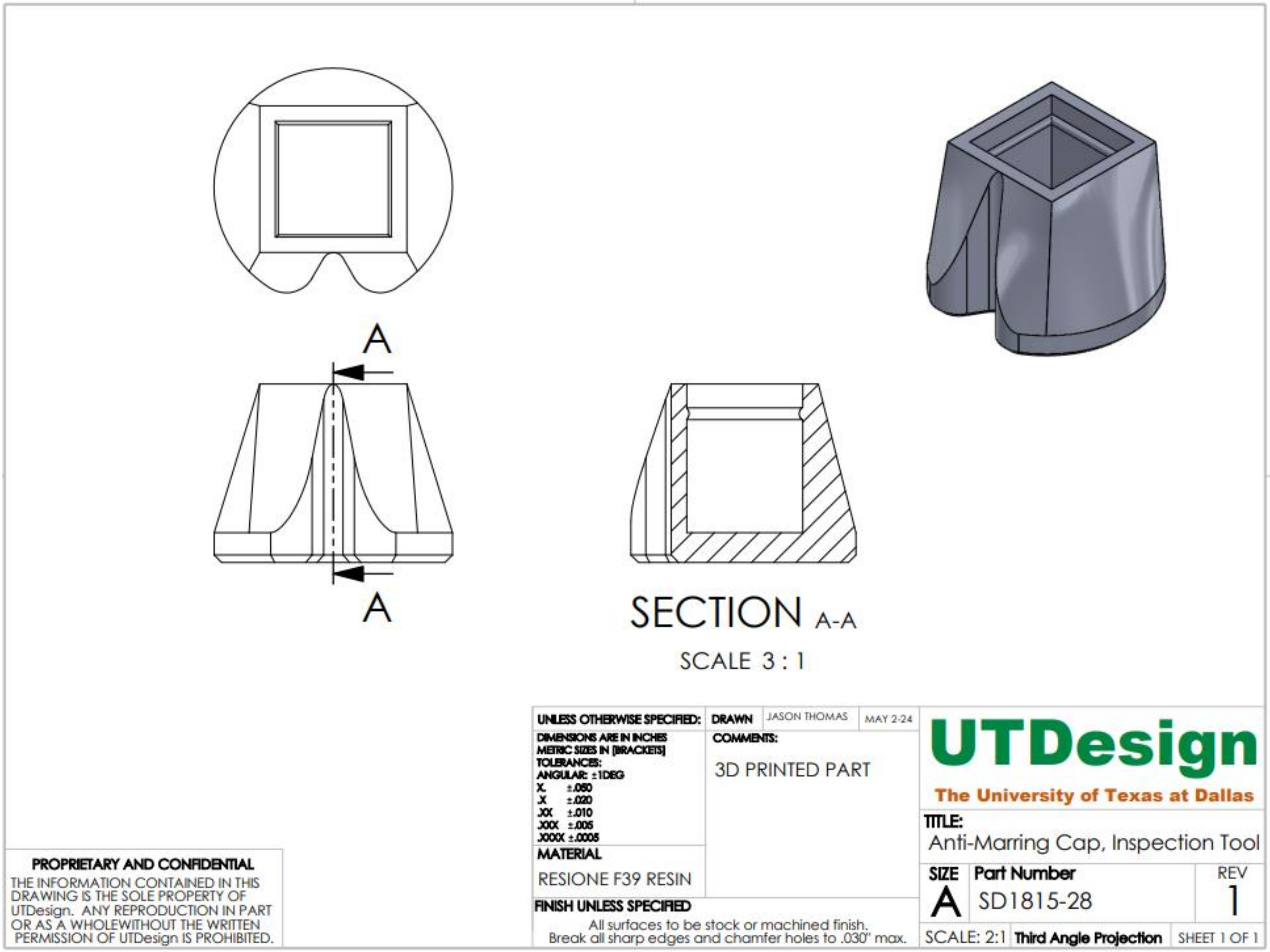


Figure 76: Anti-Marring Cap, Inspection Tool Drawing

