PROJECT TEAM - 23017

Automated Universal Part Singulator

Final Report

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0.0 Nomenclature

AUPS	Automated Universal Part Singulator
CA	Cartesian Actuator
UA	Unified Architecture
TCP	Transmission Control Protocol
ATP	Acceptance Test Procedure
SME	Subject Matter Expert
TDP	Technical Data Package
FOV	Field of View
FEA	Finite Element Analysis
IO	Input/Output
AME	Aerospace and Mechanical Engineering

1.0 Introduction/Project Description

1.1 Background

A common feeding technology used in automated assembly lines in vibratory bowl feeding. This involves vibrating a spiral conveyor full of parts and passing them through an outlet which will reject parts that have defects in their physical dimensions. These feeding systems have very good throughput, but are not reconfigurable. They are designed with micrometer precision to a part's physical dimensions and therefore can only be used for one specific part. They also have other drawbacks such as part jamming and are incompatible with parts greater than 50 cubic centimeters.

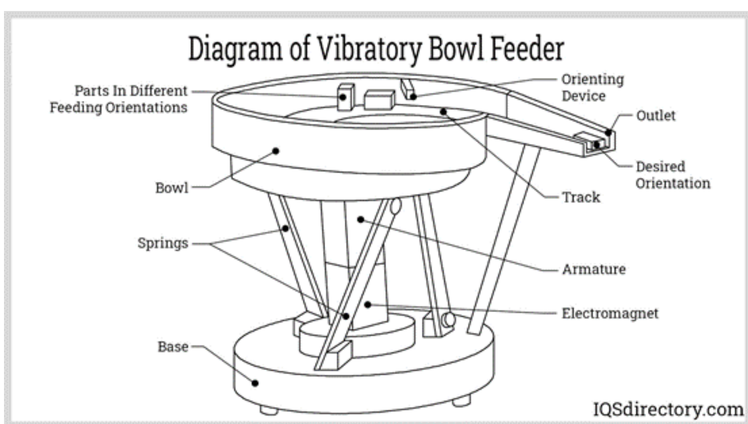

Figure: Vibratory Bowl Feeder

The Automated Universal part Singulator, eliminates those drawbacks. Although the potential initial cost of our system may be higher, since it is reconfigurable, it allows companies to save hundreds of thousands of dollars in long term cost with the same reliability and efficiency as a vibratory bowl feeder.

1.2 Scope

With millions of dollars being spent on tooling for automated assembly lines, companies are relying more on reconfigurable part feeding and sorting mechanisms to save costs in the long run. This project provides a solution by being easily adaptable to any assembly process without compromising effectiveness or reliability.

The Automated Universal Part Singulator (AUPS) consists of a cartesian robot, a high resolution camera, a gripping mechanism and a vibrating table. The robot is controlled using the CtrlX Machine Controller developed by Rexroth and an Arduino is used for controlling the sensors and gripper. Parts are fed onto the vibrating table manually and the camera identifies and locates the parts allowing the robot to travel, pick up and sort them correctly. If no parts are detected, the system uses the vibratory table to rearrange/disperse parts until the camera can locate one. The gripping mechanism is attached to the end of the Z-axis of the robot and is capable of handling parts between 2-10 cm3 with a weight limit of 0.5kg or approximately 1lb.

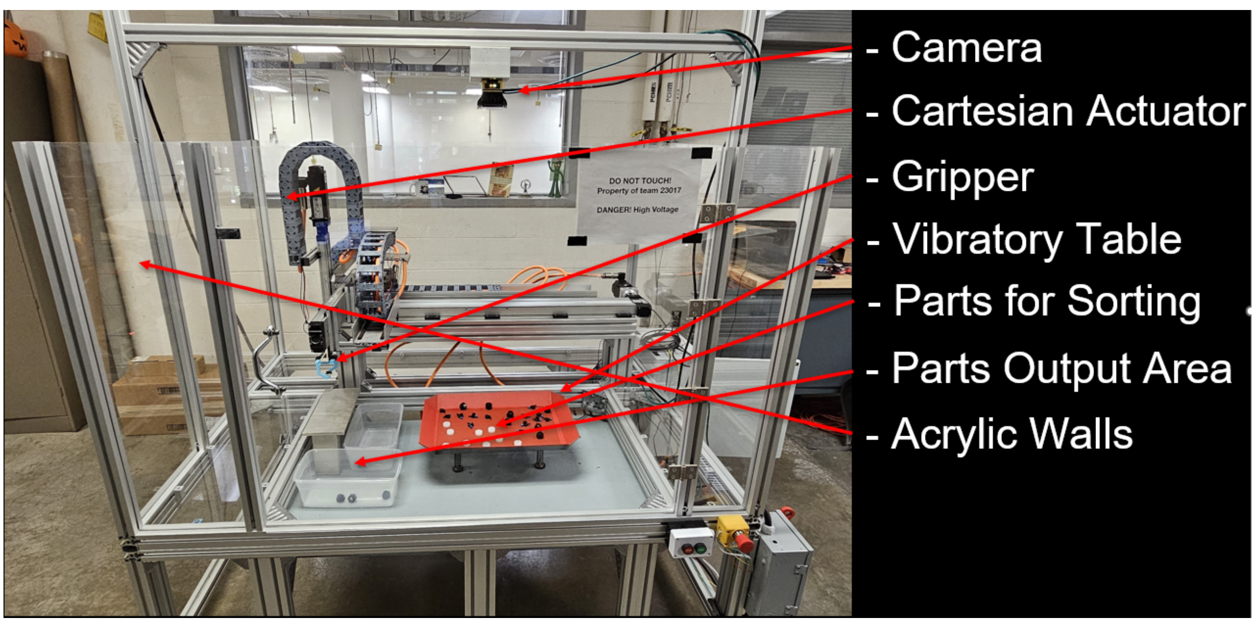

Figure: Image of Full System

This system can automatically sort parts based on their shape and size. It is designed to operate in an enclosed, factory floor environment and is therefore shielded from external interference with a metal frame and acrylic walls.

The AUPS is automated as it utilizes advanced software and a sequence of communication between the machine controller and the smart camera to operate without the need for manual intervention. The system provides a flexible part sorting solution that supports a wide range of parts of different shapes and sizes. New parts can be quickly introduced to the assembly sorting process through image profiling on the camera software. The AUPS is reliable with object recognition capabilities that go as far as to allow for sorting out parts with visual defects. The system is highly versatile and can be used in industries including manufacturing, automotive, pharmaceutical, food processing, etc.

2.0 System Description

2.1 System Architecture

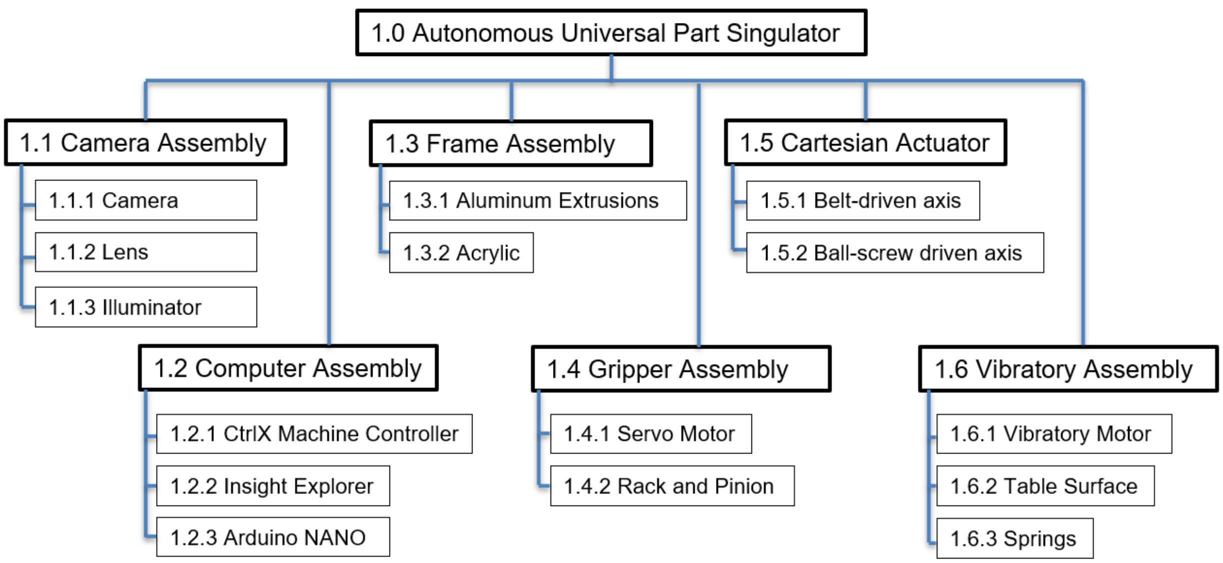

Figure: System Architecture

The system architecture shows all the main assemblies of the system and their subcomponents. Further description and breakdown of each subcomponent can be found in section 1 of the TDP.

2.2 System Block Diagram

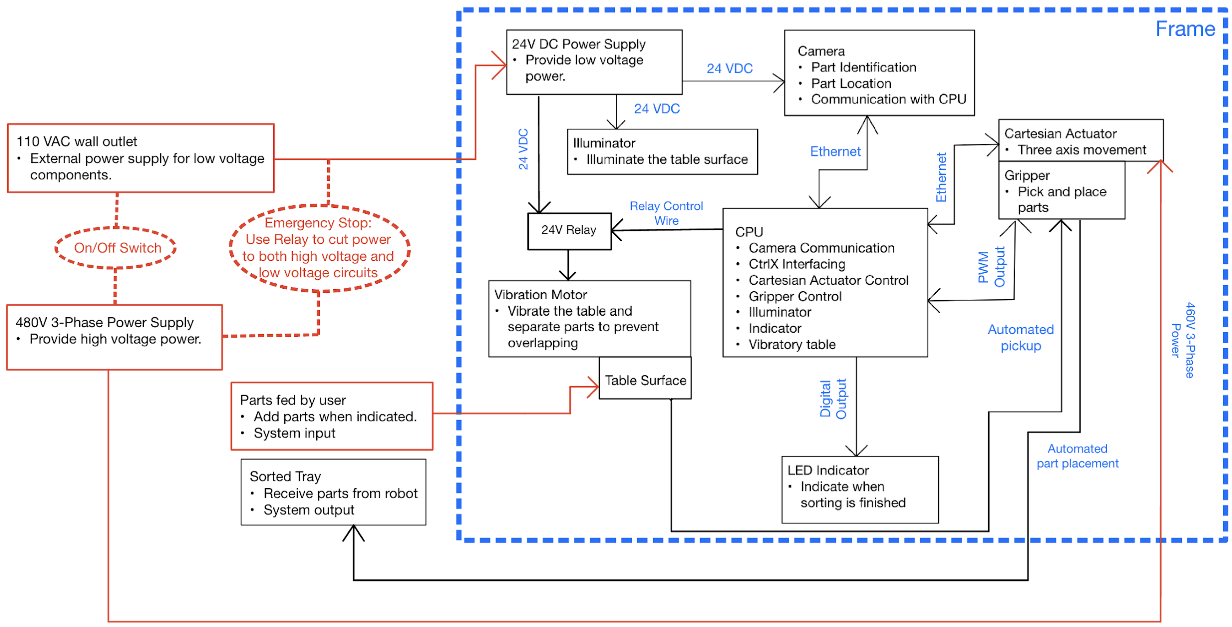

Figure: System Block Diagram

The system block diagram highlights how the core components of the system communicate with each other. The system has two power sources, one for low voltage (24 VDC) and one for high voltage (480V 3-phase). Both of these power sources are connected to an emergency stop button that can cut all power to the system when necessary.

Low voltage components:

- Vibratory table
- Camera
- Gripper assembly
- Controller

High voltage components:

- Cartesian actuator: X, Y and Z axis motors

The main input to the system is the user placing parts on the vibratory table. The output from the system is the parts placed in the sorting location. The two compute units are the camera and the CtrlX Machine controller. The camera and the controller are connected via an ethernet cable and communicate with OPC UA protocol. The controller is also connected to the following components:

- Cartesian actuator: Connected via 3-phase power cables and motor encoder cable to move the robot
- Vibratory table: Connected via a relay and controlled with digital output
- LED indicator: Controlled with digital output
- Gripper microcontroller: This is an Arduino NANO which receives a digital input from the controller to open/close servo.

The camera contains a proprietary LED illuminator mounted around the lens to illuminate the parts on the vibratory table based on lighting conditions.

2.3 System Operation:

2.3a Power

- Plug 3-phase power cord into 480V 30A 3-phase outlet.
- Plug 24VDC power supply cable into regular 110VAC outlet.
- Turn on low voltage power by flipping the switch on the power strip located in the NEMA Enclosure.
- Turn on high voltage power by flipping the lever on the disconnect switch to the 'ON' position.
- Wait for lights on the CtrlX Motor Drives to turn green (at this point the servo motors on the CA should produce a high pitched noise).
- Make sure the Arduino indicator is on and showing a red LED.
- At this point the system is ready for operation.

2.3b Initial Setup

- Place a desired part on the vibratory table surface. Trigger the camera manually or via the Cognex Insight Interface.
- Profile the part using the InSight Spreadsheet PatMax function (See InSight Explorer Documentation for details).
- Profile all possible orientations of the part by placing the part in different orientations and repeating the previous steps.
- Repeat the previous steps for all different parts necessary.
- Choose three different parts for sorting operation.
- Place all of the chosen parts on the vibratory table (25 unit capacity).
- Make sure sorting bins 1 and 2 are in the drop point positions for part output.
- Make sure the acrylic door is closed before starting the system.

2.3c Operation

- Press the green start button to begin part sorting.
- The robot will go to the home position and start the part sorting process.
- The robot will continue until all parts are sorted.
- When the vibratory table is empty, the table will go through 5 vibration cycles and the robot will go back to home position.
- In case of an emergency press hard on the Emergency Stop button until it locks into position (this will stop all moving components in place and end the operation).
- To reset the e-stop, turn the button counterclockwise until it pops out.
- Press the red stop button to clear the e-stop command.

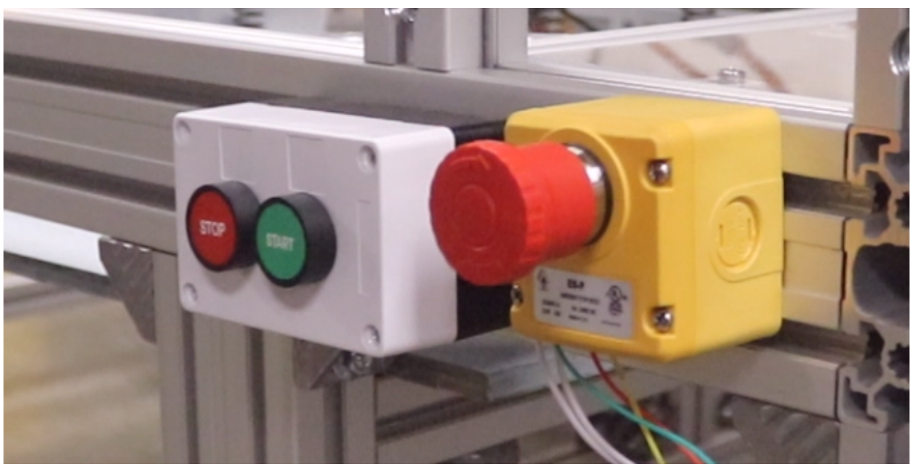

Figure: AUPS User Input Buttons

3.0 Technical Data Package

PROJECT TEAM - 23017

Technical Data Package (TDP)

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3.1 System Breakdown

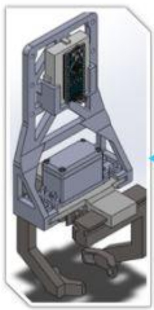


Figure: Gripper Sub-Assembly (MVP2)

Figure: Cartesian Actuator (Bosch Rexroth provided)

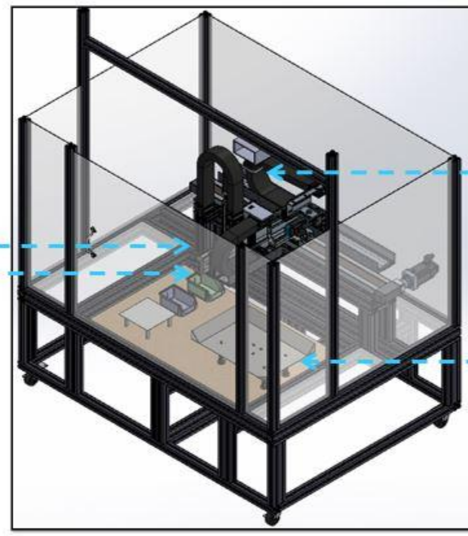


Figure: System Frame Assembly

Figure : Cognex Camera (MVP1, CAID Automation provided)

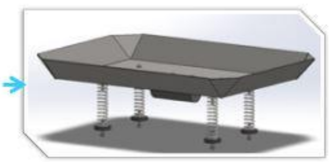


Figure: Vibratory Table Sub-Assembly

3.1a Camera

The smart camera was decided by the sponsor and includes a 1600x1200 sensor, a white LED for illumination, a power cable, an ethernet cable for communications, a c-mount lens, and machine vision software. The device is able to save information to memory storage, making it optimal for communications and part identification without the use of external storage. The smart camera also required a 24VDC power supply which was provided by CAID Automation. The power supply was also used to power other devices, such as an arduino nano, that were integrated into the system.

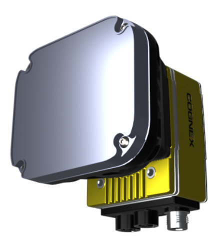


Figure: Cognex Camera Solidworks Model

The smart camera initially came with an 8 mm focal length lens which wasn't optimal for the working distance it would operate at. By considering the dimensions of the vibratory table and the desired working distance, it was calculated that a focal length of 12.6 mm was needed. The working distance was decided by determining the required clearance from the robotic arm so the actuator wouldn’t crash into the machine vision system. A c-mount 12 mm lens was acquired from Cognex and was exchanged for the 8 mm lens.

Figure: Smart Camera and Camera mount

A mount was acquired for fabrication and interfacing with the frame. Materials and fabrication were provided by the College of Optical Science and Engineering and the College of Aerospace and Mechanical Engineering. There are multiple m6 through holes in the camera mount and this is due to testing for optimal positioning and field of view. The positioning, in tandem with the 12mm lens, allowed for sufficient performance for identification of parts and a complete field of view of the vibratory table. It was later decided that the white LED created noise in part identification and therefore was disabled. The In-Sight Explorer software operates in spreadsheet format which allows for coordinate communication to be sent to the robotic arm; other values and parameters from the spreadsheet were important to consider such as annulus and contrast. An annulus function was included so that the gripper would have the appropriate clearance to pick up an individual part without interference from surrounding parts. Clearance was determined by considering the difference in contrast from the table surface relative to any interfering part within the annulus. A red background was used for testing and in the final product, this is because red made it easier to find the difference in contrast for the annulus. Since the camera operates in monochrome, it can be deduced that a longer wavelength would allow for greater contrast resolution, hence the red background further improved the smart camera's ability to identify parts and overall system performance.

3.1b Gripper

The gripper is the part of the system that interacts with the parts being sorted. In order for the system to be as universal as possible the gripper needs to be extremely versatile in its design and functionality. The gripper is fully 3D printed to give the team full control over all aspects of it. A rack and pinion mechanism was chosen due to its wide range of motion and compact design. The rack gears slide along 3D printed linear slides and a servo mounted between the rack gears provides sufficient torque to securely grab all the sorting parts. Custom grip fingers at the end of the rack gears were specially designed to accommodate the widest variety of parts possible. High friction material was attached to the end of the grip fingers to improve their performance. The gripper is controlled by a microcontroller secured in an integrated housing slot built into the gripper design. The gripper was designed with a custom mounting bracket, adapted to connect securely to the end of the Cartesian Actuator.

Various prototypes (some of which are pictured below) were created to test and refine the different components of the gripper. The first prototype proved not only the viability, but the effectiveness of the 3D printed linear slides. The second prototype added mounting hardware to securely hold all of the internal components together. The third prototype included a mounting bracket, a holder for the microcontroller, and a sensor mount. The fourth and final prototype simplified and optimized the mounting bracket and the microcontroller holder. The sensor mount was removed as it was deemed unnecessary through testing.

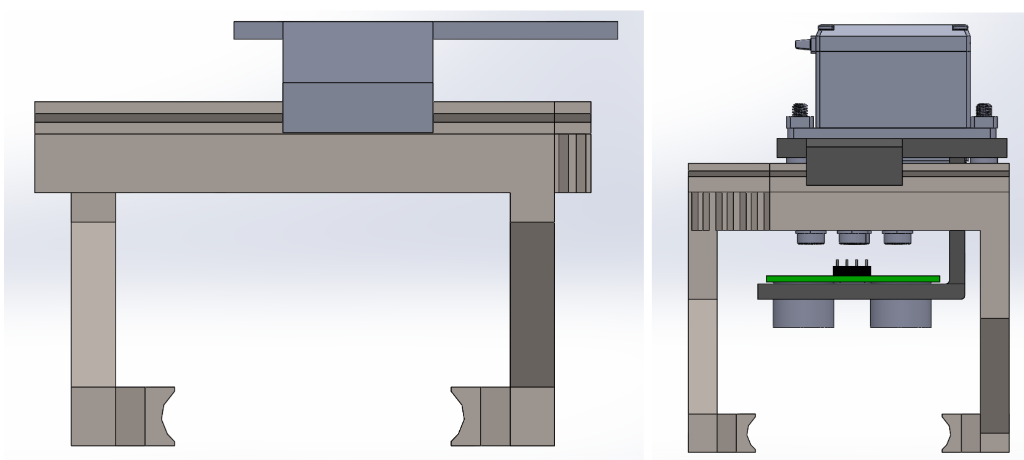


Figure: 1st and 2nd gripper prototypes from left to right

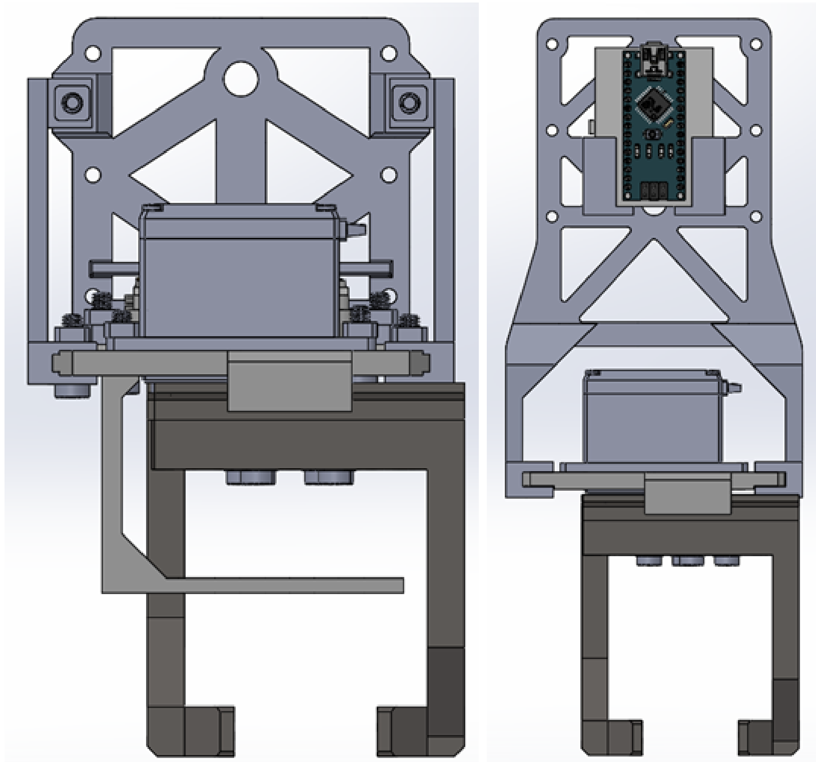


Figure: 3rd and 4th gripper prototypes from left to right

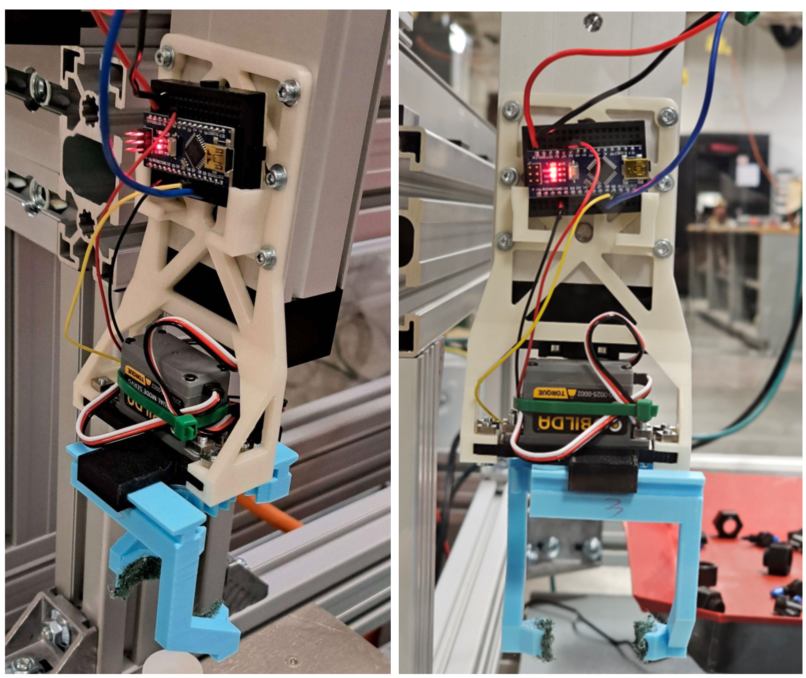


Figure: Final gripper design mounted on the CA

Full testing documentation for the gripper can be found in section 5. Force analysis for the gripper can be found in section 4.1.

3.1c Vibratory Table

The vibratory table is an open-ended design that is in control of dispersing parts for the system. Its vibration aids the camera in vibrating the parts so they are feasible to pick up. When the parts are within each other's annulus, the mechanism will vibrate with five short bursts of vibration. The vibratory table's major components consist of compression springs, rubber bushings, a vibratory motor, mild steel table and triangles. When the motor is turned on it creates an unbalanced force that causes the table to vibrate. The amplitude and frequency of the vibration can be adjusted to suit the type of parts being sorted. The table is bent at a 45 degree angle. This is to facilitate the gripper’s ability to grab parts near the edge and to prevent parts from falling out. Throughout testing, a cardboard was placed on top of the table to assist the parts in spreading out consistently when it vibrates. Full testing documentation for the vibratory table can be found in section 5.

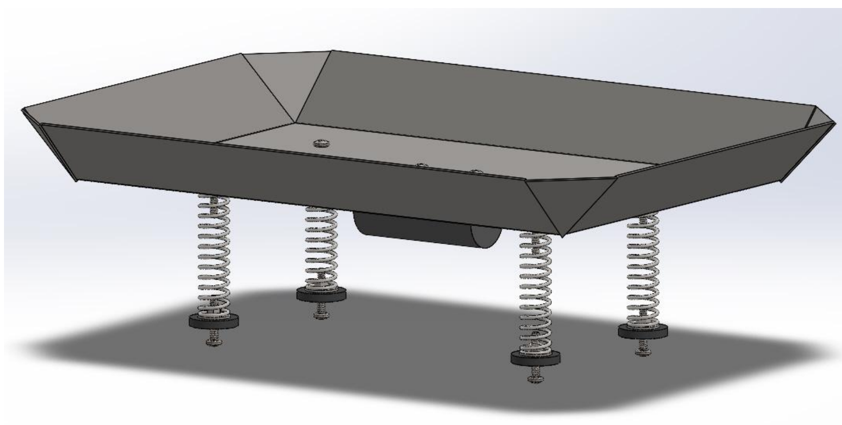


Figure: Vibratory Table Sub-Assembly

3.1d Cartesian Actuator

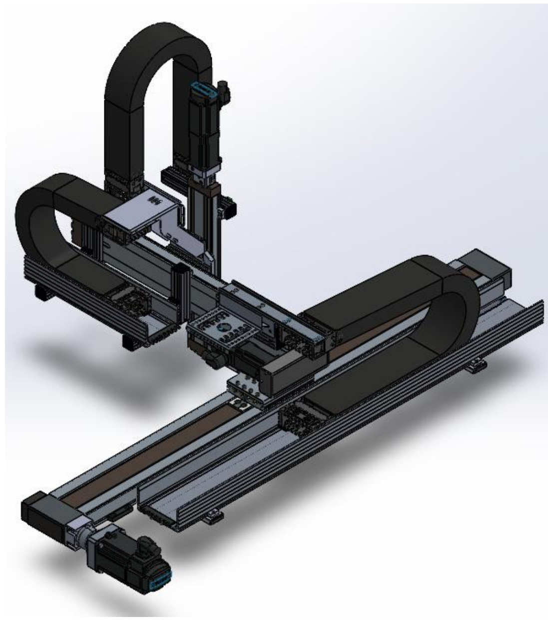


Figure: Cartesian Actuator

The Cartesian Actuator (CA) came as a part of Rexroth's Smart Function Kit for Handling. This was configured by the sponsor and provided to the team for the purpose of this project. The robot has a 3-axis system setup as follows:

- X Axis: Belt driven axis with 1000 mm of travel
- Y Axis: Ball screw driven axis with 400 mm of travel
- Z Axis: Ball screw driven axis with 300 mm of travel

3.1e Frame

The frame provides support, safety and stability to the system. Its skeleton is made out of aluminum extrusions that are lightweight, yet strong and durable that can be easily assembled. There is acrylic surrounding the upper half for safety. Its major dimensions had a few redesigns when considering cost, cartesian actuators x, y, and z travel, CA's weight, Cognex camera's height flexibility, vibratory table height flexibility and also its transportation in/out of the AME building. Below you can see the different stages of design for the frame.

Figure: Concept Design

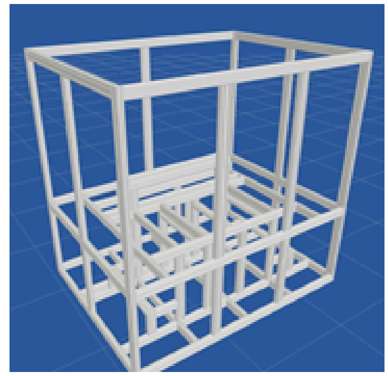


Figure: Frame One - Budget Constraint

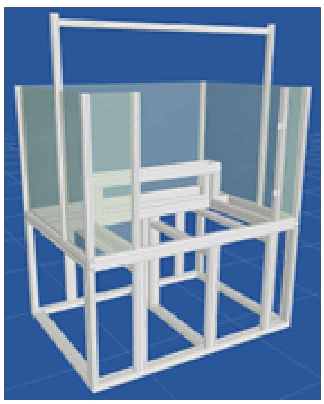


Figure: Frame Two - Height Constraint

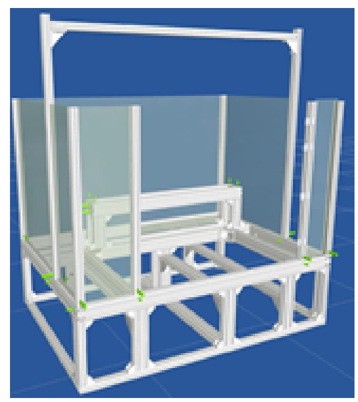


Figure: Final Frame Design

Frame One’s design was not within the team's $4000 budget and so the design had to be simplified. In Frame Two’s design, its height prohibited this system to be able to be transported out the doors of the AME building. Since the camera’s height flexibility is a must, the legs of the frame had to be shortened. As can be seen in the Final Frame design figure. Full documentation for the Frame can be found in section 5.

3.3 Functional Requirements:

These requirements govern the system's ability to accomplish the desired functionality as defined by our sponsor. After assessing the projected capabilities of the final system the following functional requirements were derived:

1. The robot shall be able to lift and maneuver different parts of a set range of dimensions.
2. The robot shall be able to move to the location of a certain part with an acceptable level of accuracy.
3. The camera shall be able to distinguish different parts.
4. The camera shall be able to locate different parts and send the coordinates to the robot.
5. The vibratory table shall be able to properly hold a number of different parts within the robot's range of motion.
6. The vibratory table shall be able to vibrate the parts and disperse them without affecting the rest of the system.
7. The gripping mechanism shall be capable of gripping one part at a time without dropping during motion.
8. The frame of the entire system shall house all components securely and keep them from external interference.
9. Adequate power shall be supplied to all electrical components to ensure smooth, optimum operation.

3.3 System Requirements

This section lists all the system requirements that must be fulfilled to get the desired functionality from the system. These requirements were derived from the initial functional requirements and divided into categories of Performance, Design, Power and Safety.

	Requirements
4.1	**Performance**
4.1.1	Position: The robot shall be able to position itself correctly within 5 mm of the desired location above the part.
4.1.2	Gripper: The gripper arms should have high friction material on the surface which comes into contact with the parts.
4.1.3	Identification: The camera shall be able to distinguish between shapes and colors.

4.1.4	Communication: The camera shall communicate coordinates to the robotic arm.
4.1.5	Resolution: The camera shall produce high resolution images.
4.1.6	Motion: The gripper shall be able to hold all differently shaped pieces tightly enough to prevent them from falling with a success rate of 99.0%.
4.1.7	Isolation: The vibe table shall not disrupt the operation of any other part of the system.
4.1.8	Effectiveness: The vibe table shall vibrate enough to sufficiently reorient and shift the parts.
4.2	**Design**
4.2.1	Load Weight: The total weight of the gripper and part it is carrying shall not exceed 5 kg.
4.2.2	Table Weight: The vibration table/springs shall be able to withstand a load of up to 5kg.
4.2.3	Material: The frame shall be made of aluminum.
4.2.4	Camera Mounting: The camera shall be mounted so 3D images can be processed.
4.2.5	Frame Size: The frame must have dimensions greater than 1000mm x 400mm
4.2.6	Table Size: The table dimensions shall not exceed 1000mm x 400mm
4.2.7	Boundary: The table shall have approximately > 1 in extrusion bordering the perimeter to keep parts from falling off.
4.2.8	Shape: The gripping mechanism shall be designed such that it can grip multiple objects of different shapes.
4.3	**Safety**
4.3.1	Emergency Stop: The system shall have an emergency stop button that cuts power to both the high and low voltage circuits
4.3.2	Isolation: The Frame should keep all moving parts of the system isolated from external interference
4.4	**Power**
4.4.1	Low Voltage Power: Low voltage sub-systems shall utilize a 12VDC power supply
4.4.2	High Voltage Power: CA shall run on 480V 3-phase power

3.4 Verification Documentation

3.4a System Verification Plan

This table lists the planned verification procedures that were performed in order to validate each of the system requirements.

	Requirements Verification
5.1	**Performance Requirements**
5.1.1	Position: Testing will be performed with CtrlX software and computer vision algorithm, in addition to visual inspection through measurements to verify that the cartesian robot is meeting the +/- 5mm requirement.
5.1.2	Gripper: The gripper will be tested extensively with different high friction materials on the section that comes into contact with the payload to demonstrate and prove that it will function as required.
5.1.3	Identification: Extensive testing on computer vision algorithms, with a variety of parts of different shapes and colors will be performed to verify that the camera meets the identification requirement.
5.1.4	Communication: Testing and Calibration with camera position will be conducted to verify that the camera is able to communicate correct coordinates of part locations in reference to the sorting table. We will be inspecting each set of coordinates by performing measurements to confirm that the communicated coordinates are correct.
5.1.5	Resolution: The camera will take a picture of a high resolution test paper and the image will be inspected to verify that the camera does produce high resolution images.
5.1.6	Motion: The gripper will be extensively tested by rapidly moving it while it is holding pieces of different shapes and sizes to ensure that the 99% success rate requirement is met.
5.1.7	Isolation: The entire system, particularly the camera, will be inspected while the vibe table is active to ensure that the table is not impacting the functions of the camera or any other part of the system.
5.1.8	Effectiveness: The vibe table will be tested with various different configurations of pieces on it to ensure that it relocates the pieces sufficiently for the camera to distinguish between them.

5.2	**Design Requirements**
5.2.1	Load Weight: Measurements with a scale will be taken for each part to ensure that the load of the gripper and part will not exceed the 5 kg weight requirement.
5.2.2	Table Weight: The spring/table will be analyzed through calculations and tested with Solidworks using load analysis.
5.2.3	Material: The frame will be designed and constructed from aluminum extrusions supplied by Bosch.
5.2.4	Camera Mounting: The camera mount will be integrated into the frame so that it does not interfere with the motion of the CA. The camera will also be positioned so that the whole vibe table fits within its FOV.
5.2.5	Frame Size: The frame dimensions will be designed to adapt for the specifications.
5.2.6	Table Size: The table dimensions will be designed to adapt for the specifications.
5.2.7	Boundary: The vibe table will be extensively tested to verify that no pieces fall off of it during operation.
5.2.8	Shape: Extensive pick and place testing will be conducted with various parts of different shapes to ensure that gripping mechanism meets the shape requirement.
5.3	**Safety Requirements**
5.3.1	Emergency Stop: Inspection with digital multimeter after the emergency stop button is pressed will be performed to verify that the emergency stop requirement is met.
5.3.2	Isolation: The frame will be designed so that none of the components of the overall system travel outside of its maximum dimensions during operation.
5.4	**Power Requirements**
5.4.1	Low Voltage Power: Inspection with digital multimeter will be used to verify low voltage power requirement.
5.4.2	High Voltage Power: Inspection with digital multimeter will be used to verify high voltage power requirement.

3.4b Verification Matrix

This table lists all the system requirements and highlights the type(s) of verification procedure that were used to validate that requirement. The different verification types are: Testing, Analysis, Demonstration and Inspection.

Requirements	Verification			
	T	A	D	I
4.1 Performance				
4.1.1 Position	X			X
4.1.2 Gripper	X		X	X
4.1.3 Identification	X		X	
4.1.4 Communication	X			X
4.1.5 Resolution				X
4.1.6 Motion	X			
4.1.7 Isolation				X
4.1.8 Effectiveness	X			
4.2 Design				
4.2.1 Load Weight				X
4.2.2 Table Weight	X	X		
4.2.3 Material			X	
4.2.4 Camera Mounting				X
4.2.5 Frame Size		X		
4.2.6 Table Size		X		
4.2.7 Boundary	X			
4.2.8 Shape	X			
4.3 Safety				
4.3.1 Emergency Stop			X	X
4.3.2 Isolation			X	
4.4 Power				
4.4.1 Low Voltage Power				X
4.4.2 High Voltage Power				X

3.4c Verification Flowdown

This table lists how the planned verification procedures flow down to each major system component. The table also specifies the type of verification procedure and identifies the minimum characteristics that need to be achieved for that requirement to be validated.

	Requirements	Sub-Systems					
		Camera	Computer	Frame	CA	Vibe Table	Gripper
4.1	**Performance**						
4.1.1	Position: (T/I) The robot shall be able to position itself correctly within 5 mm of the desired location above the part.		(T-Direct Flow) X, Y and Z coordinates from the camera are properly translated and sent to the robot.		(I-Direct Flow) Robot arm will move to the correct location based off of the camera's response.		
4.1.2	Gripper: (T/D/I) The gripper arms should have high friction material on the surface which comes into contact with the parts.						(I-Direct Flow) Friction material shall be applied to the gripper.
4.1.3	Identification: (T/D) The camera shall be able to distinguish between shapes and colors.	(T-Derived) Diffraction limit	(T-Direct Flow) Camera will be able to differentiate between color and				

			shaped based off of what profile is put into the software				
4.1.4	Communication: (T/I) The camera shall communicate coordinates to the robotic arm.	(T-Direct Flow) Camera will output coordinates that can be translated into a cartesian format to drive robot	(T-Direct Flow) Coordinates from the camera will then be translated to drive the robotic arm to corresponding locations				
4.1.5	Resolution: (I) The camera shall produce high resolution images.	(I-Direct Flow) Will be determined based of the quality of the images					

4.1.6	<u>Motion</u>: (T/A) The gripper shall be able to hold all differently shaped pieces tightly enough to prevent them from falling with a success rate of 99.0%				(T-Direct Flow) Gripper will be placed on the end of the arm.		(T-Direct Flow) Tests shall be performed to ensure pieces do not slip out of the gripper during motion. (A-Direct Flow) Statistical analysis shall be performed to determine a success rate of approximately 99.0%
4.1.7	<u>Isolation</u>: (I) The vibe table shall not disrupt the operation of any other part of the system.			(T-Direct Flow) Vibe table shall be mounted to the frame in a manner that isolates		(T-Direct Flow) Vibration motor shall be run at a speed that does not interfere with the rest of	

				it from interfering with the rest of the system.		the system.	
4.1.8	<u>Effectiveness</u>: (T) The vibe table shall vibrate enough to sufficiently reorient and shift the parts.		(T-Direct Flow) Table will be programmed to run long enough to sufficiently shift parts.			(T-Direct Flow) Vibration motor shall be selected to ensure that parts are shifted sufficiently. (T-Direct Flow) The table shall be designed to ensure that parts are shifted sufficiently.	
4.2	**Design**						

4.2.1	Load Weight: (I) The total weight of the gripper and part it is carrying shall not exceed 5 kg.						(T-Allocation) Gripper shall be constructed so that its total weight does not exceed 3 kg.
4.2.2	Table Weight: (T/A) The vibration table/springs shall be able to withstand a load of up to 5kg.					(A-Derived) Load calculations shall be performed to ensure that the table will withstand applied forces.	
4.2.3	Material: (D) The frame shall be made of aluminum.			(D-Direct Flow) The frame shall be made out of aluminum extrusions.			