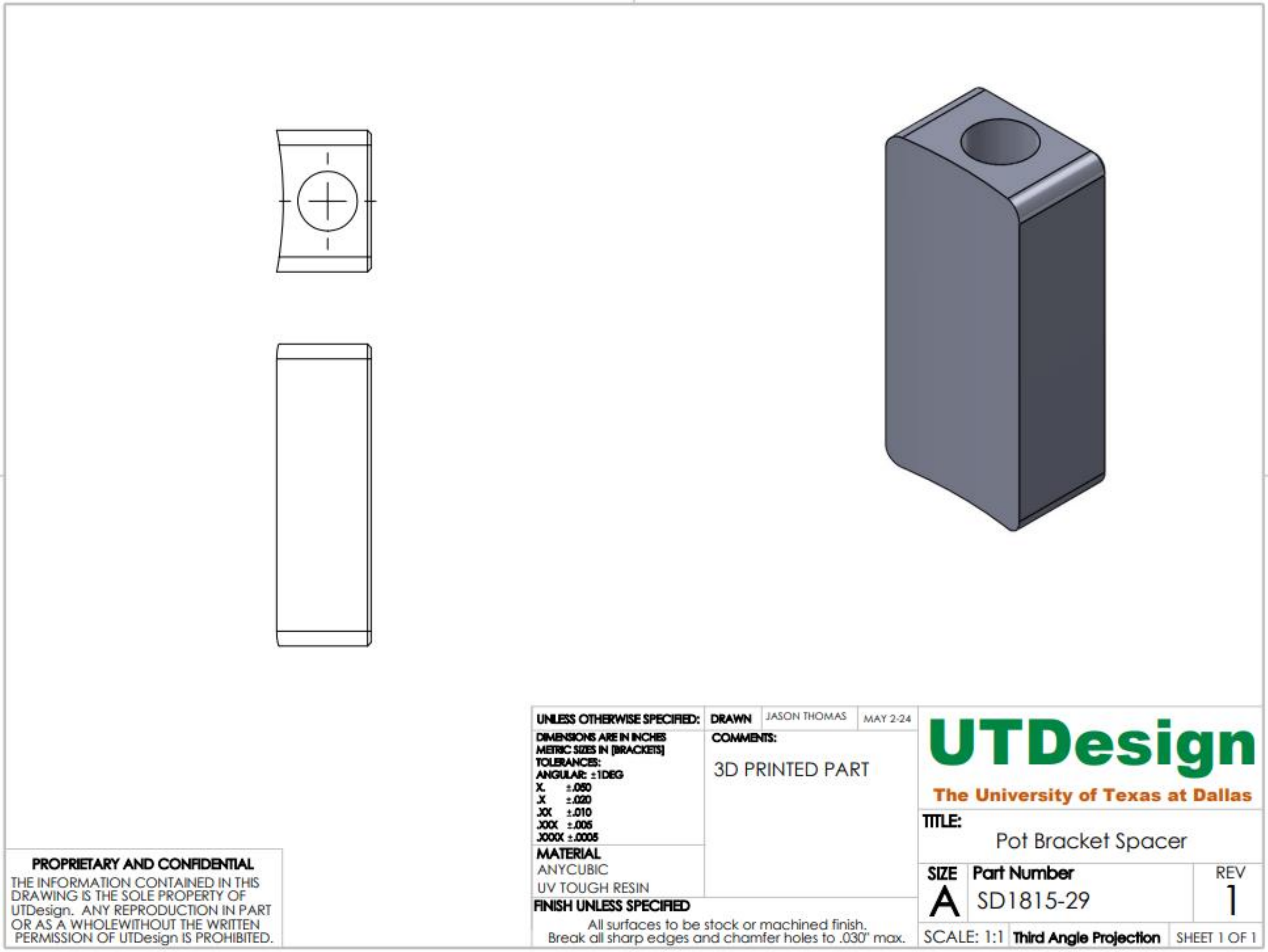


Figure 77: POT Bracket Spacer Drawing