4.2.4	Camera Mounting: (I) The camera shall be mounted so 3D images can be processed.	(I-Derived) Field of view Magnification Working distance		(I-Direct Flow) Camera will be mounted in optimal place so images can be resolved			
4.2.5	Frame Size: (I) The frame must have dimensions greater than 1000mm x 400mm			(I-Direct Flow) The frame shall have dimensions greater than 1000mm x 400mm.			
4.2.6	Table Size: (I) The table dimensions shall not exceed 1000mm x 400mm					(I-Direct Flow) The vibe table top shall not exceed 1000mm x 400mm.	
4.2.7	Boundary: (T) The table shall have					(T-Direct Flow)	

	approximately > 1 in extrusion bordering the perimeter to keep parts from falling off.					The vibe table top shall be built with angled edges to prevent pieces from sliding off during operation.	
4.2.8	Shape: (T) The gripping mechanism shall be designed such that it can grip multiple objects of different shapes.						(D-Direct Flow) The design of the gripper claws shall be tailored to best fit the pieces it needs to pick up.
4.3	**Safety**						
4.3.1	Emergency Stop: (D/I) The system shall have an emergency stop button that cuts power to both the high and low voltage circuits		(D-Allocation) The computer shall be powered down when the emergenc	(I-Allocation) After the shutoff a digital multimeter will	(D-Allocation) The CA shall be powered down when the		

			y stop button is pressed.	be placed to verify the stop button works.	emergency stop button is pressed.		
4.3.2	<u>Isolation</u>: (D) The Frame should keep all moving parts of the system isolated from external interference			(I-Direct Flow) The frame shall be designed to extend beyond all moving parts within the system.			
4.4	**Power**						
4.4.1	<u>Low Voltage Power</u>: (I) Low voltage sub-systems shall receive necessary power supply	(I-Allocation) Camera shall be provided with 24V DC power.				(I-Allocation) The Vibratory motor shall receive a 12V/24V DC power.	(I-Allocation) The servo motor shall be provided with 5V DC power.
4.4.2	<u>High Voltage Power</u>: (I) CA shall run on 480V 3-phase power				(I-Allocation) Actuato		

					r shall be provided with 460V 3-phase power		

3.5 Indentured Document List (IDL)

Part Number		**Document**
1000000		Full System Assembly
1010000		Camera Assembly
	1010100	Camera
	1010200	Lens
	1010300	Illuminator
1020000		Computer Assembly
	1020100	CtrlX Machine Controller
	1020200	Insight Explorer
	1020300	Arduino NANO
1030000		Frame Assembly
1040000		Gripper Assembly
	1040220	Gripper Pinion Gear Assembly
	1040202	Gripper Pinion Gear

	1906-0025-0032	Low Profile Servo Hub
	1040203	Gripper Cross Frame
	1040201	Gripper Rack Gear
	2000-0025-0002	Servo Motor
1050000		Cartesian Actuator
1060000		Vibratory Assembly
	1060201	Vibratory Table
	1060202	Triangles
	FM-220621-A	Rubber Bushings
	9657K515	Compression Springs
	3650	Vibratory Motor
1070000		Electrical Components
	1070100	NEMA Enclosure
	1070300	3-phase wall plug L-16-30R
	1070400	24VDC Relay
	1070500	Voltage Buck Converter (24V to 12V)
	1070600	Voltage Line Filter
1080000		Software Design Document
	1080100	Camera Software
	1080200	Controller Software
	1080300	Arduino Software
1090000		Electrical Circuit Diagrams
1100000		CA Maintenance Manual [Appendix A]
1110000		Software Manual [Appendix B]
1120000		Cognex Camera Manual [Appendix C]

3.6 Electrical Circuit

IDL# 1090000

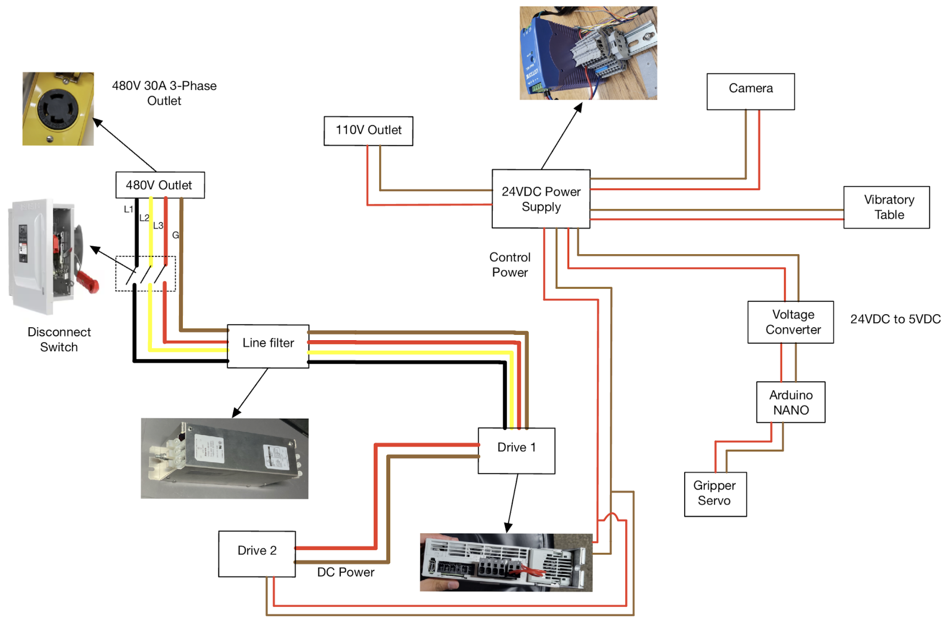


Figure: Power Circuit

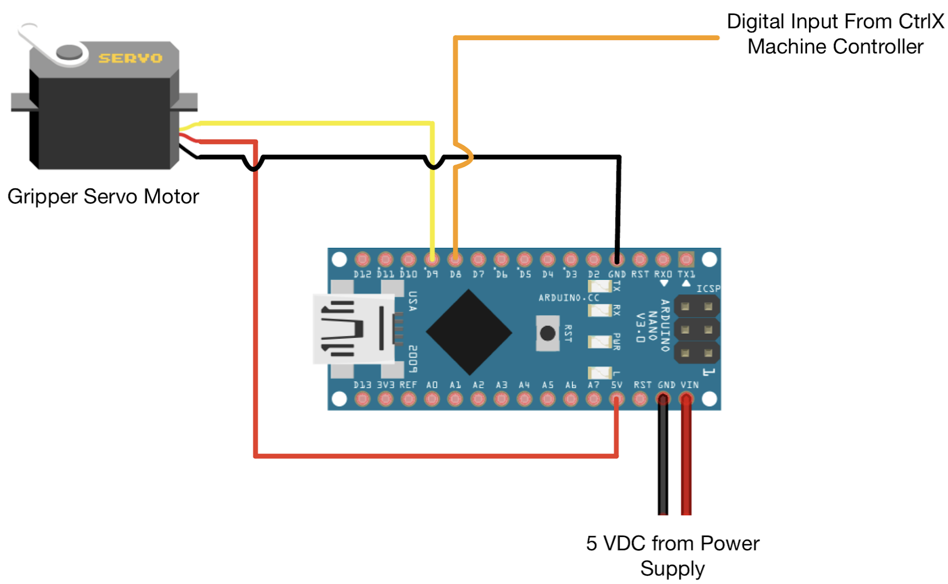


Figure: Arduino Circuit

All high voltage wiring was done with 10-gauge wires with thick rubber insulation rated for up to 600V. Low voltage power circuitry was wired using 12-gauge wires and 22-gauge was used for control wires. All metal contact surfaces were grounded and Major Electrical components were housed inside a Type 1 lockable NEMA Enclosure.

Figure: Major Circuit Components inside NEMA Enclosure

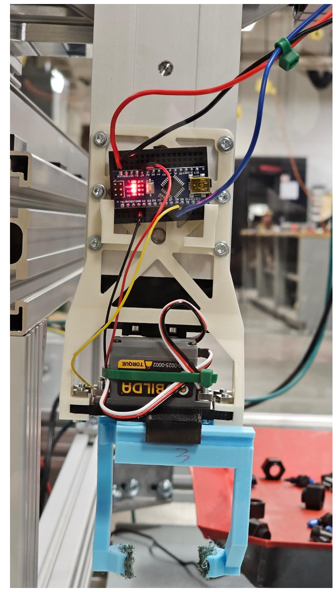


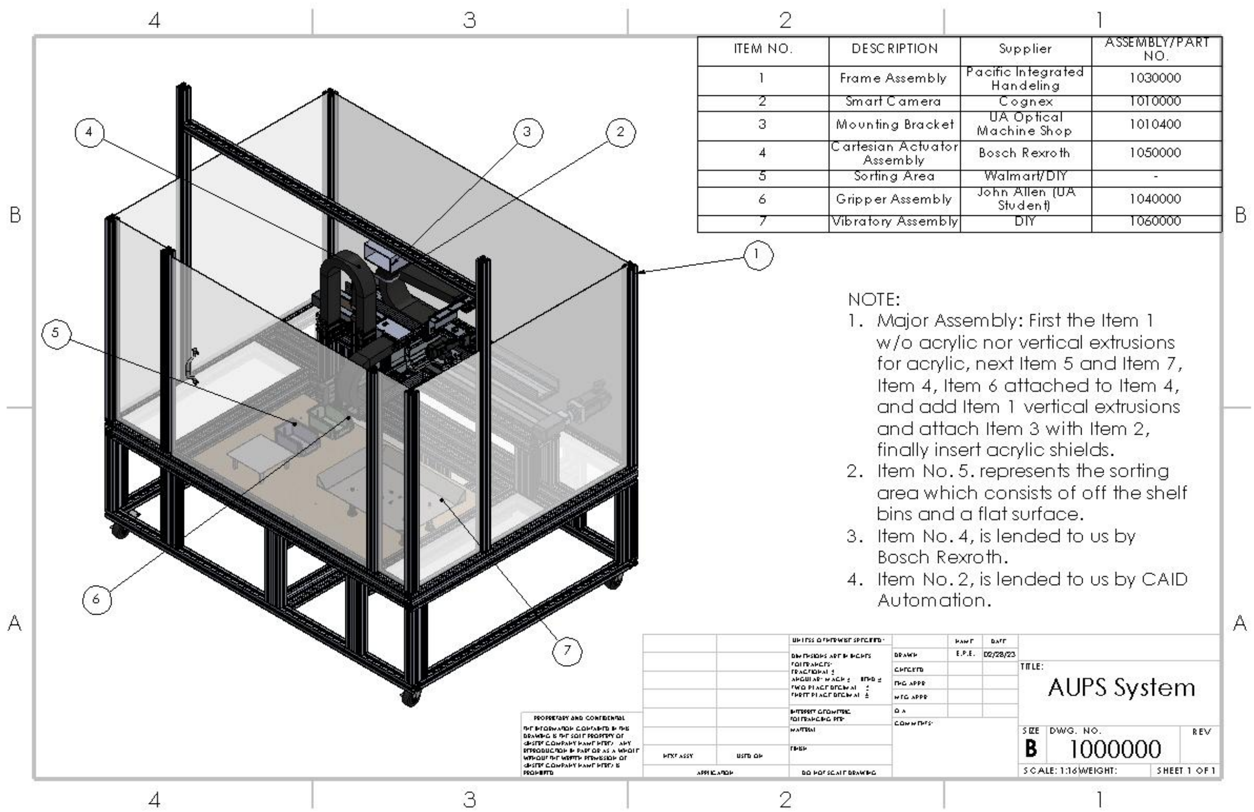
Figure: Arduino Circuit on Gripper

3.7 Hardware Drawing Package

This section contains drawings for all the major sub-components that make up the system as well as a full system drawing. Drawings for different parts that make up each sub-component can be found in the Appendix.

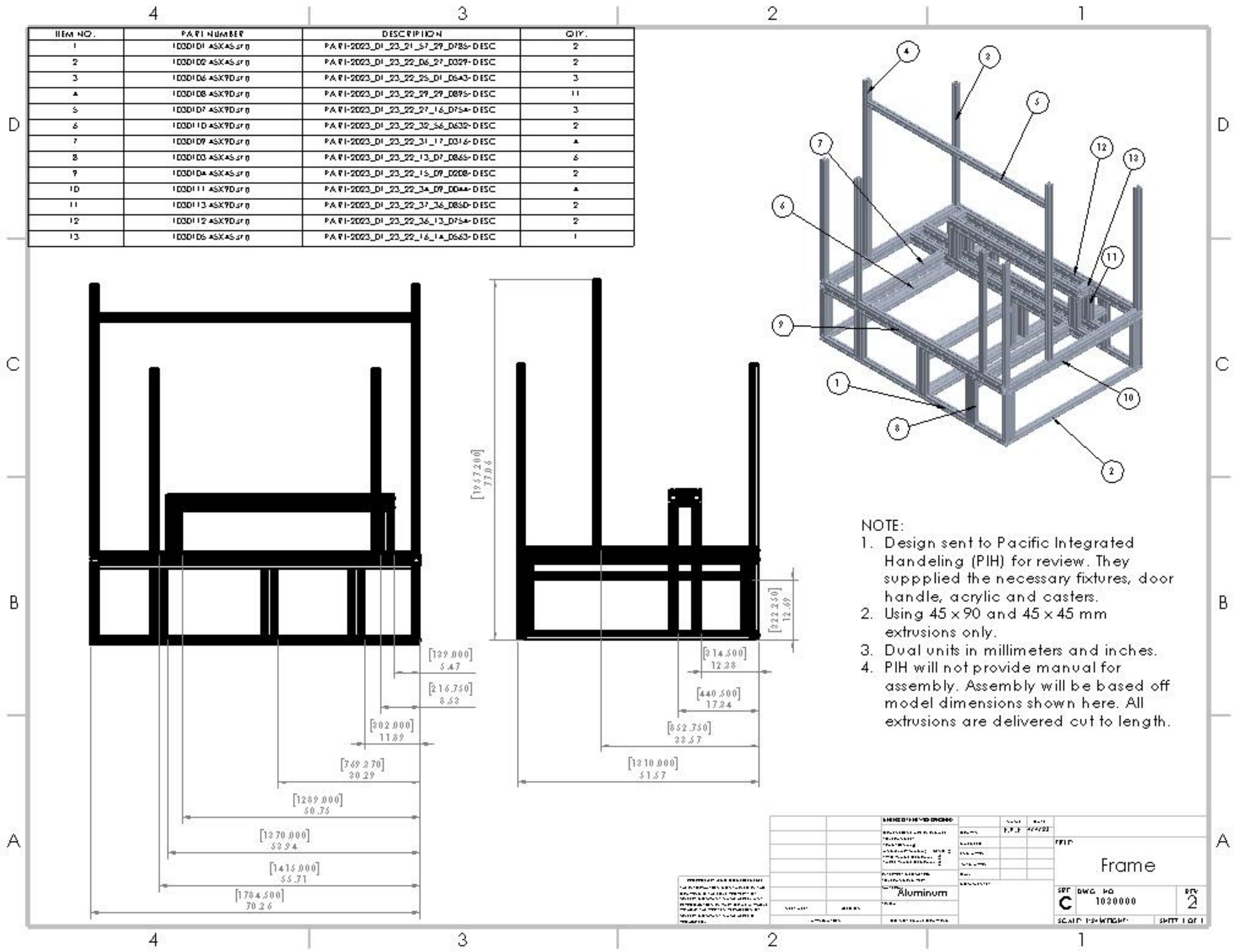
3.7a Top Assembly Drawing

IDL# 1000000



3.7b Frame Assembly:

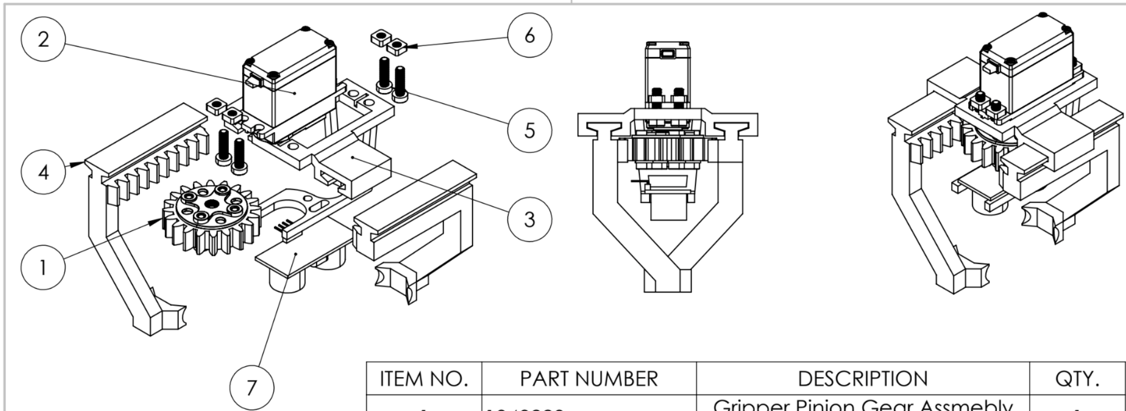
IDL# 1030000



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1030101 45X45.sr0	PART-2023_01_23_21_57_29_0785-DESC	2
2	1030102 45X45.sr0	PART-2023_01_23_22_06_27_0329-DESC	2
3	1030106 45X90.sr0	PART-2023_01_23_22_25_01_0643-DESC	3
4	1030108 45X90.sr0	PART-2023_01_23_22_29_29_0875-DESC	11
5	1030107 45X90.sr0	PART-2023_01_23_22_27_16_0754-DESC	3
6	1030110 45X90.sr0	PART-2023_01_23_22_32_56_0632-DESC	2
7	1030109 45X90.sr0	PART-2023_01_23_22_31_17_0316-DESC	4
8	1030103 45X45.sr0	PART-2023_01_23_22_13_07_0865-DESC	6
9	1030104 45X45.sr0	PART-2023_01_23_22_15_09_0208-DESC	2
10	1030111 45X90.sr0	PART-2023_01_23_22_34_09_0044-DESC	4
11	1030113 45X90.sr0	PART-2023_01_23_22_37_36_0850-DESC	2
12	1030112 45X90.sr0	PART-2023_01_23_22_36_13_0754-DESC	2
13	1030105 45X45.sr0	PART-2023_01_23_22_16_14_0663-DESC	1

3.7c Gripper Assembly:

IDL# 1040000



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1040220	Gripper Pinion Gear Assmebly Rev2	1
2	2000-0025-0002	Servo Motor	1
3	1040203	Gripper Cross Frame Rev2	1
4	1040201	Gripper Rack Gear Rev2	2
5	2804-0004-0014	Low Profile Steel Screw	4
6	2803-0007-0007	Square Nut	4
7	1040401	Ultrasonic Sensor	1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DSM	1/24/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

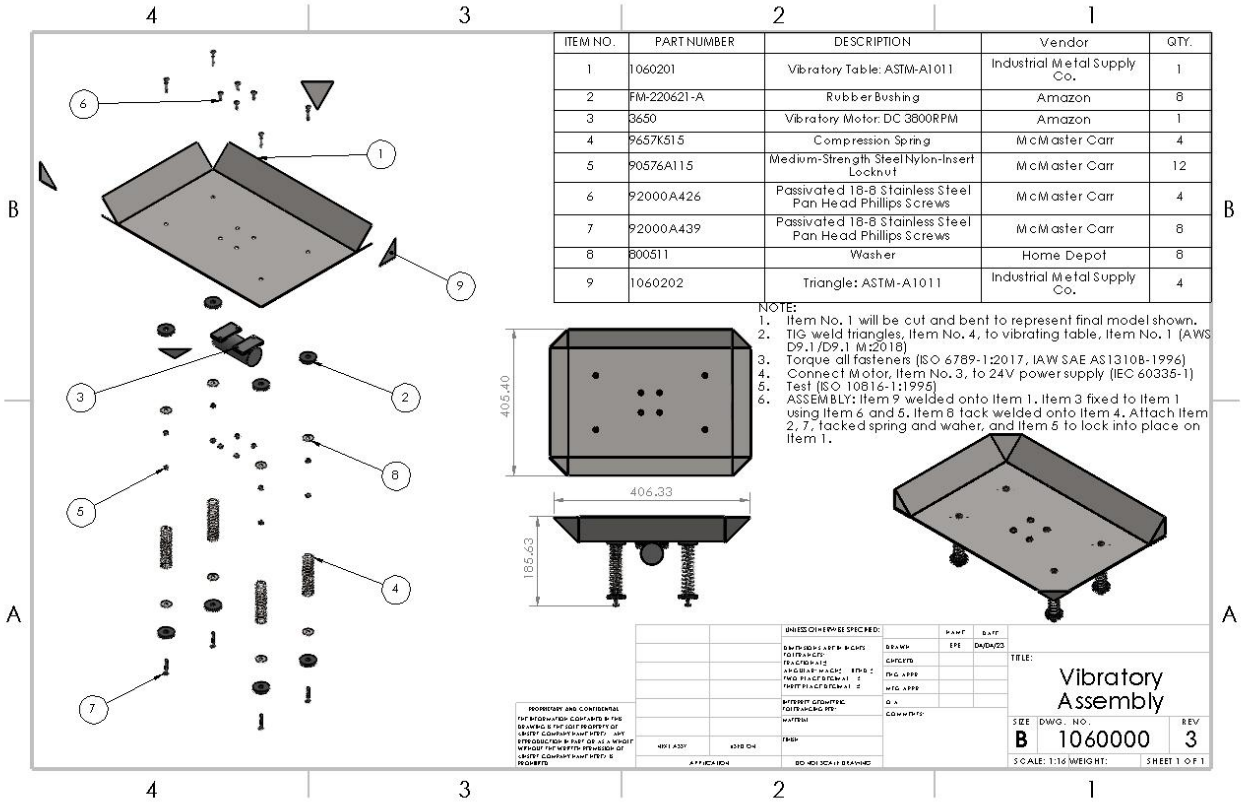
TITLE: Gripper Assembly

SIZE A | DWG. NO. 1040000 | REV 3

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

3.7d Vibratory Table Assembly:

IDL# 1060000



ITEM NO.	PART NUMBER	DESCRIPTION	Vendor	QTY.
1	1060201	Vibratory Table: ASTM-A1011	Industrial Metal Supply Co.	1
2	FM-220621-A	Rubber Bushing	Amazon	8
3	3650	Vibratory Motor: DC 3800RPM	Amazon	1
4	9657K515	Compression Spring	McMaster Carr	4
5	90576A115	Medium-Strength Steel Nylon-Insert Locknut	McMaster Carr	12
6	92000A426	Passivated 18-8 Stainless Steel Pan Head Phillips Screws	McMaster Carr	4
7	92000A439	Passivated 18-8 Stainless Steel Pan Head Phillips Screws	McMaster Carr	8
8	800511	Washer	Home Depot	8
9	1060202	Triangle: ASTM-A1011	Industrial Metal Supply Co.	4

3.8 Software Design Documentation (SDD)

IDL# 1080000

Table of Contents:

3.8a Software Introduction

The software for the Automated Universal Part Singulator functions to provide an automated and flexible solution to part sorting. The software is structured into two major components which are the Cognex camera and the CtrlX machine controller. The following documentation pertains to the software design and procedures for the Automated Universal Part Singulator.

3.8b Camera Software

The smart camera software serves to provide the system with computer vision by profiling images of various parts for part recognition. The camera itself is mounted above the vibration table in our system so that it can identify different parts that are scattered on top of the table. A range of parts were profiled and stored in the camera's memory including different orientations for certain parts. When parts are identified after the camera is triggered, the camera uses a built-in image processing algorithm to identify pixel coordinates for the part locations from the camera's perspective. An annulus was also programmed for each part to allow for detecting parts that are not pickable. The camera was configured to utilize OPC Unified Architecture communication protocol so that it could send pixel coordinate data to the CtrlX machine controller.

3.8c CtrlX Software

The CtrlX software serves as the main control unit for the system. This includes control for the cartesian actuator, vibration table motor, camera trigger, and the arduino. The control for the cartesian actuator involves programming for kinematic motion to move the axes to a particular location. The control for the vibration table motor consisted of programming an output pin on the machine controller to send digital pulses to a relay for supply power. To control the camera trigger, the digital trigger wire for the camera was wired to a digital output pin on the controller. The arduino was controlled by a digital output signal from the machine controller to command it to perform a PWM output to close the gripper claws.

The CtrlX software also has programming to handle inputs. A start button, stop button, and emergency stop button are all wired to digital inputs for the machine controller. The pixel coordinate inputs communicated from the camera are processed through an algorithm to scale the units to millimeters and apply necessary offsets to align the cartesian actuator’s coordinate system with the camera’s coordinate system.

3.8d Arduino Software

The Arduino was used to simplify communication between the gripper and the machine controller. The controller only sent a constant digital signal to the Arduino and the Arduino handled the PWM output to move the gripper servo. In the Arduino code, the gripper was programmed to have an open and closed state based on the controller’s digital signal. The exact open and closed positions were determined by using the dimensions of the largest part being sorted.

3.8e System State Machine

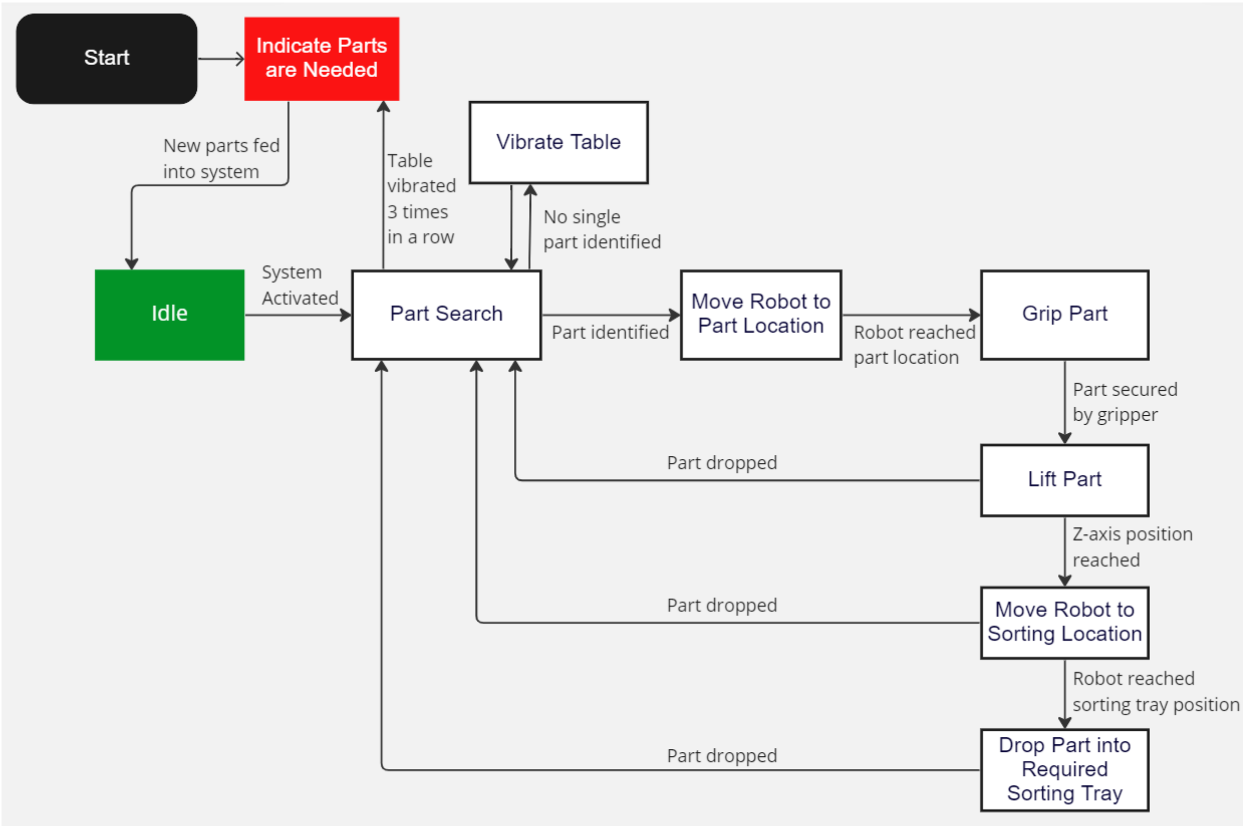


Figure: System State Machine

This is a state machine which controls the behavior of the software in the Automated Universal Part Singulator System. The initial state of the system indicates to the user that parts need to be fed to the vibratory table. When this condition is met the system will enter an idle state where it will wait for user input for system activation. From here the system will act autonomously following a communication between the CtrlX machine controller and Cognex Camera to trigger necessary events. After the system iterates through all of the parts that need to be sorted, it will transition back to the original state indicating more parts are needed.

3.8f System Sequence Diagram

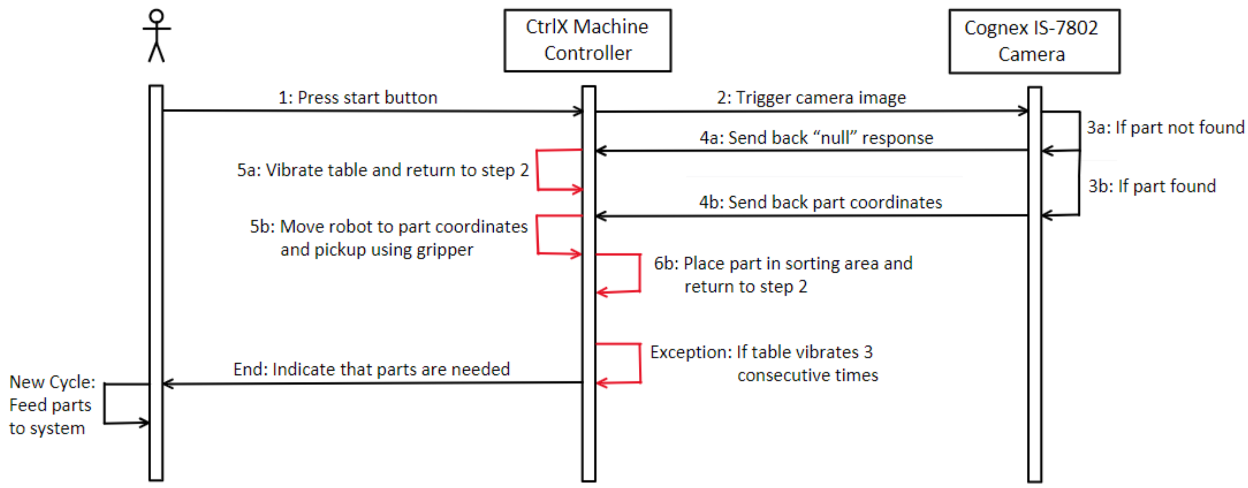


Figure: Software Sequence Diagram

This is a sequence diagram which helps better visualize the communication between the CtrlX machine controller and the Cognex Camera. The user begins the sequence of operations by pushing the start button, and then the system begins to sort parts autonomously. Communication between the controller and the camera is necessary so that the control system can access part location information which is provided by the camera. The camera communicates by either providing coordinates for robot movement or a null response which indicates to the CtrlX module that table vibration is necessary to shift the parts.

3.8g Software Test/Plan

Procedure:

- Mount camera on adjustable tripod at 800mm working distance
- Place red backdrop in camera's field of view
- Program camera with parts of different shapes, sizes and colors
- Test camera's ability to:
  - Identify and locate parts
  - Identify and locate parts that are asymmetrical
  - Identify and locate a set quantity of parts
  - Identify and locate parts in different orientations
  - Reject parts that are not pickable or surrounded by too many obstacles

Figure: Camera Test Setup

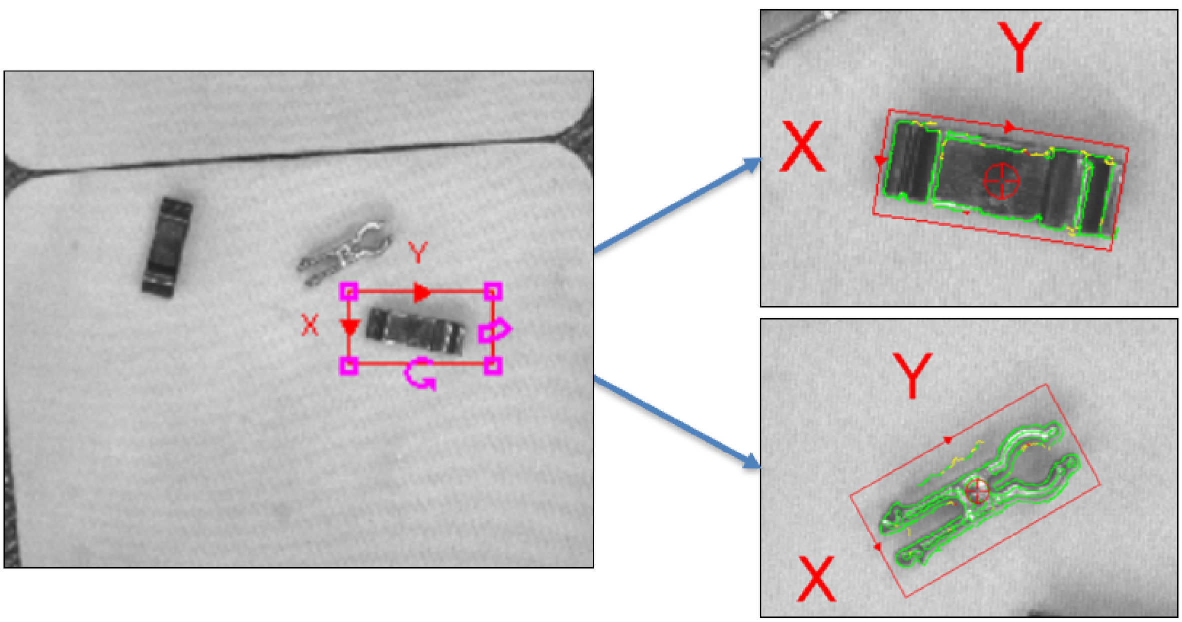


Figure: Profiling Parts with Camera

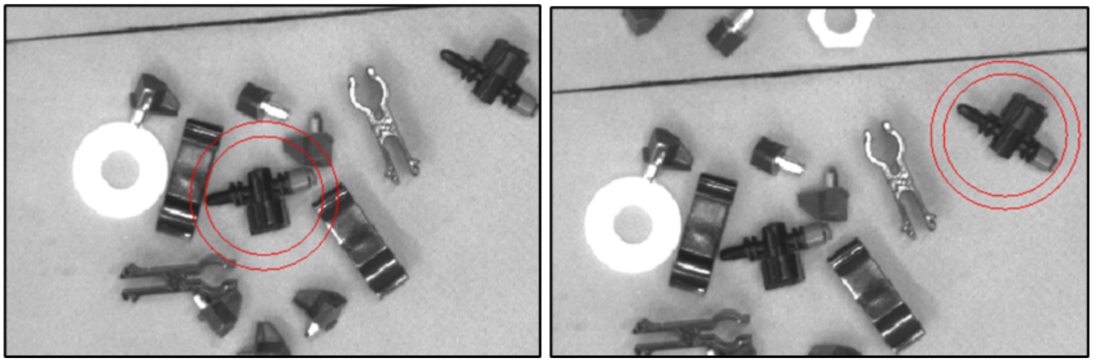


Figure: Software Boundary to Choose parts that do not have obstacles

Location process Micro Spray Fan																						
Patterns	1.000																					
	Index	X	Y	Angle	Scale	Score	Color				Thresh	Contrast	Pass/Fail	Multisatus	Pass/Fail ErrFree	ErrFree Angle	ErrFree Contrast	Adjusted Contras				
Patterns	0.000	884.424	1198.700	-123.185	99.977	66.681	8.000	Plot		Hist	200.000	9.671	1.000		1.000	-123.185	9.671	9.671				
	1.000	687.896	1128.056	112.575	99.955	64.688	8.000	Plot		Hist	200.000	9.400	1.000		1.000	112.575	9.400	9.400				
	2.000	973.147	689.609	143.637	100.010	64.439	8.000	Plot		Hist	200.000	11.181	1.000		1.000	143.637	11.181	11.181				
	3.000	556.300	970.685	97.552	99.941	64.103	8.000	Plot		Hist	200.000	8.745	1.000		1.000	97.552	8.745	8.745				
	4.000	1014.734	1057.484	-37.467	99.978	62.513	8.000	Plot		Hist	200.000	14.468	1.000		1.000	-37.467	14.468	14.468				
	5.000	551.441	427.573	175.343	99.947	60.609	8.000	Plot		Hist	200.000	8.747	1.000		1.000	175.343	8.747	8.747				
	6.000	849.527	934.754	164.635	99.995	59.626	7.000	Plot		Hist	200.000	74.597	0.000		0.000	164.635	74.597	74.597				
	7.000	661.996	592.346	-157.659	99.939	59.230	8.000	Plot		Hist	200.000	8.101	1.000		1.000	-157.659	8.101	8.101				
	8.000	741.633	690.807	57.678	99.889	53.983	7.000	Plot		Hist	200.000	63.772	0.000		0.000	57.678	63.772	63.772				
	9.000	841.158	451.893	150.809	99.989	53.541	7.000	Plot		Hist	200.000	55.154	0.000		0.000	150.809	55.154	55.154				
																					Output X	Output Y
	7.000	661.996	592.346	-157.659	99.939	59.230	8.000	Plot		Hist	200.000	8.101	1.000		1.000	-157.659	8.101		661.996	592.346	661.996	592.346

Figure: Screenshot of Insight Explorer Spreadsheet Interface

This is a table from the Insight software which provides part information for the objects that were profiled. The table contains a column for X and Y coordinates of the parts that we performed tests with. The coordinates seen in the sheet represent the data that is relevant for communication with the CtrlX machine controller. Another important set of information that can be seen is the score column which provides a metric for the camera's ability to identify the part that was originally profiled in that particular image. The pass/fail column is determined by a software boundary protocol that was designed to create a boundary around parts so that we can program the camera to trigger table vibrations when parts are in too close proximity to one another.

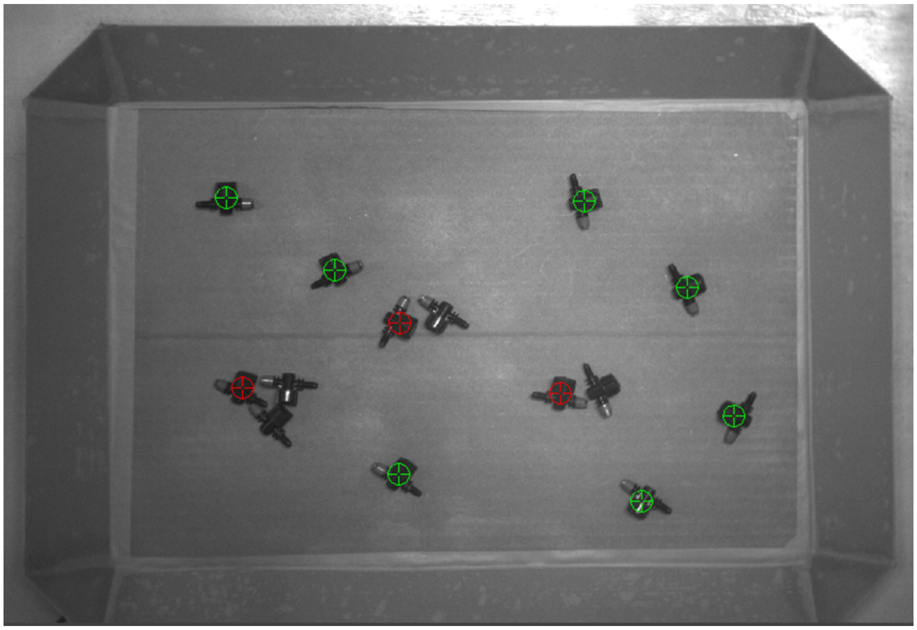


Figure: Camera View when testing Annulus

Multiple iterations were run with the camera software to determine the perfect annulus setting to reject parts that have obstacles around them. This was done by measuring the gripper's desired open position both in mm and in pixels and setting inner and outer radii for a software 'ring' around the part. The camera was programmed to detect obstacles by checking the contrast values within the software ring. A threshold value for the contrast was set based on lighting conditions and part colors as well as the table's background contrast. The image above shows the camera rejecting parts (red) that have obstacles and would be difficult for the gripper to pick up, and accepting parts that pass the criteria (green).

4.0 Models / Analyses

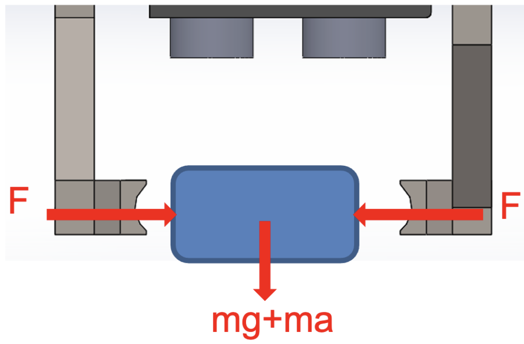
4.1 Gripper Models

As a part of the testing for the gripper, a preliminary FEA load analysis was performed using Solidworks. The analysis shows that the gripper rack gears, which will be the first point of failure, can withstand a worst case scenario where the part it is picking up has a mass of 0.4 kg with a friction coefficient of 0.2 (assuming plastic to plastic contact). The model proved that, under such conditions, the gripper could apply enough force to securely pick up the specified part while experiencing less than half of the force required for plastic deformation. Below are shown the numerical values from the model compared to the measured or expected real world values.

	Force required by model	Force able to be supplied by gripper
Results of force requirement model	14.7 N	106 N
	Max stress experienced under model conditions	Max yield stress of gripper rack gear
Results of yield stress model	11,700,000 N/m^2	26,000,000 N/m^2

The average mass of the parts used in normal operation of the AUPS is 2 grams and the realistic friction coefficient under normal conditions is 0.6-0.7 (estimation due to different material composition of different parts) meaning normal operation will see the gripper experiencing even lower forces and stresses than the ones present in the model.

The following shows completed CAD and software models. That being the gripper's ability to grab parts and the smart camera's ability to to view the desired area with a certain lens

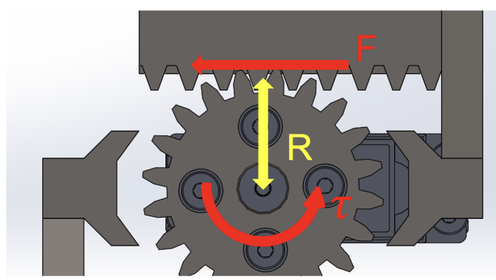


$$2F = \frac{m(g+a)}{\mu}$$

Figure : Free Body Diagram

Assumptions:
Part mass m = .4 kg
Friction coefficient μ = .2
Vertical acceleration a = 4.9 m/s^2

Grip force needed is F = 14.7 N



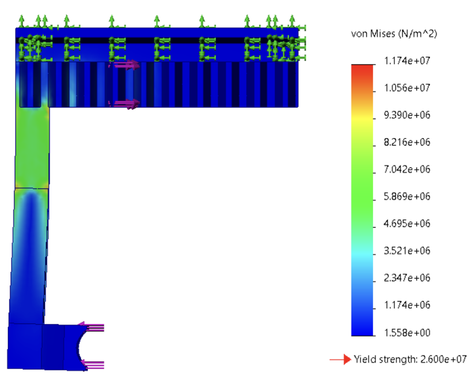
Max Torque = 300 oz in
=> 2120 N mm

R = 20 mm

$$F = \frac{\tau}{R} = 106\ N$$

Figure : Force Conversion

Servo Can Supply Force



Analysis performed with F = 15 N.

Yield Strength is 2x max experiences stress.