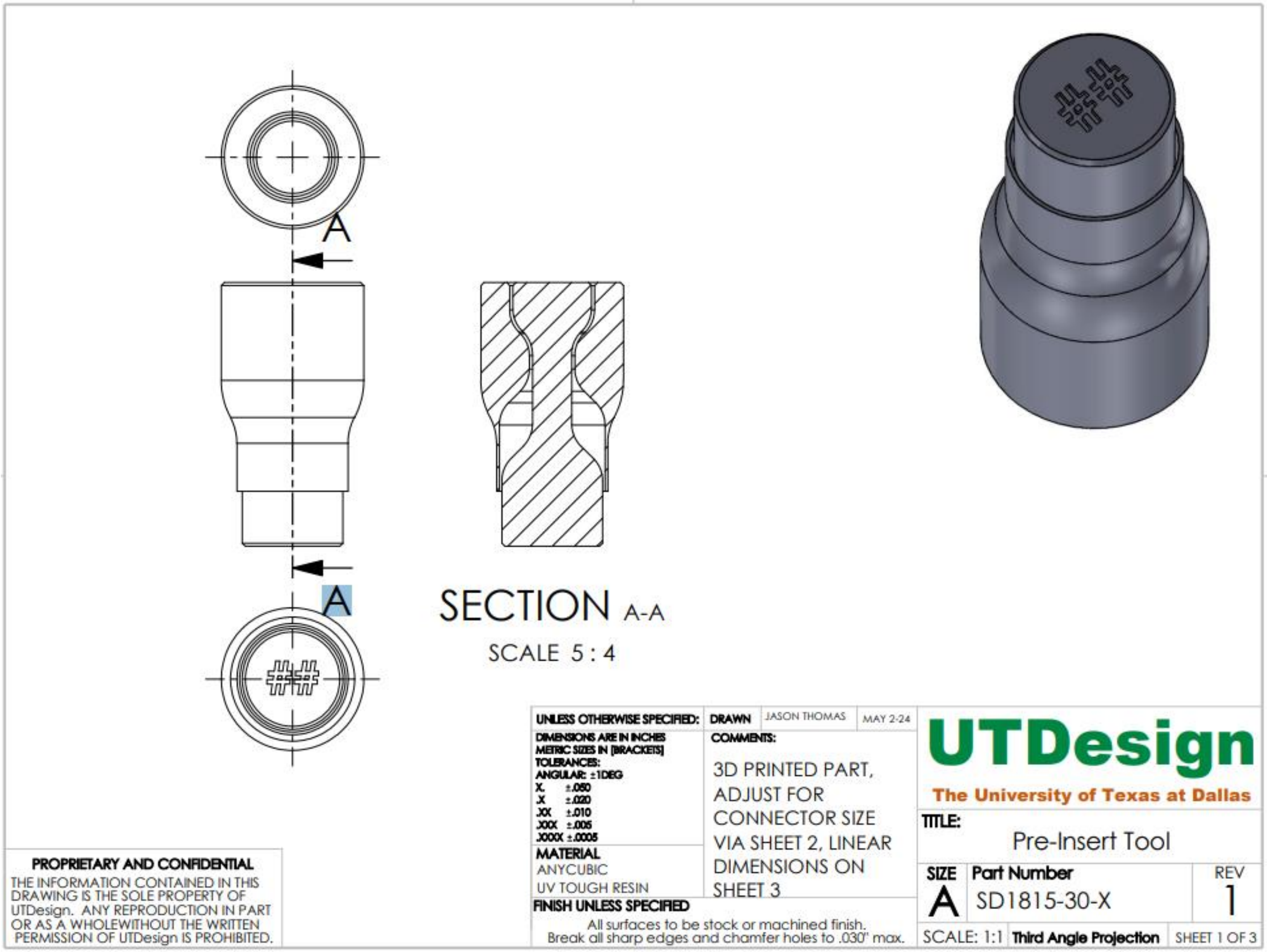


Figure 78a: Pre-Insert Tool drawing (1/3)