Figure : Solidworks Load Analysis

4.2 Camera Field of View Model

```
% in units of mm
L = 7.2; % vertical sensor dimension
W = 5.4; % Horizontal sensor dimension
FOVv = 457.2; % derived from y table dimension
FOVh = 304.8; % derived from x table dimension
WD = 800; % camera distance from vibratory table

fv = (L/2)*((2*WD)/FOVv);
fh = (W/2)*((2*WD)/FOVh);
```

Command Window

```
Required vertical focal length:12.5984
Required horizontal focal length:14.1732
```

Figure: Matlab Field of View Calculation

	Focal Length (mm)	Working Distance (mm)	Width (mm)	Height (mm)
Closest Higher	16.0	1015.556	457.000	342.750
Exact	12.6	800.000	457.000	342.750
Closest Lower	12.5	793.403	457.000	342.750

Figure: Cognex Lens Advisor Table

5.0 Acceptance Test Procedure (Procedures & Data sheets)

5.1 Introduction

This section showcases the verification tests and procedures that were performed to validate the system requirements. As well as a verification table showing pass/fail of all requirements.

5.2 Pass/Fail Table

System Requirement Verification				
Requirement	**Method**	**Limit/Reference**	**Measured/Ref Value**	**Pass/Fail**
1. Performance Requirements				
Position: The robot shall be able to position itself correctly within 5 mm of the desired location above the part.	T, I	<5mm	< 1mm	Pass
Gripper: The gripper arms should have high friction material on the surface which comes into contact with the parts.	T, D, I	Sufficient Material Applied	Material hold's parts 100% of the time	Pass
Identification: The camera shall be able to distinguish between shapes.	T, D	Insight Spreadsheet score > 80	Insight Spreadsheet score > 80	Pass
Communication: The camera shall communicate coordinates to the robotic arm.	T, I	Valid real number Cartesian Coordinates	Robot positioned to within 0.5mm with coordinates	Pass
Resolution: The camera shall produce high resolution images.	I	Insight Explorer Histogram	Insight Explorer Histogram	Pass
Motion: The gripper shall be able to hold all differently shaped pieces tightly enough to prevent them from falling with a success rate of 99.9%.	T	>=99% accuracy	100% Accuracy	Pass
Isolation: The vibe table shall not disrupt the operation of any other part of the system.	I	Drawing 1060000	N/a	Pass
Effectiveness: The vibe table shall vibrate enough to sufficiently reorient and shift the parts.	T	Parts dispersed sufficiently	At least 1 part available for pickup after vibration	Pass
2. Design Requirements				

Load Weight: The total weight of the gripper and part it is carrying shall not exceed 5 kg.	I	<5kg	≅ 1 kg	Pass
Table Weight: The vibration table/springs shall be able to withstand a load of up to 5kg.	T,A	>5kg	20.7kg	Pass
Material: The frame shall be made of aluminum.	D	Drawing 1030000	Drawing 1030000	Pass
Camera Mounting: The camera shall be mounted so images can be processed.	I	vertical FOV > 342.75 mm. horizontal FOV > 457.00 mm. WD = 800 mm.	horizontal FOV = 479.85. vertical FOV = 359.9 mm. mm. WD = 800 mm.	Pass
Frame Size: The frame must have dimensions greater than 1000mm x 400mm	I	l > 1000mm w > 400mm	l = 1784.5mm w = 1310mm	Pass
Table Size: The table dimensions shall not exceed 1000mm x 400mm	I	l < 1000mm w < 400mm	l = 453.64mm w = 301.24mm	Pass
Boundary: The table shall have approximately > 1 in extrusion bordering the perimeter to keep parts from falling off.	T	>1in	≅ 2in	Pass
Shape: The gripping mechanism shall be designed such that it can grip multiple objects of different shapes.	T	Drawing 1040201	Drawing 1040201	Pass
3. Safety Requirements				
Emergency Stop: The system shall have an emergency stop button that cuts power to both the high and low voltage circuits	D,I	System Shutdown	N/a	Pass
Isolation: The Frame should keep all hazardous parts of the system isolated from external interference	D	No external interference	N/a	Pass
4. Power Requirements				
Low Voltage Power: Low voltage sub-systems shall utilize a 24VDC power supply	I	Voltage ≅ 24VDC Current < 10A	24.2 VDC 100 mA on average	Pass
High Voltage Power: CA shall run on 480V 3-phase power	I	Voltage ≅ 480VAC 3-Phase Current < 30A	≅ 480 VAC ≅ 22 A	Pass

<table>
<tr><td colspan="4">Acceptance Test Data Sheet</td></tr>
<tr><td colspan="4">5.3a: Electrical Verification</td></tr>
<tr><td colspan="4">Unit(s) Under Test (UUT):

Name: | Part number:
Disconnect Switch | N/a
NEMA Enclosure | 1070100
High Voltage Wiring | N/a</td></tr>
<tr><td colspan="2">Results (Pass / Fail): Pass</td><td colspan="2">Date of Test: 3/15/2023</td></tr>
<tr><td>Recording of Test Measurement:

● Electrical Continuity
● Ground voltage
● Line voltage
● Load voltage</td><td>Requirement:

● High voltage power
● Low voltage power</td><td>Test Equipment:

Digital Multimeter</td><td>Adjusted Test Limit:

N/a</td></tr>
</table>

Computations, (Include Analyses Results, if any):

Each high voltage component was tested for electrical continuity between contact points. This was done to ensure no components were shorted and all connections were strong enough to withstand vibrations.

The ground voltage for each of the ground terminals and component casings were measured to check for proper grounding and to eliminate “floating” components.

Electrical Isolation Requirement

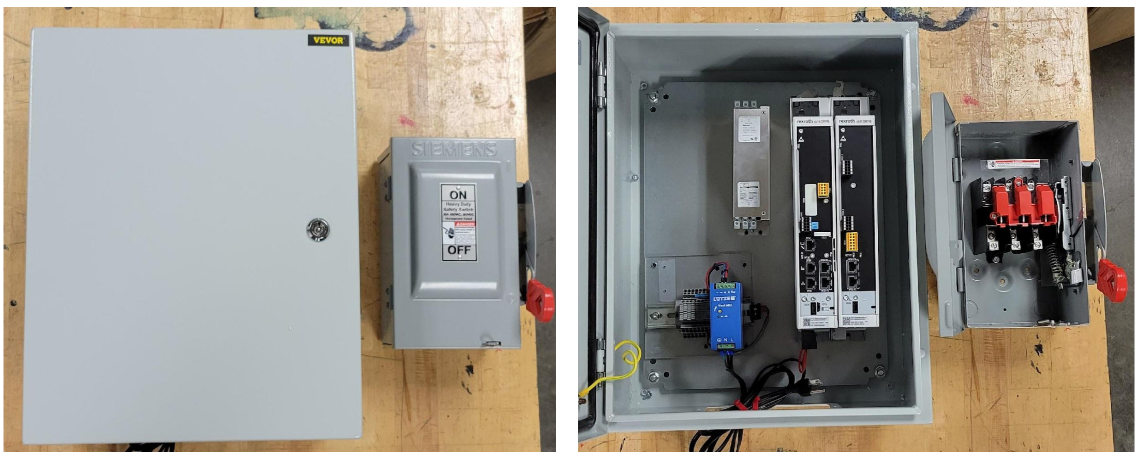


Figure: Nema Enclosure and Three-Phase Disconnect Switch

To satisfy the electrical isolation requirement for the system, a type 1 NEMA enclosure is being used to house all of the major electrical components. The image on the right for the figure above provides a visualization of how the electrical components are organized and mounted inside the enclosure. This will keep the high voltage components isolated from external interference providing protection against hazards such as electric shock or fire. This enclosure prevents unauthorized access to the electrical components, as a key is required for maintenance reducing the risk of accidents and injuries.

The three-phase disconnect switch is essential for the system to provide a means to isolate the circuit from its power source. This isolation is crucial for the safety of personnel as well as preventing damage to the equipment during maintenance, repair, or emergency situations. When the switch is in the open position, it breaks the electrical connection between the power source and the equipment, which ensures that no power is flowing through the circuit. This electrical isolation eliminates the risk of accidental electrical shocks, and fires that could occur if work were to be carried out on a live circuit. Additionally, this disconnect switch can be locked out to prevent unauthorized access, which provides an extra layer of safety to the system.

Result:

All electrical components are properly isolated and electrical circuitry has zero faults. For further verification, the circuit was tested and evaluated by a professional electrician.

Signatures:

Tester ___________Nafisul Khondaker________________

Customer Brett Dooley

<table>
<tr><td colspan="4">Acceptance Test Data Sheet</td></tr>
<tr><td colspan="4">5.3b: Gripper Verification</td></tr>
<tr><td colspan="4">Unit(s) Under Test (UUT):
Name: Gripper Assembly
Part number: 1040000</td></tr>
<tr><td colspan="2">Results (Pass / Fail): Pass</td><td colspan="2">Date of Test: 3/10/2023</td></tr>
<tr><td>Recording of Test Measurement:
● Failure Percentage
● Friction
● Load Analysis
● Force</td><td>Requirement:
● Gripper Performance
● Gripper Motion
● Load Weight
● Shape</td><td>Test Equipment:
● Demo Parts
● Weighing scale
● Testing Software</td><td>Adjusted Test Limit:
Does not drop parts during movement 99.9% of the time.</td></tr>
</table>

Computations, (Include Analyses Results, if any):

Gripper Performance and Shape Requirement

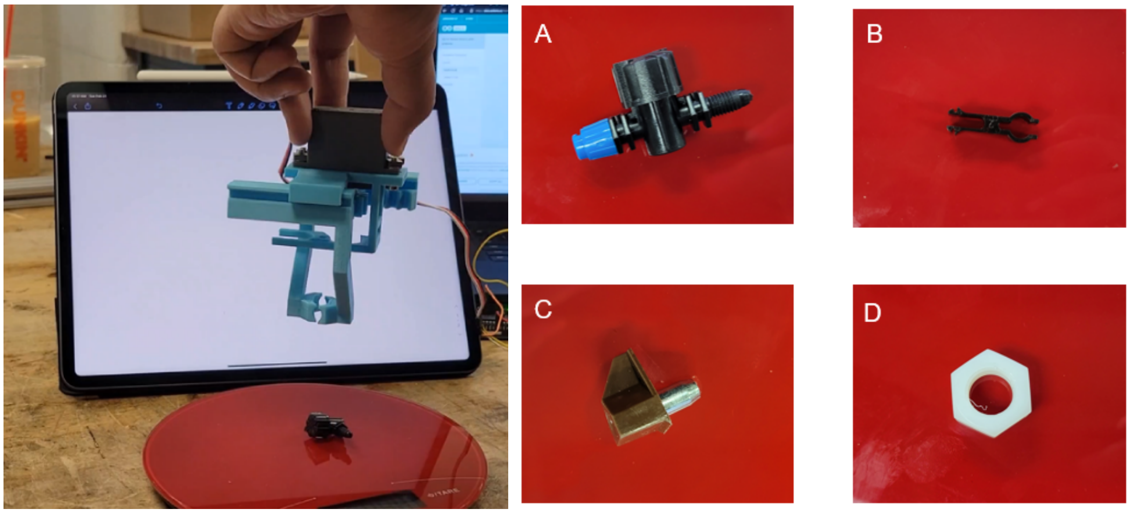


Figure: Gripper Performance Test and Parts

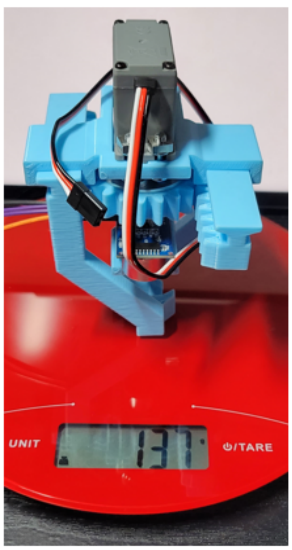
This requirement was validated by testing the gripper with four different parts and three different contact surfaces. The goal was to demonstrate the gripper's ability to grip and hold on to parts of different shapes and sizes. All the parts were in the 5 cubic centimeter threshold that we designed our system to work with. Once gripped, the gripper was shaken vigorously to test the friction of the material on the contact surface. The results are shown in the table below.

Trials	Part A			Part B		
	Silicon	Grip Tape	Bare Surface	Silicon	Grip Tape	Bare Surface
1	Pass	Pass	Pass	Pass	Pass	Pass
2	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Pass
5	Pass	Pass	Pass	Pass	Pass	Pass
6	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass
9	Pass	Pass	Pass	Pass	Pass	Pass
10	Pass	Pass	Pass	Pass	Pass	Pass

Trials	Part C			Part D		
	Silicon	Grip Tape	Bare Surface	Silicon	Grip Tape	Bare Surface
1	Pass	Pass	Pass	Pass	Pass	Pass
2	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Pass
5	Pass	Pass	Pass	Pass	Pass	Pass
6	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass
9	Pass	Pass	Pass	Pass	Pass	Pass
10	Pass	Pass	Pass	Pass	Pass	Pass

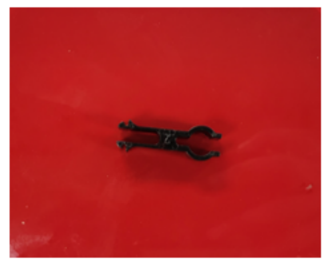
Figure: Gripper Performance Test Results

System Payload Requirement

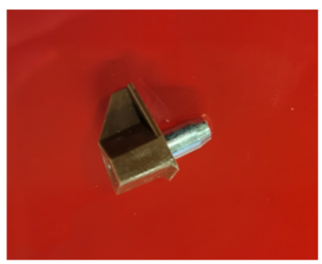


Gripper with Servo and Sensor: 137g

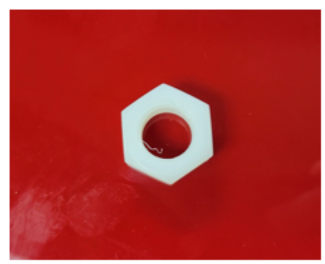
Part A: 2g



Part B: 2.5g



Part C: 1.8g



Part D: 1.8g

Figure: System Payload Test Results

The purpose of this test was to verify that the gripper along with its electrical components and while holding a part would not exceed the total payload capacity of the cartesian actuator. The actuator provided by the sponsor has a payload limit of 5000 g or 5 kg and from the results above, the system is well below that threshold.

Results:

High friction pads were added to the grippers contact point. Gripper sensor was removed from assembly as the failure percentage was insignificant.

Signatures:

Tester ____________Daniel Mack_______________________

Customer Brett Dooley

Acceptance Test Data Sheet			
5.3c: Cartesian Actuator Verification			
Unit(s) Under Test (UUT): Name: Cartesian Actuator, CtrlX Machine Controller Part number: 1050000, 1020100			
Results (Pass / Fail): Pass		**Date of Test:** 4/10/2023	
Recording of Test Measurement: • Motion Accuracy • Part Acquisition capability	**Requirement:** • Cartesian Actuator Position • Gripper Motion	**Test Equipment:** • CtrlX SFK Software	**Adjusted Test Limit:** • 1mm positioning accuracy • Does not drop parts during movement 99.9% of the time

Computations, (Include Analyses Results, if any):

The cartesian actuator was rigorously tested to examine its ability to translate camera pixel coordinates into real world millimeter coordinates. This was done by first computing a scaling factor from pixels to mm. Origin points for camera and CA were determined which were in turn used to determine offsets which resulted in proper positioning of gripper around parts. The formulas for calibrating the data conversion algorithm are shown below.

$$x_R = \left(\frac{p_x - p_r}{\lambda}\right) + x_r$$

x_R: *Robot x-coordinate* (*mm*)

p_x: *Camera x-coordinate* (*pixels*)

p_r: *Camera reference x-coordinate* (*pixels*)

x_r: *Robot reference x-coordinate* (*mm*)

λ: *Scaling Factor* $\left(\frac{pixels}{mm}\right)$

$$y_R = -\left(\frac{p_y - p_r}{\lambda}\right) + y_r$$

y_R: *Robot y-coordinate* (*mm*)

p_y: *Camera y-coordinate* (*pixels*)

p_r: *Camera reference y-coordinate* (*pixels*)

y_r: *Robot reference y-coordinate* (*mm*)

λ: *Scaling Factor* $\left(\frac{pixels}{mm}\right)$

$$\lambda = \frac{|p_1 - p_2|}{m}$$

λ: *Scaling Factor* $\left(\frac{pixels}{mm}\right)$

p_1: *Part* 1 *coordinate* (*pixels*)

p_2: *Part* 2 *coordinate* (*pixels*)

m: *Distance between parts* (*mm*)

Further testing was done to verify the velocity and acceleration of the CA to ensure gripper is not dropping part during motion.

Results:

The Cartesian Actuator can effectively position itself within 1mm of desired location. The Gripper did not drop a single part during motion in all of our tests.

Signatures:

Tester ____________Nafisul Khondaker_________________

Customer _________Brett Dooley_________

Acceptance Test Data Sheet			
5.3d: Camera Verification			
Unit(s) Under Test (UUT): Name: Part number: Cognex Camera 1010100 Camera Lens 1010200 Illuminator 1010300 Insight Explorer Software 1020200			
Results (Pass / Fail): Pass		**Date of Test:** 2/20/2023	
Recording of Test Measurement: ● Resolution ● Part Edge Detection ● Working Distance ● Focal Length	**Requirement:** ● Identification ● Resolution ● Communication ● Mounting ● Table Size	**Test Equipment:** ● CtrlX SFK Software ● Insight Explorer Software	**Adjusted Test Limit:** N/a

Description:	Model Number:	Accuracy:
• Cognex Camera	• IS-7802	• 1600 x 1200 pixels resolution.
• M12 Lens	• LM12-12-01	• 12mm focal length
• Illuminator/Ring LED	• ISLM-7000-WHI	• 4000K color temperature
• Compatible Laptop/Desktop PC	• N/a	• N/a
• Vertical stand for camera	• N/a	• N/a
• Various hardware parts	• N/a	• N/a
• Red Backdrop	• N/a	• N/a

Computations, (Include Analyses Results, if any):

Camera Software Test/Plan

Procedure

a. Mount lens on top of camera sensor.
b. Mount illuminator/ring LED around the camera lens.
c. Use a vertical metal stand with mounting points and mount camera at a vertical distance of 800mm above the table surface.
d. Profile and identify 5 different parts:
    - 2 parts white in color
    - 2 parts black in color
    - 1 part neither white or black in color
    - All must have acceptable dimensions
e. Place one variable part and one white part on the table.

f. Program camera to identify both parts.

g. Document results.

h. Place one white part and two black parts on the table.

i. Program camera to identify both parts.

j. Document results.

k. Place all the parts on the table.

l. Program camera to identify and provide coordinates for profiled parts.

Check coordinate accuracy by taking real time measurements with a ruler.

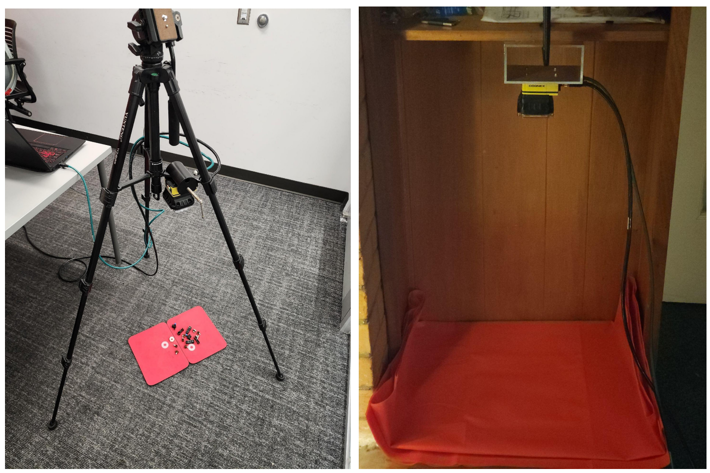


Figure: Camera Test Setup

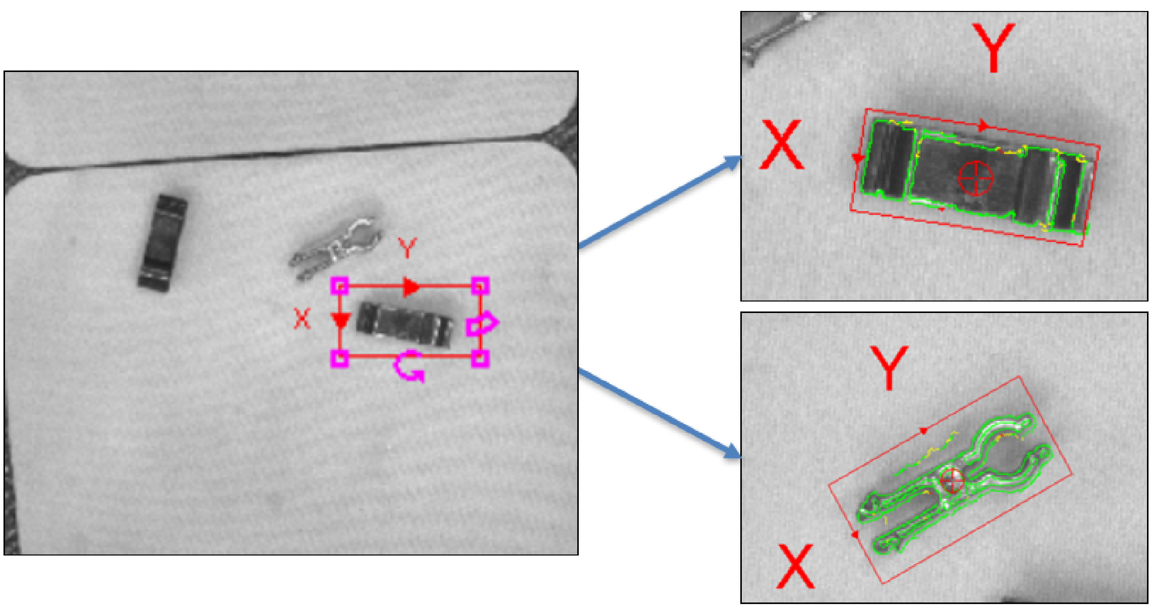


Figure: Profiling Parts with Camera

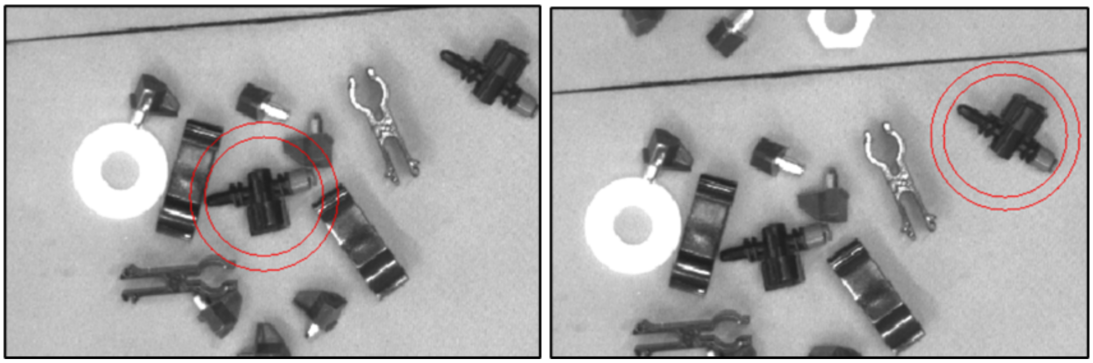
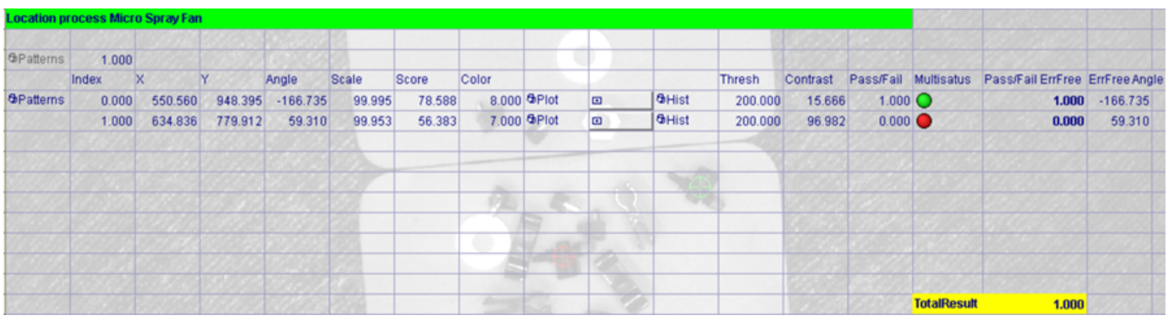


Figure: Software Boundary to Choose parts that do not have obstacles



Location process Micro Spray Fan																
Patterns	1.000															
	Index	X	Y	Angle	Scale	Score	Color				Thresh	Contrast	Pass/Fail	Multisatus	Pass/Fail ErrFree	ErrFree Angle
Patterns	0.000	550.560	948.395	-166.735	99.995	78.588	8.000	Plot		Hist	200.000	15.666	1.000		**1.000**	-166.735
	1.000	634.836	779.912	59.310	99.953	56.383	7.000	Plot		Hist	200.000	96.982	0.000		**0.000**	59.310
														TotalResult	**1.000**	

Figure: Screenshot of Insight Explorer Spreadsheet Interface

This is a table from the Insight software which provides part information for the objects that were profiled. The table contains a column for X and Y coordinates of the parts that we performed tests with. The coordinates seen in the sheet represent the data that is relevant for communication with the CtrlX machine controller. Another important set of information that can be seen is the score column which provides a metric for the camera's ability to identify the part that was originally profiled in that particular image. The pass/fail column is determined by a software boundary protocol that was designed to create a boundary around parts so that we can program the camera to trigger table vibrations when parts are in too close proximity to one another.

The communication protocol between the camera and the CA was chosen to be OPC UA which is based on TCP/IP Communication. This was tested by sending multiple messages

to the CA from the camera and evaluating and adjusting for message delays. Digital I/O communication was also set between camera and robot for automatic triggering. Results: Camera and robot can automatically set up communication and interpret instructions without user intervention. Robot is capable of triggering the camera whenever a new image is needed.
Signatures: Tester ___________Anthony Phillips________________ Customer ________Brett Dooley________________

Acceptance Test Data Sheet			
5.3e: Vibratory Table Verification			
Unit(s) Under Test (UUT): Name: Part number: Vibratory Assembly 1060000 Rubber Bushings FM-22621-A Compression Springs 9657K515 Vibratory motor 3650			
Results (Pass / Fail): Pass		**Date of Test:** 2/25/2023	
Recording of Test Measurement: ● Vibration Capability ● Digital Control	**Requirement:** ● Effectiveness ● Table Size ● Table Boundary	**Test Equipment:** ● CtrlX Machine Controller ● Demo parts ● Measuring Tape	**Adjusted Test Limit:** ● Can successfully disperse up to 40 individual parts

Computations, (Include Analyses Results, if any):

Vibratory table size was tested and determined based on part capacity and frame real-estate as well as camera FOV

Vibratory table effectiveness as tested by placing multiple parts on top of table surface and using a regulator to vibrate motor and determine optimum motor speed to effectively disperse up to 40 different parts.

Simultaneously, the table's ability to provide a boundary to retain parts was also tested with inclination of side panels was set at 45 degrees.

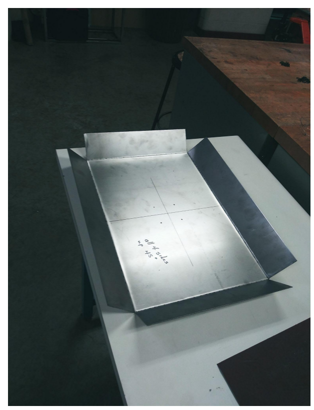


Figure: Height of Table *FIgure: Bent Full View*

Vibratory motor communication was tested by sending digital pulses from the controller and determining its ability to operate the table automatically.

Results:

All functionality of the vibratory table has been successfully verified. Cardboard has been attached to the surface to make it level and flat and cover mounting screws. Table surface painted red to aid in part detection by camera.

Signatures:

Tester ____________Esmeralda Pimentel Enriquez________

Customer ____________Brett Dooley____________

Acceptance Test Data Sheet			
5.3f: Emergency Stop Verification			
Unit(s) Under Test (UUT): Name: CtrlX Machine Controller Part number: 1020100			
Results (Pass / Fail): Pass		**Date of Test:** 3/30/2023	
Recording of Test Measurement: ● Ability to stop actuator in motion ● Ability to cut power to high voltage	**Requirement:** ● Emergency Stop	**Test Equipment:** ● CtrlX Machine Controller ● Digital Multimeter	**Adjusted Test Limit:** ● N/a

Computations, (Include Analyses Results, if any):

Emergency Stop Requirement

Figure: Emergency Stop Button

An emergency stop circuit is implemented into the system design as a crucial safety feature for an industrial application. This button serves as a fail-safe mechanism to immediately stop the operation of the system in the event of an emergency. The CtrlX core as seen in the left figure above features a safety port which provides safety logic in its hardware. Parameters such as the worst case stopping time for moving axes are configurable through programming. The port provides safe torque off (STO) functionality which ensures that no torque can act on the actuators by blocking off incoming electrical signals. The STO function requires manual reset so that the system cannot be accidentally started again after the emergency stop button is pressed.

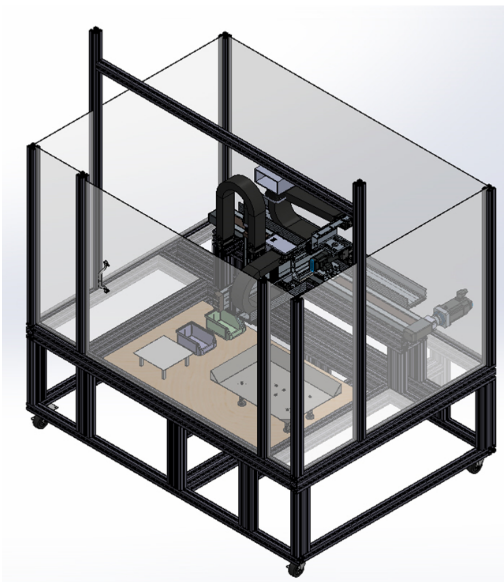
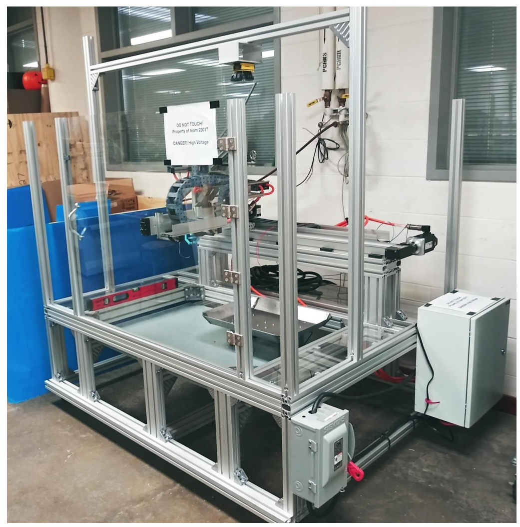
The emergency stop button has a simple circuit design, requiring wiring between two of the safety pins and the normally closed (N.C.) contacts of the button. This means that the circuit will be opened when the button is pressed, sending a signal for emergency shutoff of the system to the built in hardware contained within the CtrlX core.

Results: The E-stop button can effectively stop the robot and prevent any further operation until it is unlocked and errors are reset. Electrical disconnect switch can cut all high voltage power to system when necessary.
Signatures: Tester ____________Kevin Gilman______________________ Customer Brett Dooley

<table>
<tr><td colspan="4">Acceptance Test Data Sheet</td></tr>
<tr><td colspan="4">5.3g: Frame Verification</td></tr>
<tr><td colspan="4">Unit(s) Under Test (UUT):
Name: Frame Assembly
Part number: 1030000</td></tr>
<tr><td colspan="2">Results (Pass / Fail): Pass</td><td colspan="2">Date of Test: 2/30/2023</td></tr>
<tr><td>Recording of Test Measurement:
● Ability to keep all hazardous components from external interference</td><td>Requirement:
● Frame Size
● Frame Materials
● Isolation</td><td>Test Equipment:
● N/a</td><td>Adjusted Test Limit:
● N/a</td></tr>
</table>

Computations, (Include Analyses Results, if any)

The system frame was designed with the position of all components in mind. Every part of the frame is made of aluminum except for the acrylic walls and wood platform for the vibratory table. The frame was tested to position the vibratory table within the camera FOV as well as in range for the cartesian actuator.

Results:

The system frame can successfully house all electrical mechanical components safely. Every component is mounted with millimeter precision and there is no inference between the moving parts

Signatures:

Tester ___________Esmeralda Pimentel Enriquez______

Customer _________Brett Dooley_________

6.0 Final Budget

	After Tax		Before Tax		Tax	Delivery Status	Date Delivered
PO 1	**Home Depot 1**	**12.7**		11.68	1.02	Delivered	11/22/2022
			Tube Clips	2.28			
			Microsprays	2.97			
			washers	1.25			
			Hex Nut	1.25			
			Steel Pins	3.93			
PO 2	**Amazon 1**	**61.59**		56.66	4.93	Delivered	12/13/2023
			Red Backdrop	12.97			
			Motor	43.69			
PO 3	**Go Bilda**	**51.7**		45.15	6.55	Delivered	01/11/2023
			Washers	1.99			
			Hex L-key	2.49			
			M4 Screws	3.69			
			Plates	4.99			
			servo	31.99			
PO 4	**Pacific Integrated**	**1915.51**		1382.49	533.02	Delivered	02/27/2023
			Base	1382.49	117.51		
PO 5	**Amazon 2**	**378.98**		348.65	30.33	Delivered	02/09/2023
			Cable 45	165.77			
			Plug	14.5			
			NEMA Enc	96.96			
			Relay	7.49			
			12 Gauge x2	25.96			
			Arduino NANO	24.99			
			Voltage Buck	12.98			
PO 6	**Home Depot 2**	**97.18**		89.4	7.78	Delivered	02/14/2023
			Disconnect	89.4			
PO 7	**Amazon 3**	**13.03**		11.99	1.04	Delivered	02/21/2023
			Bushings	11.99			
PO 8	**McMaster 1**	**26.26**		24.97	1.29	Delivered	02/15/2023

			Compression Springs	14.87			
			Shipping	10.1			
PO 9	**AutomationDirect**	**47.5**		44.5	3	Delivered	02/09/2023
			EMERG Stop	34.5			
			Shipping	10			
PO 10	**Amazon 4**	**92.2**		84.82	7.38	Delivered	02/27/2023
			25 ft Power Strip	22.99			
			Wire Stripper	22.99			
			Ring terminals	7.99			
			22 gauge wire	12.58			
			0.5ft CAT6 Ethernet	4.28			
			Zip ties	13.99			
PO 11	**McMaster 2**	**30.49**		28.82	1.67	Delivered	02/27/2023
			M5x0.8mm (18mm length) bolts	11.59			
			M5x0.8mm nuts	3.56			
			M5 washers	4			
			Shipping	9.67			
PO 12	**Amazon 5**	**10.86**		9.99	0.87	Delivered	02/27/2023
			M6 T nuts	9.99			
PO 13	**McMaster 3**	**10.27**		8	2.27	Delivered	02/27/2023
			M6 Bolts	8			
PO 14	**McMaster 4**	**20.18**		19.34	0.84	Delivered	03/13/2023
			M6 Bolts	9.67			
			Shipping	9.67			
PO 15	**McMaster 5**	**103.62**		95.39	8.23	Delivered	03/15/2023
			M6 screws	11.46			
			phillip screws	13.44			
			T-slot fasteners	60			
			shipping	10.49			
PO 16	**Home depot 4**	**37.91**		34.91	3	Delivered	03/15/2023
			Ply wood	34.91			
PO 17	**Amazon 6**	**63.98**		58.86	5.12	Delivered	04/04/2023
			Red Vinyl	9.9			
			Laser range system	13.99			

			22 gauge wire	19.98			
			Start/Stop button	14.99			
PO 18	**Amazon 7**	**31.93**		29.38	2.55	Delivered	04/03/2023
			24V LED	21.99			
			5V Relay	7.39			
PO 19	**Home Depot 5**	**99.87**		91.88	7.99	Delivered	04/20/2023
			EZ Plug	10.05			
			Nylon Spacer	11.25			
			MSH-2pk	17.82			
			Multimeter	52.76			
PO 20	**Home Depot 6**	**44.99**		41.28	3.71	Delivered	04/28/2023
			3/4 bushing	3.45			
			flag emitter	10.47			
			40PK screws	14.8			
			Magnet Block	12.56			
			1/2 bushing	1.42			
PO 21	**UOFA motor pool**	**240**		240	0	Delivered	04/11/2023
			Truck rental	240			
PO_Out of Pocket 1	**Home Depot 7**	**25.38**		23.36	2.02	Delivered	02/10/2023
			Washers, nuts & bolts	23.36			
PO_Out of Pocket 2	**Industrial Metal Supply**	**39.54**		37.27	2.27	Delivered	02/10/2023
			Vibratory Table & Triangles Material	37.27			
Shirts	**UA**	**243.49**		243.49		Delivered	02/14/2023
			Shirts	243.49			
Poster	**UA**	**125**		125		Delivered	
			Poster	125			
	Total	3824.16	Total Before	3187.99			
	Total Budget	4000	Remaining	175.84			

The team allocated a total of $3,824.16 toward various components required for the construction of the project.

The frame assembly, which serves as the foundation of the project, was acquired at a discounted price of $1,500 from $2760, with an additional cost of $415.51 for shipping. The Team invested a total of $1,915.51 towards the frame.

The team has also spent $108.7 toward the gripper system. This cost includes expenses related to the motor and its assembly, sensors such as laser and ultrasound, and an Arduino. It didn't count for the 3d printing because it was done for free through the team’s connections.

The team allocated $728.57 towards electrical components, including wiring, a NEMA enclosure, emergency stops, and a disconnect to ensure safe and efficient power distribution.

Additionally, the team has invested $199.48 towards the construction of the vibe table, which includes a motor, a wooden base, compression springs, bushing, and the metal required to build the table.

Finally, the team has spent $871.8 on miscellaneous purchases, including screws, bolts, items for the gripper to pick up, the poster, and the shirts.

The project has received parts from the sponsor who contributed a smart function kit worth $40,000, as well as a camera system and illuminator valued at $13,100. These contributions, amounting to a total of $53,100, were not included in the budget breakdown.

The team finished the project while being within budget and only $175 remained from the allocated $4000 that was given on the start of this project.

7.0 Project Retrospective (lessons learned)

There were several challenges that the team faced throughout the entirety of the project. One of which was the unexpected delay of the system frame. Its multiple redesigns and incorrect shipping location hindered its delivery. This delay had a significant impact on the project's timeline. Without a frame, the project wouldn't be able to get off the ground. It shortened the time available for testing and integration. The team had to work efficiently to meet deadlines, which was a valuable lesson in time management. The experience highlighted how important it is to prepare for worst-case scenarios and have backup plans. To have clear communication with all parties and work together to achieve our goals.

Another challenge faced was the exclusivity of the cartesian actuator. Since it was delivered from Germany and the software was a brand new product line in the United States, there was a limit on accessible information. German forums were continuously used to get any additional insight for the CA. This helped debug some issues the team had with the CA. This limited access brought new challenges but also presented new opportunities for the team to learn and grow.

Hidden expenses were an unforeseen surprise. In ordering the frame its shipping cost was not accounted for, and so it limited our remaining budget by half. Although the team was able to get all the items required to have a working system, it did put a damper on any future expenses. This made clear the importance of having a correct understanding of shipping costs and taxes.

Finally, during testing, the team realized that the complexity of the vibratory table was underestimated. This ended up resulting in high error rates (8%-12%) for the system in each iteration and required a full week of testing to find a viable mitigation strategy within the remaining time frame. However, the team was able to recover and had brought down the system error rates to under 1% which satisfied our system requirements.

In summary, this project faced multiple challenges, including delays, changes in design, accessible information, and costs. However, we learned the importance of time management, effective communication, critical thinking, and planning. We will surely benefit from these lessons as we move forward in our engineering careers.

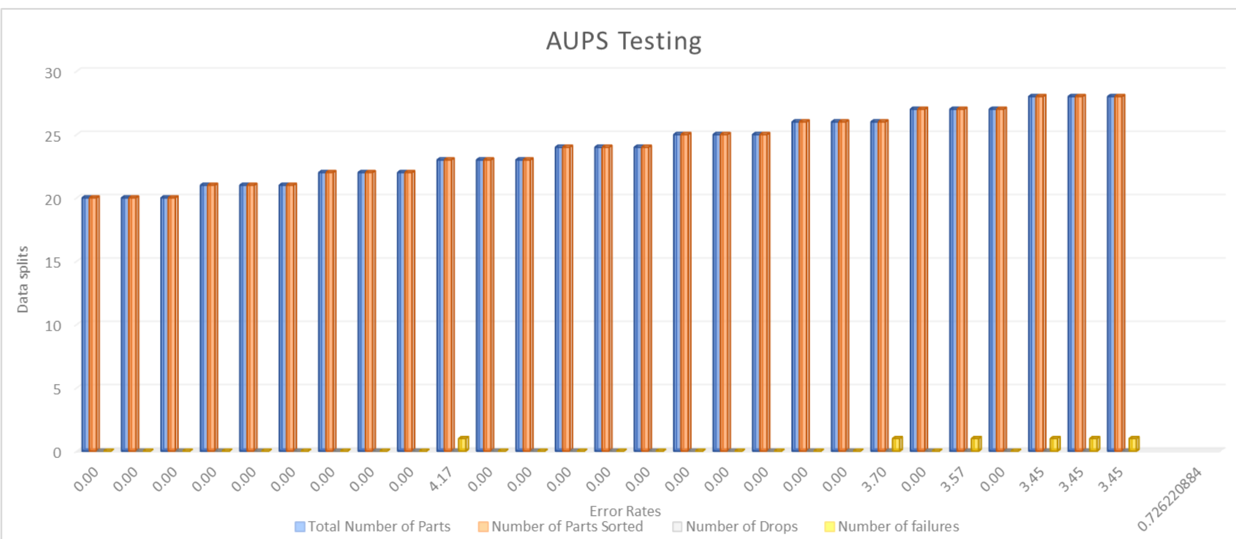
8.0 Conclusion & Recommended Next Steps

8.1 Conclusion

Overall, every single sponsor requirement was met. Through a collaborative effort, the team was able to achieve our project objectives and integrate various subsystems to create a functional automated system. This project required a lot of planning, research, and testing to ensure that the system design met the project requirements and specifications.

The team faced several challenges during the design and construction phase, including delays in communication, software implementation, system complexities, and integration of all the components into a cohesive and reliable final product. However, with perseverance and teamwork, the team was able to overcome these challenges.

Ultimately, this engineering project was a great learning experience, and the team is proud of the end result. The team evaluated the performance of the final system between a range of different parts. The average error rate for the overall system was 0.73%. Even though this was not a sponsor requirement, it demonstrated the capabilities of the fully integrated system.



8.2 Recommended Next Steps

Even though the team successfully completed all sponsor requirements, there are some parts that can be improved to increase longevity.