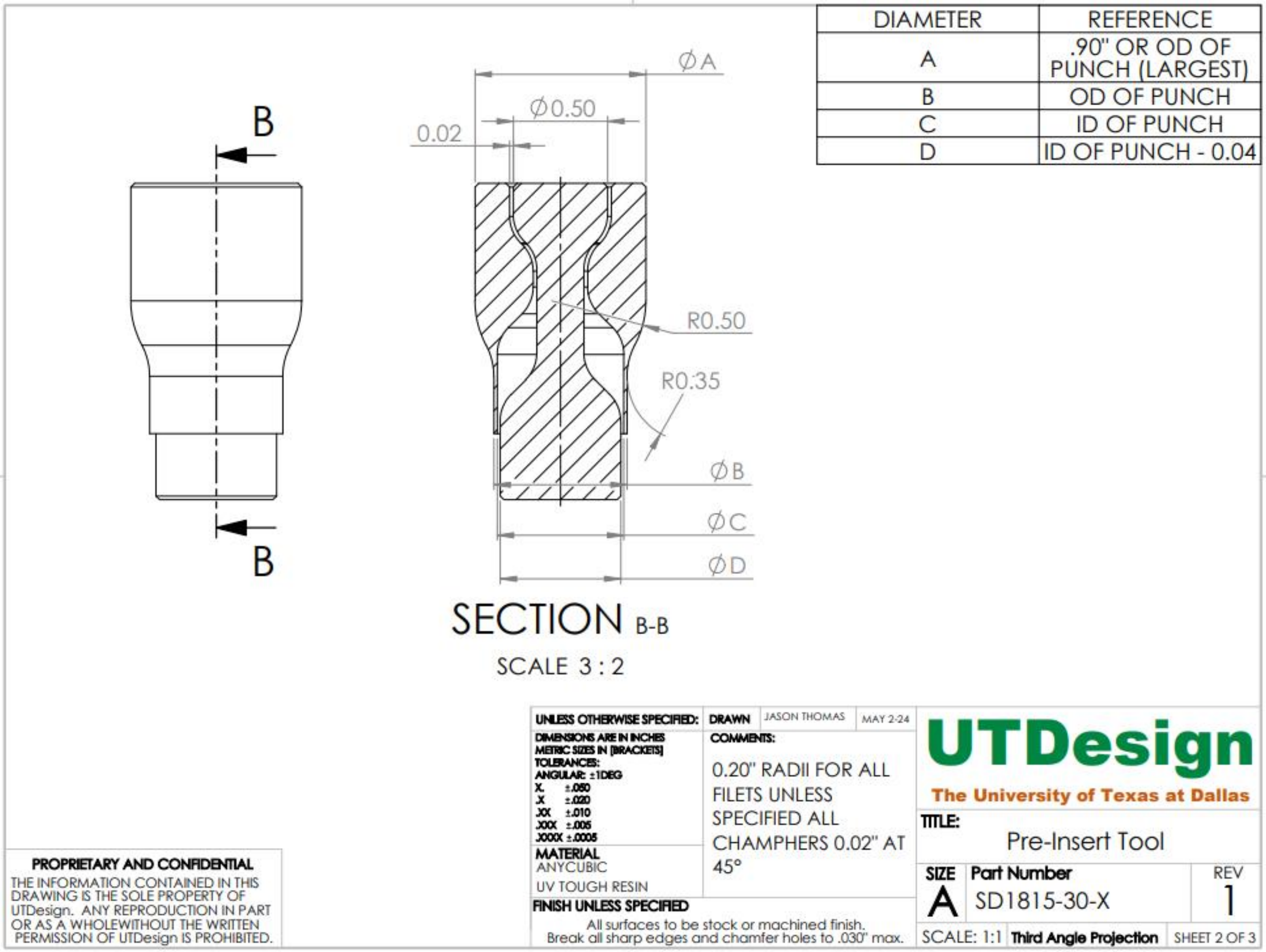


Figure 78b: Pre-Insert Tool drawing (2/3)

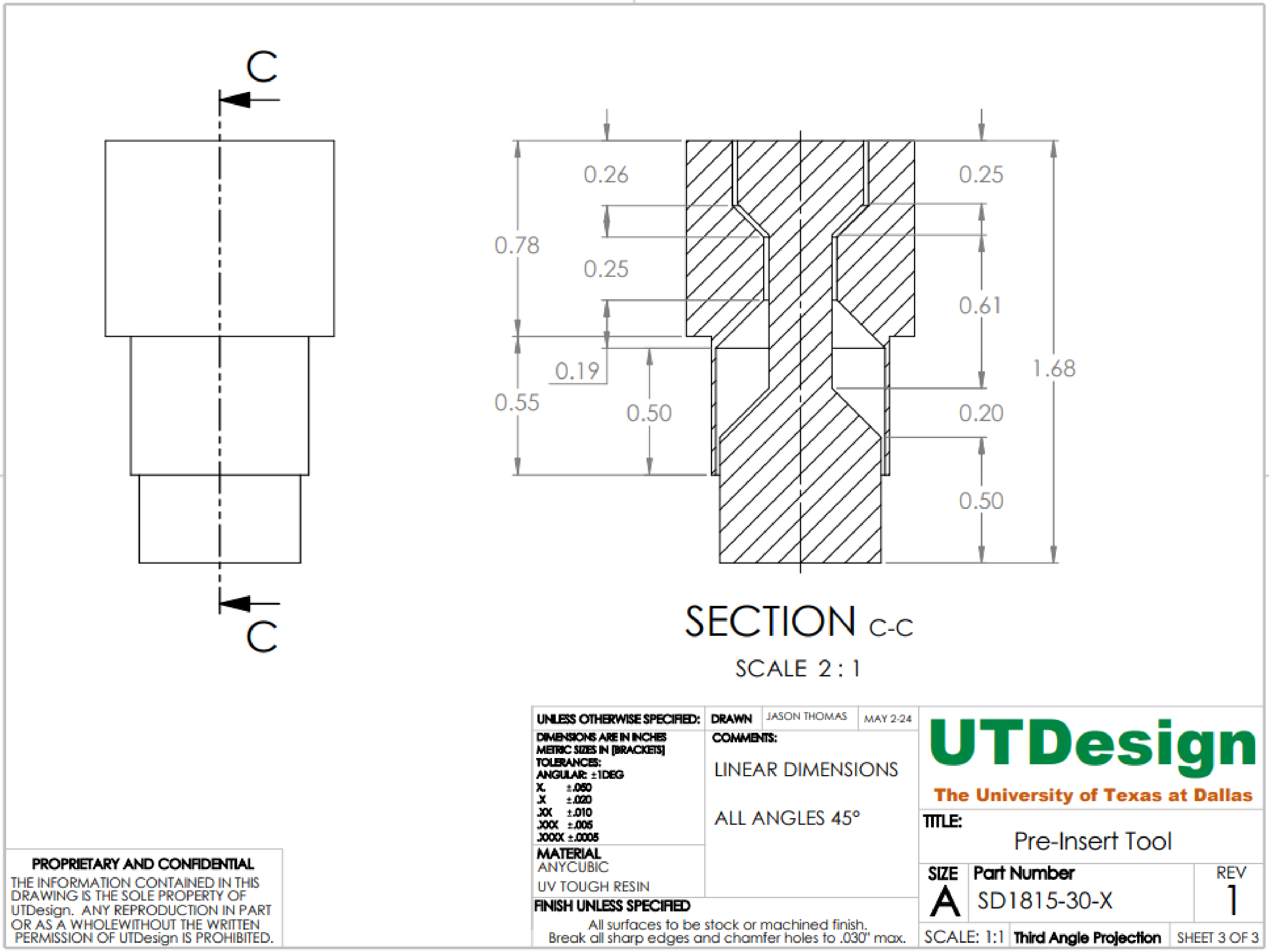


Figure 78c: Pre-Insert Tool drawing (3/3)

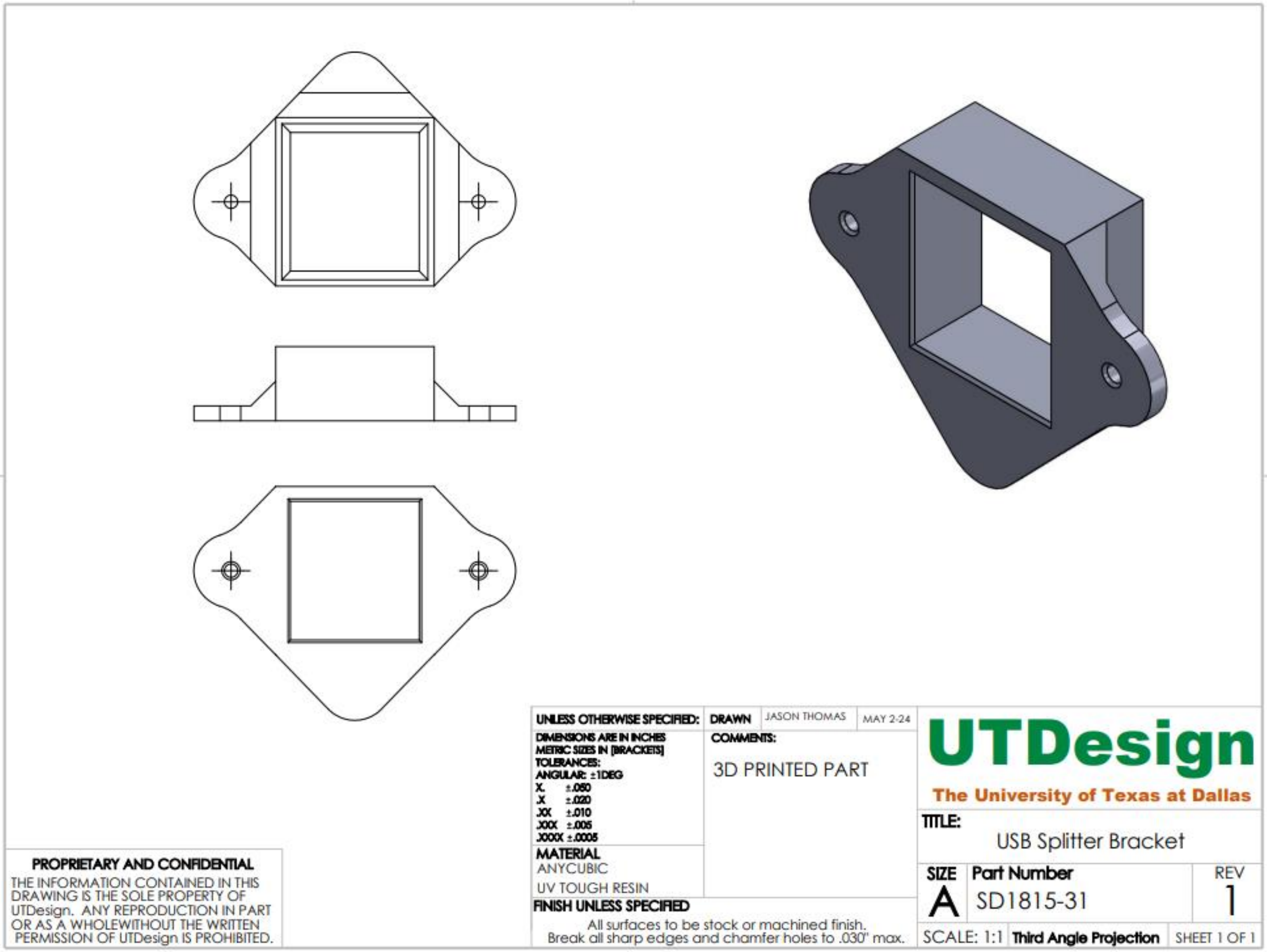


Figure 79: USB Splitter Bracket Drawing

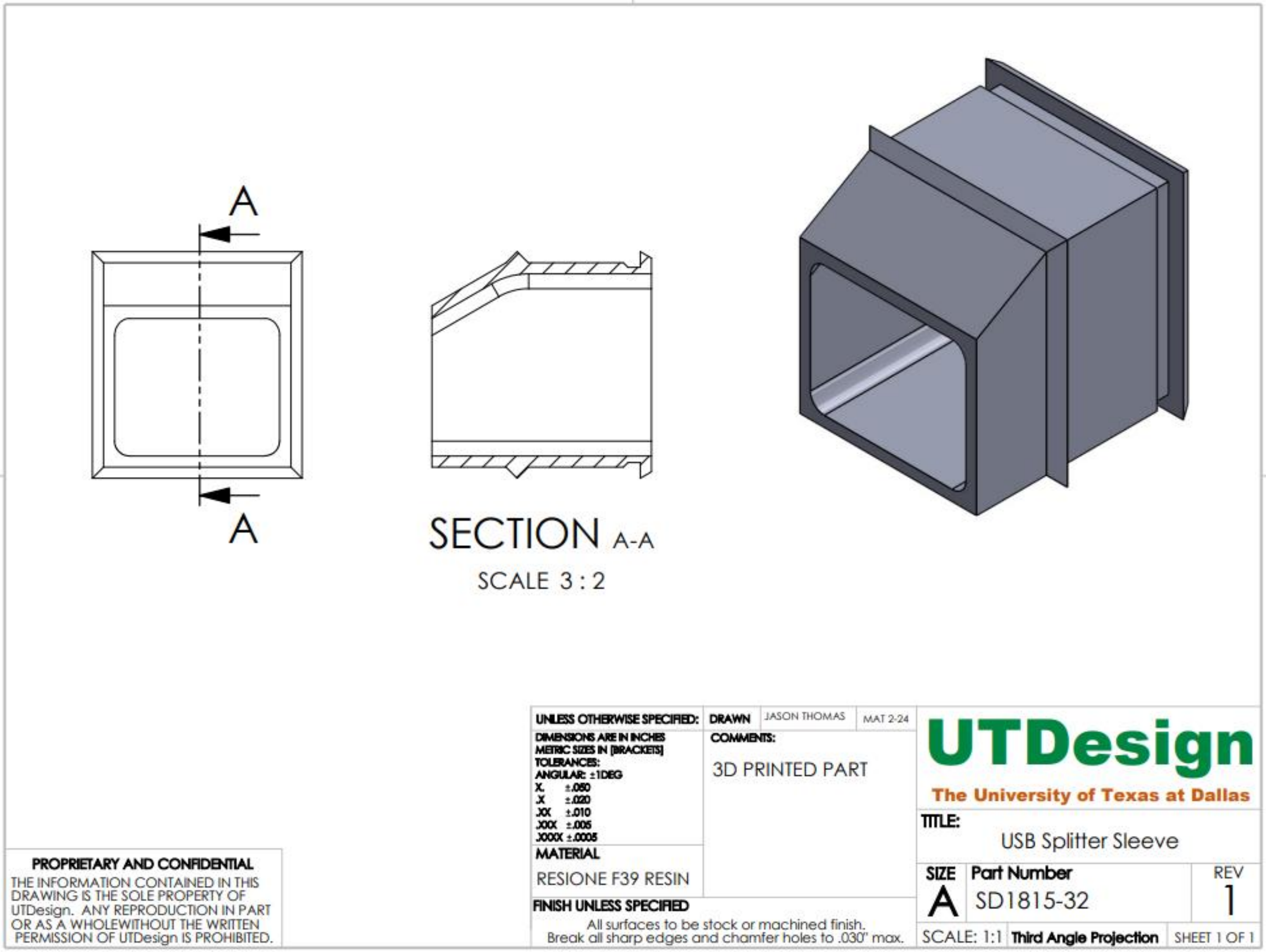


Figure 80: USB Splitter Sleeve Drawing

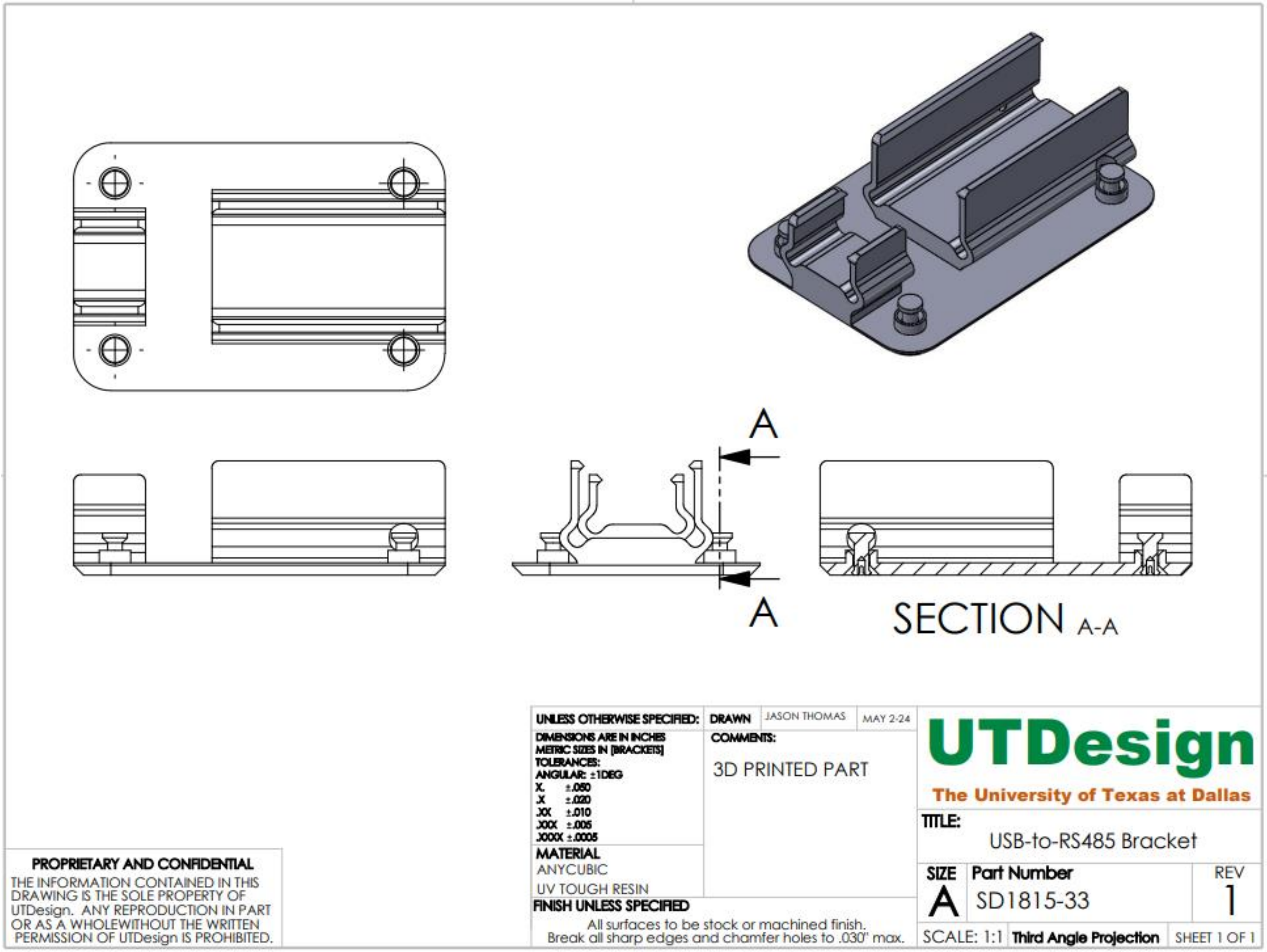


Figure 81: USB-to-RSV Bracket Drawing

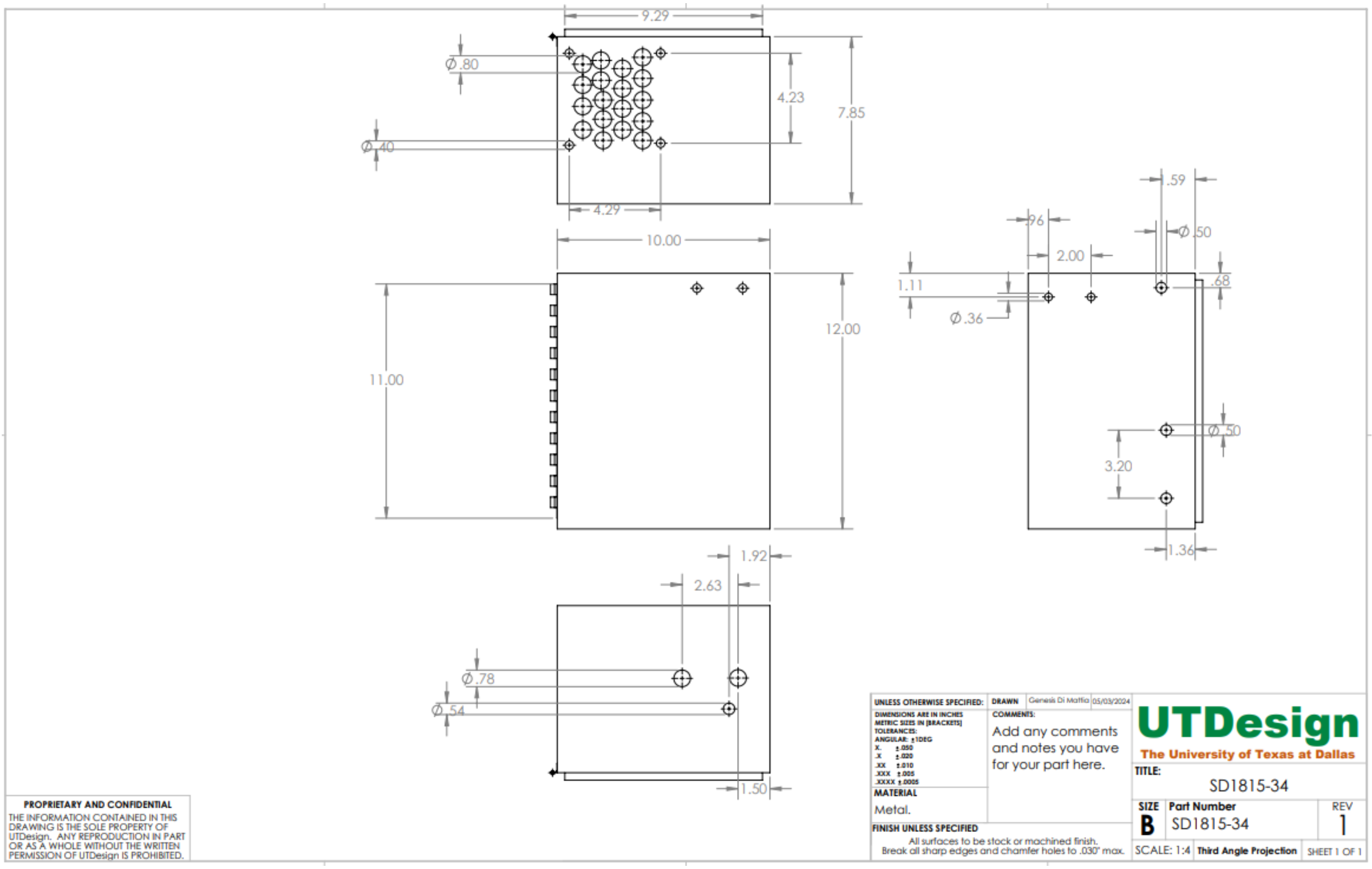


Figure 82: SD1815-34, Electrical Cabinet Drill Hole Drawing