The final vibratory table surface was made using cardboard, both due to procurement and time constraints. A more permanent solution would be to use a metal plate welded on top of the screws and hammered into the desired concave shape. The vibratory motor was powerful enough to handle all the parts that were demonstrated, but for larger/heavier parts a motor that is 50% more powerful would be recommended.

The frame was designed with no ambient light protection for the camera. The team already required a discount from the frame manufacturer to stay within budget and any further improvements would require more funding. This can be an issue in locations where ambient lighting is not consistent. Therefore a frame and mounting mechanism that provided a better lighting mechanism for the camera would be recommended.

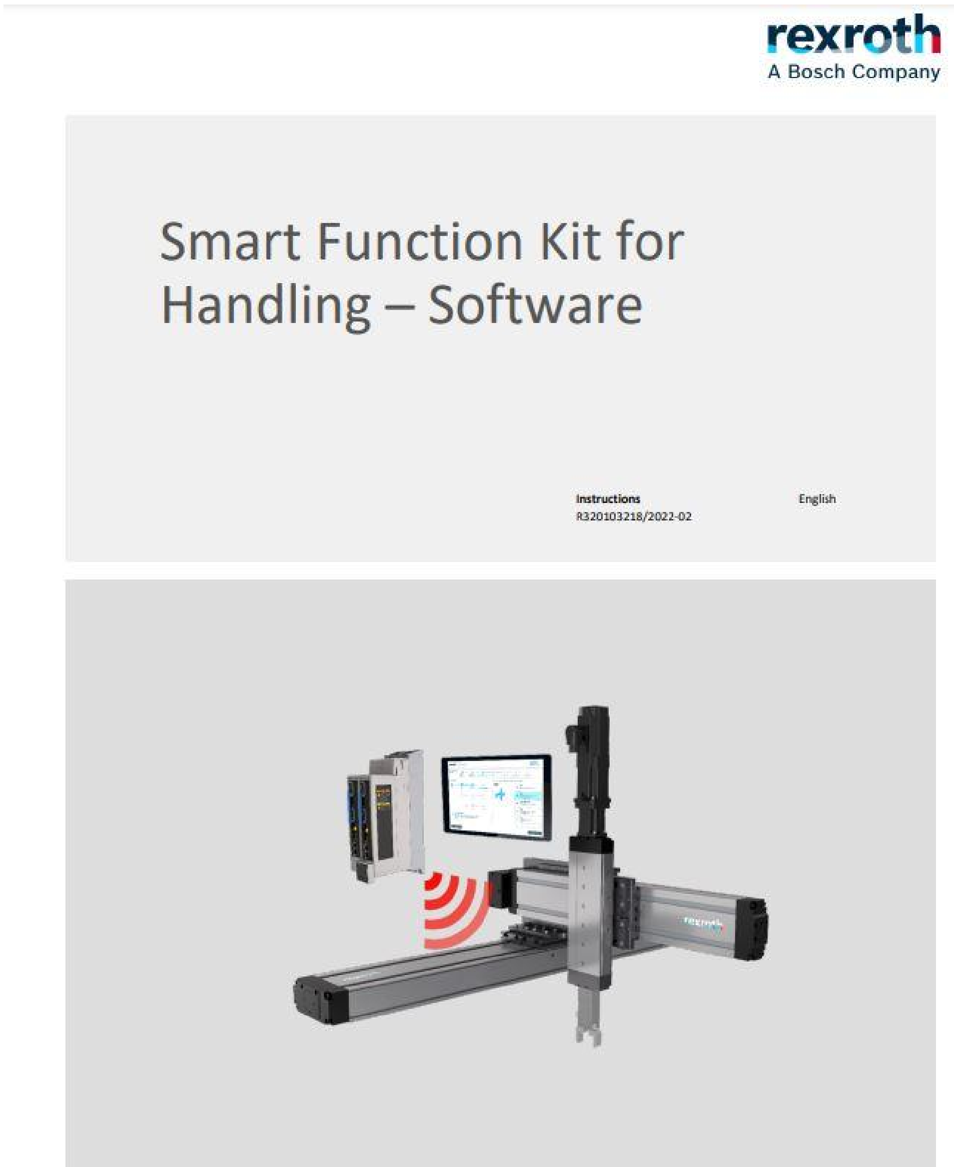
9.0 Appendix

Appendix A: CA Manual

Note: Hard copy provided by sponsor

Appendix B: Software Manual

Note: Sponsor provided



rexroth
A Bosch Company

Smart Function Kit for Handling – Software

Instructions
R320103218/2022-02

English

Figure: Software Manual SFK4H_EN_V2.0

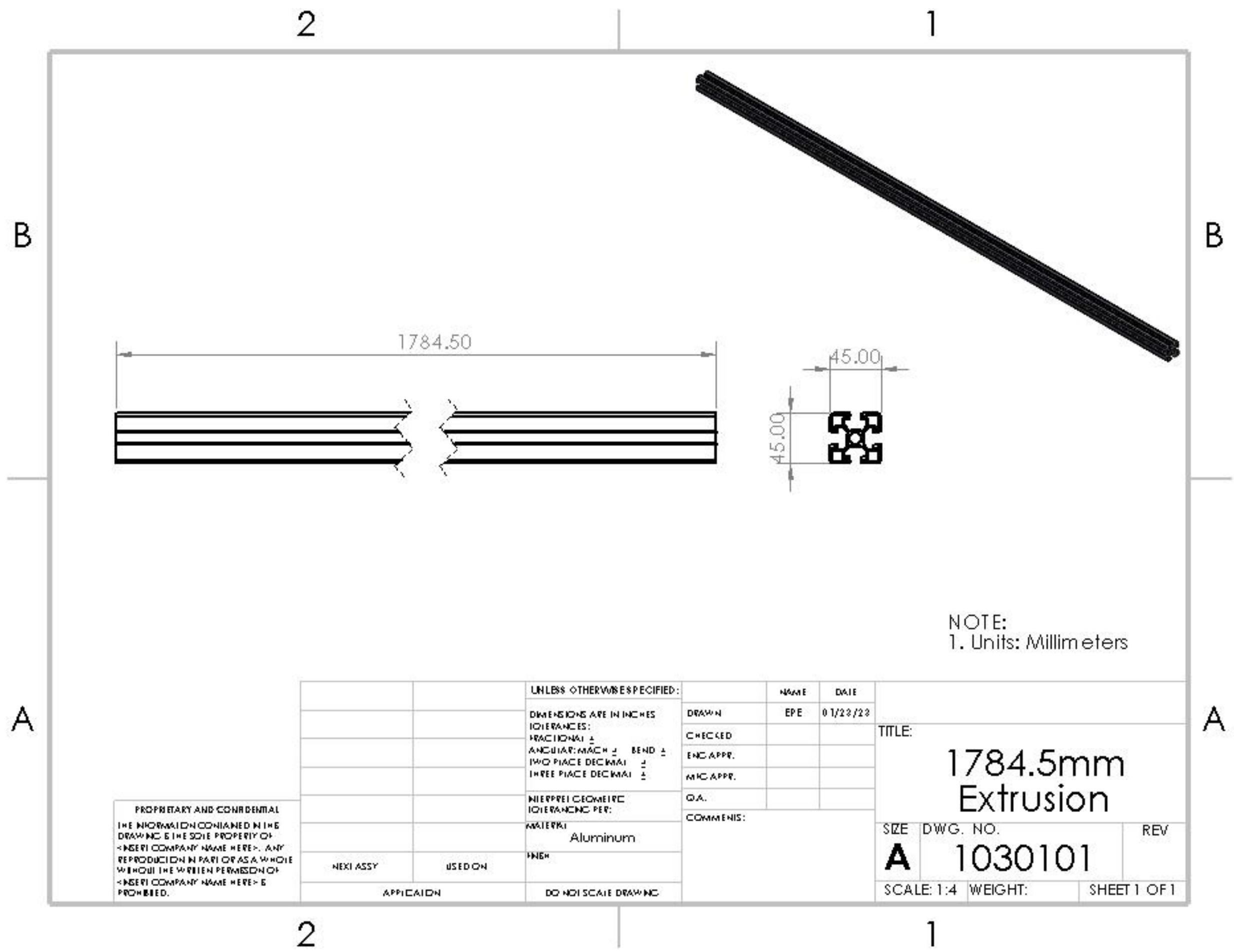
Appendix C: Cognex Manual

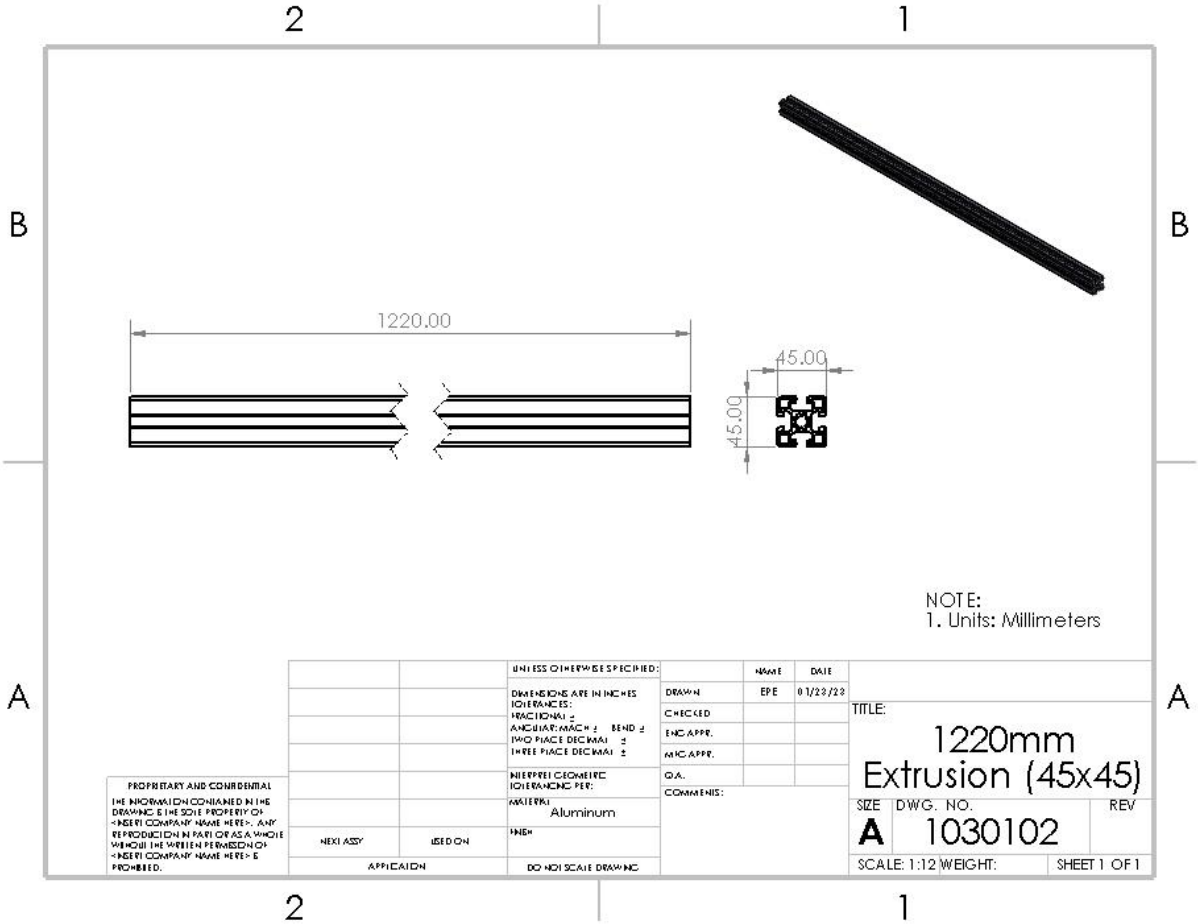
Note: Provided link
https://drive.google.com/file/d/1RKUq5q61jq-fwGyF2AxXRCTzLFEzOl1I/view?usp=share_link

Figure: Cognex Manual

Appendix D: Part Drawings

Frame Part Drawings:





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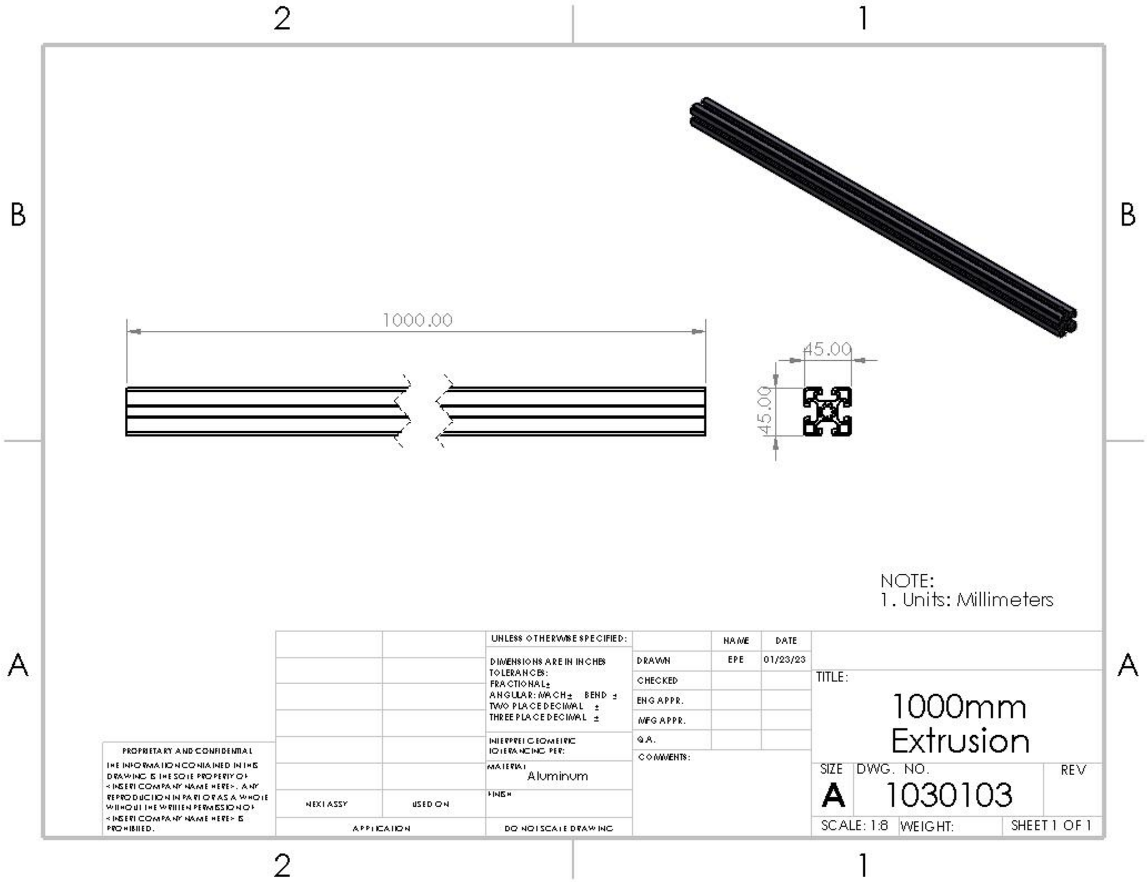
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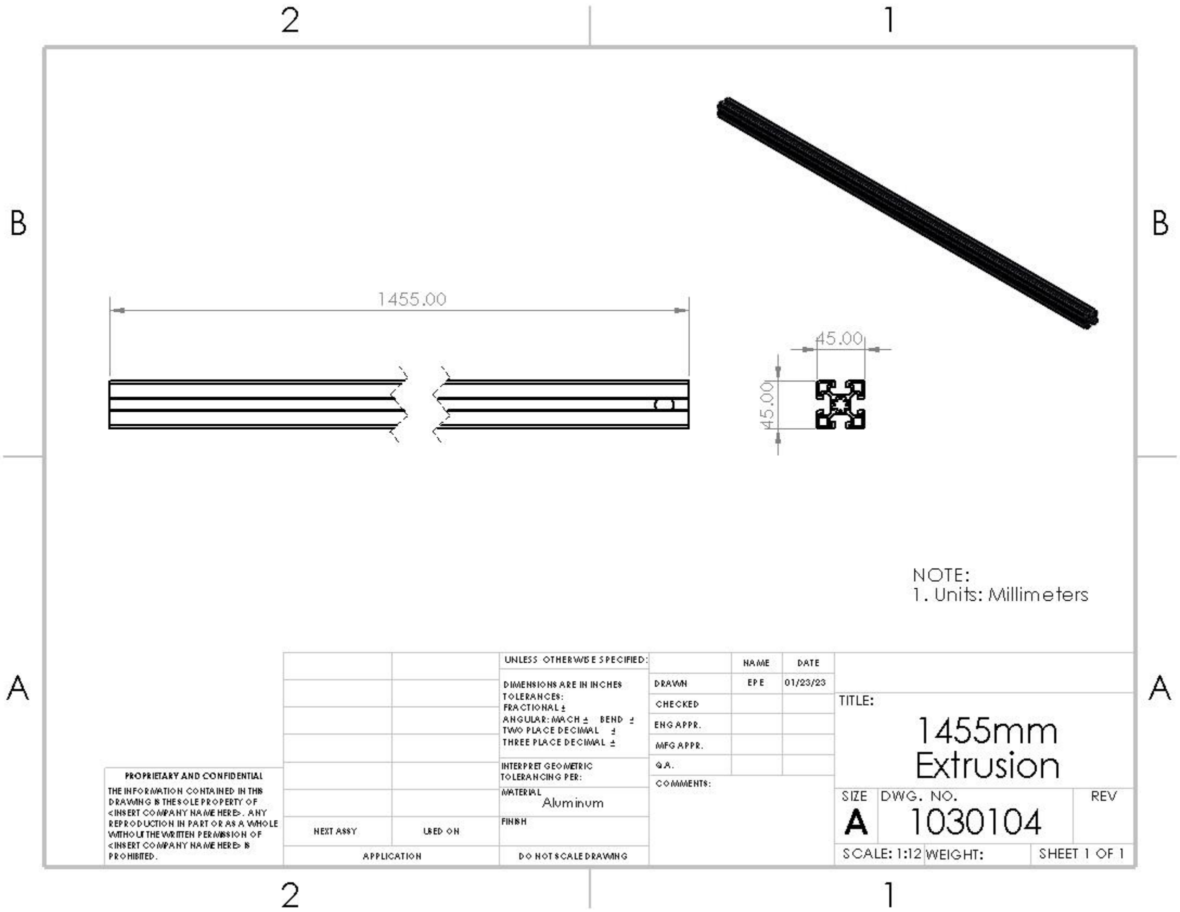
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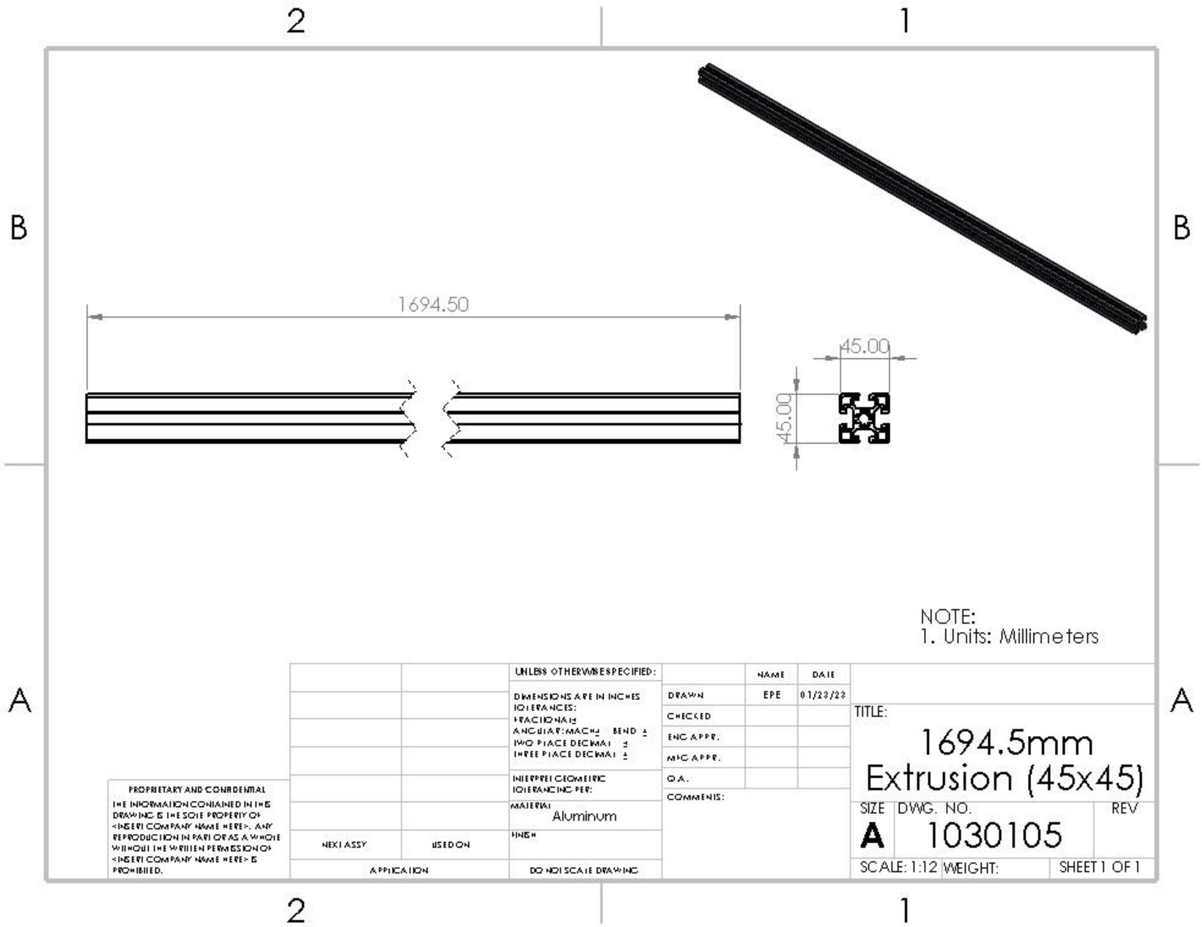
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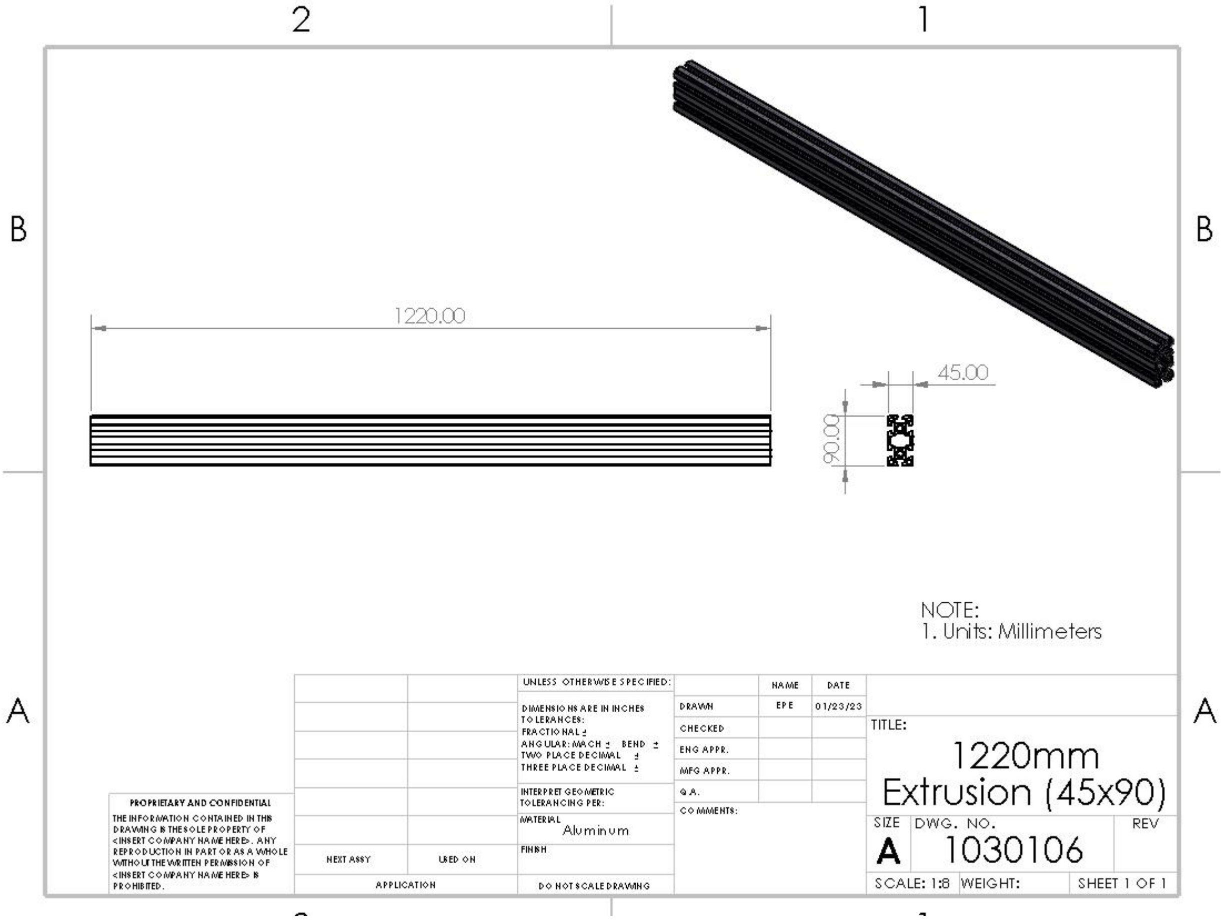
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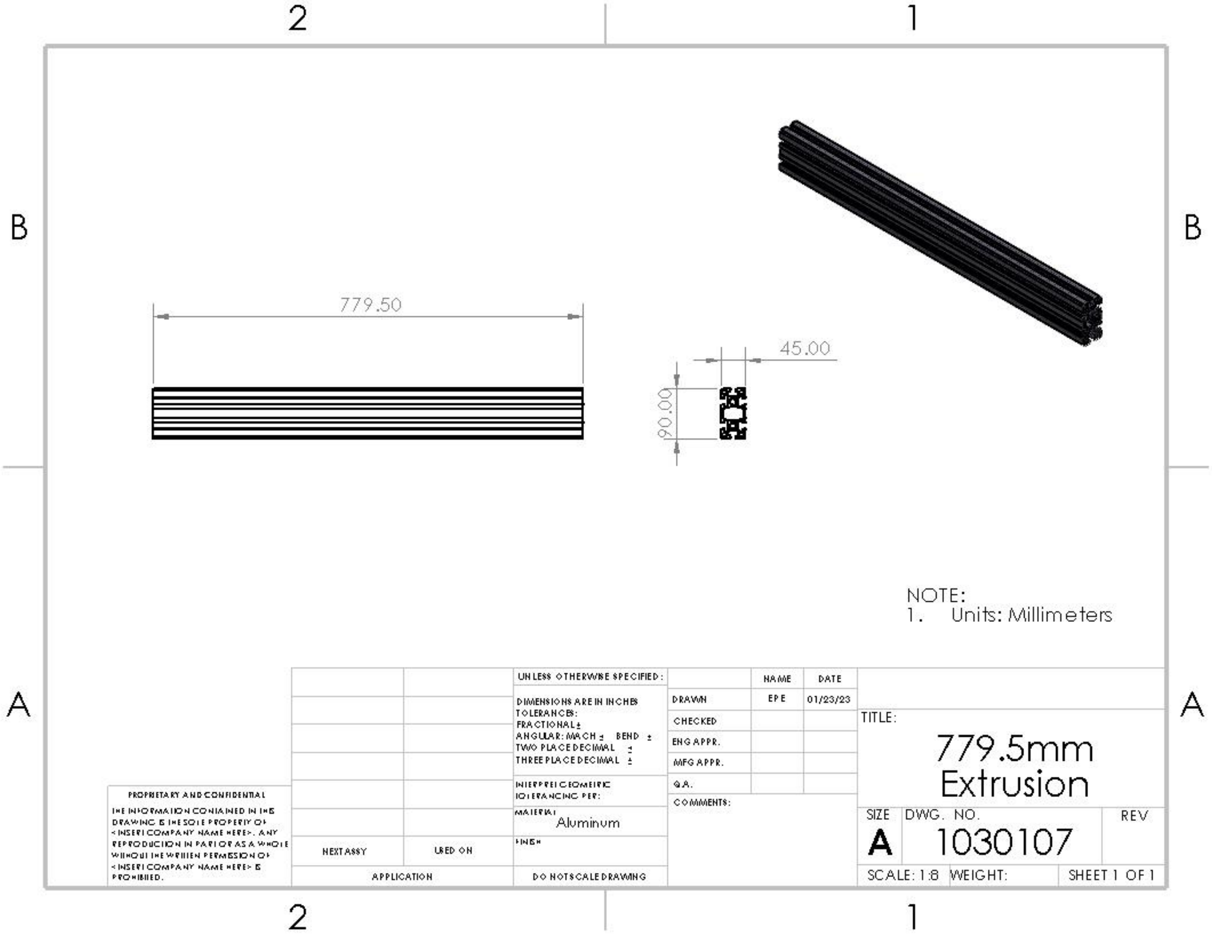
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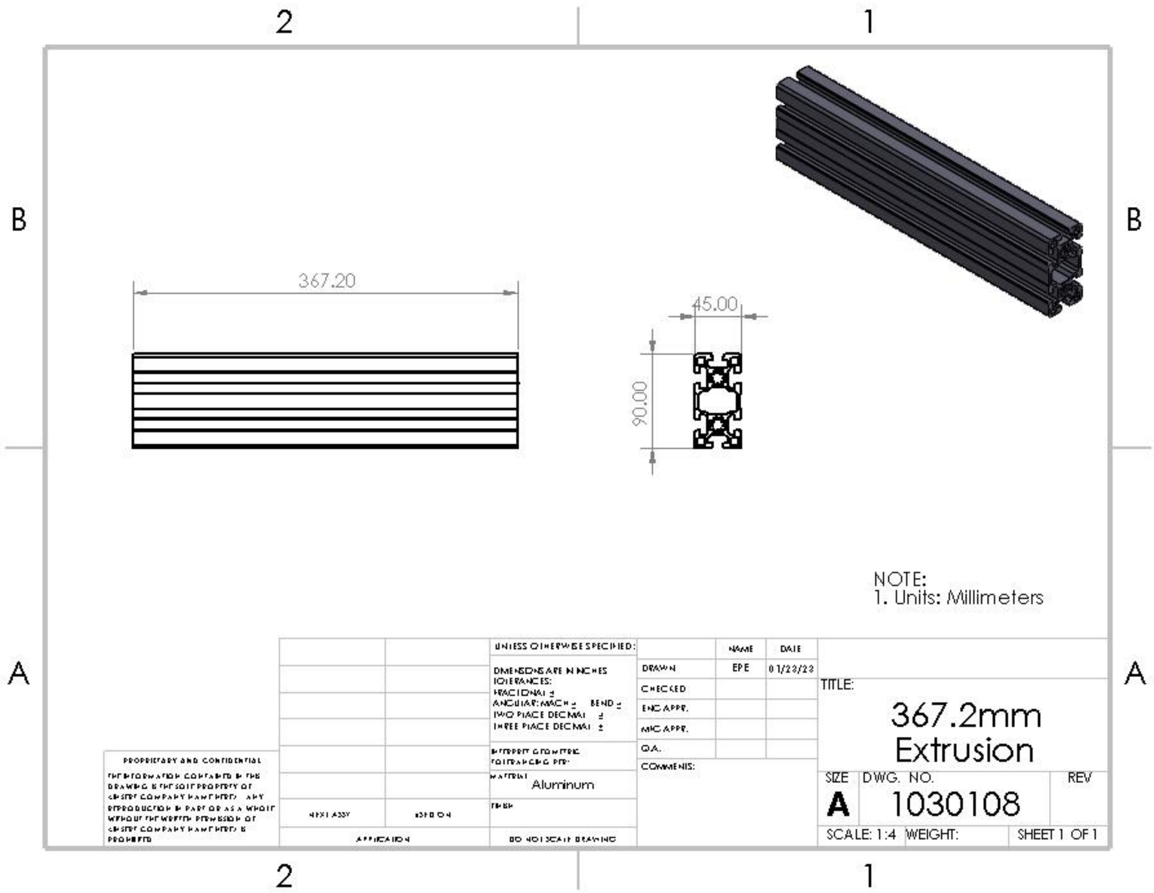
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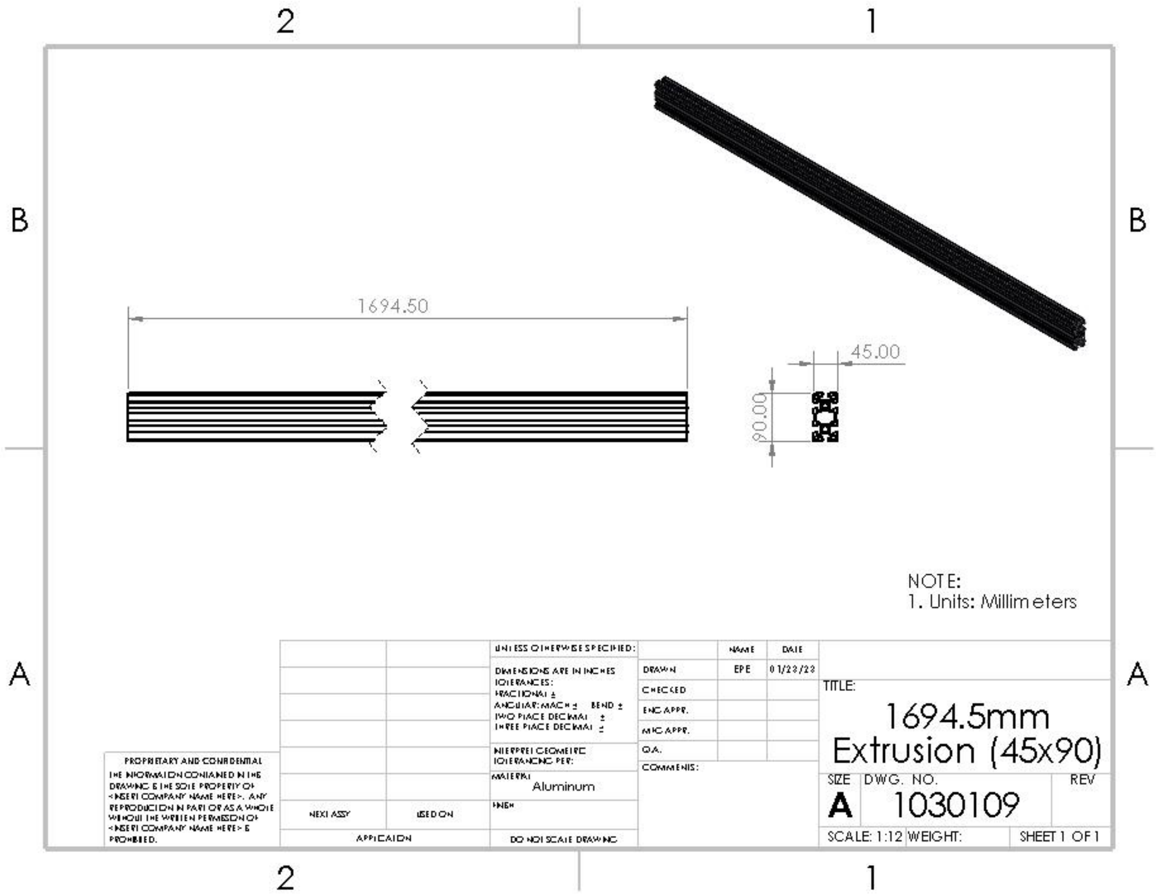
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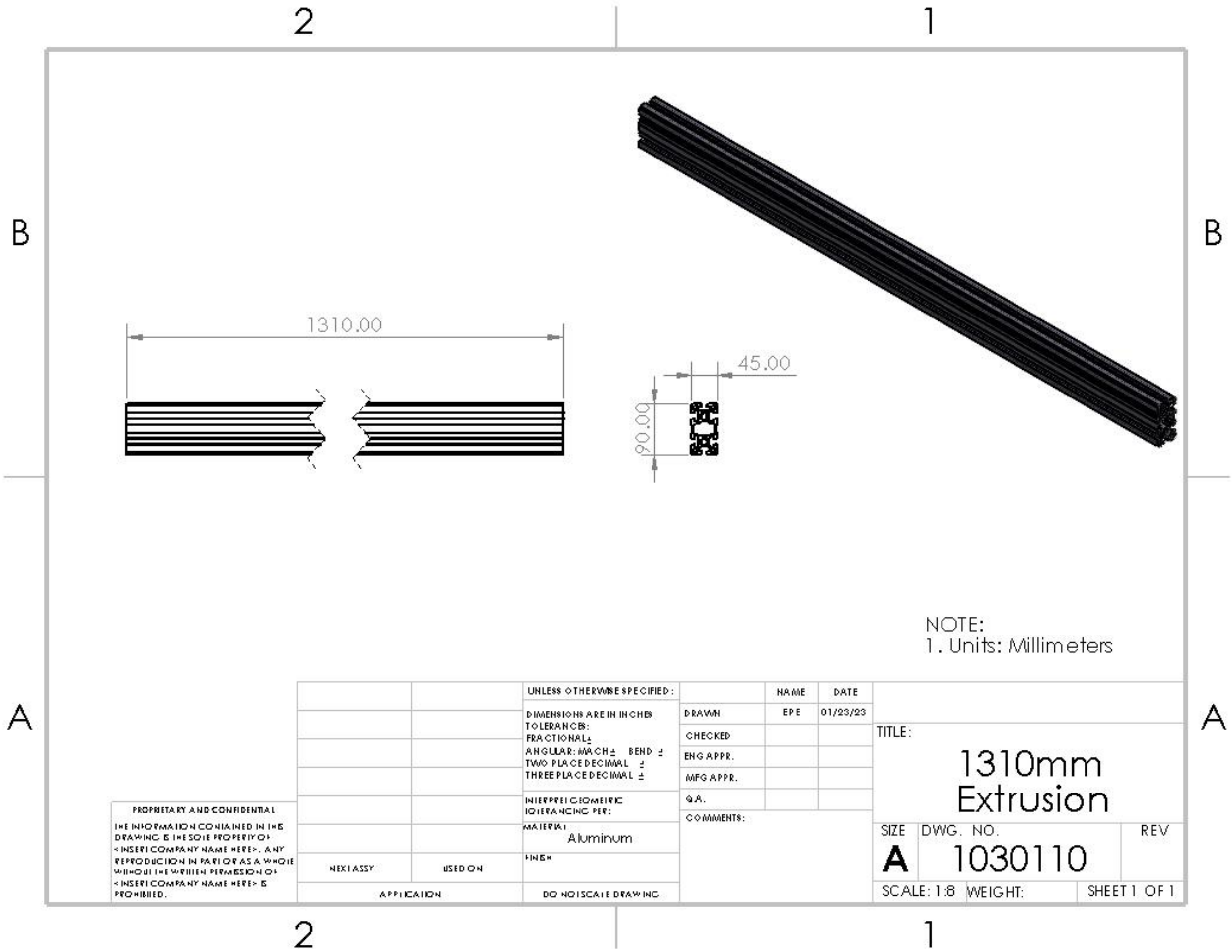

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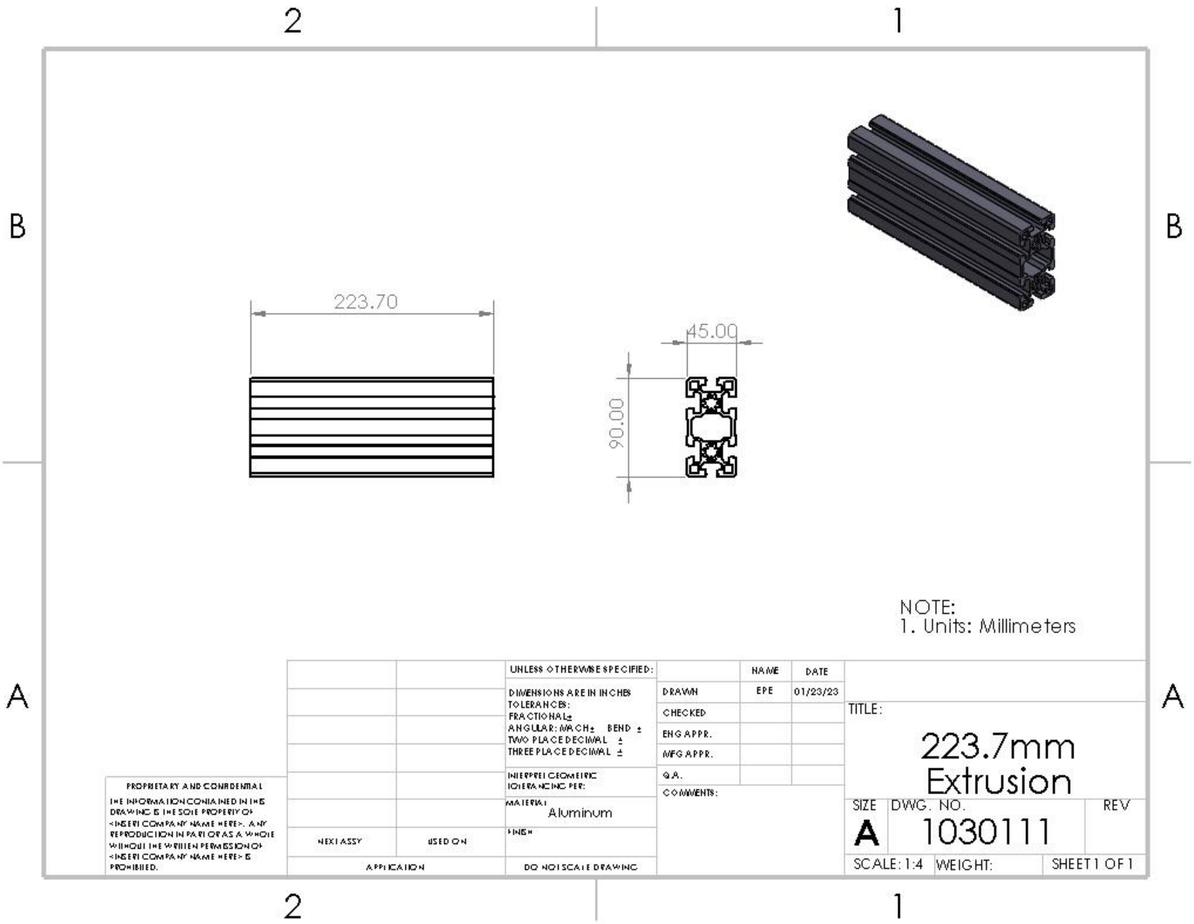
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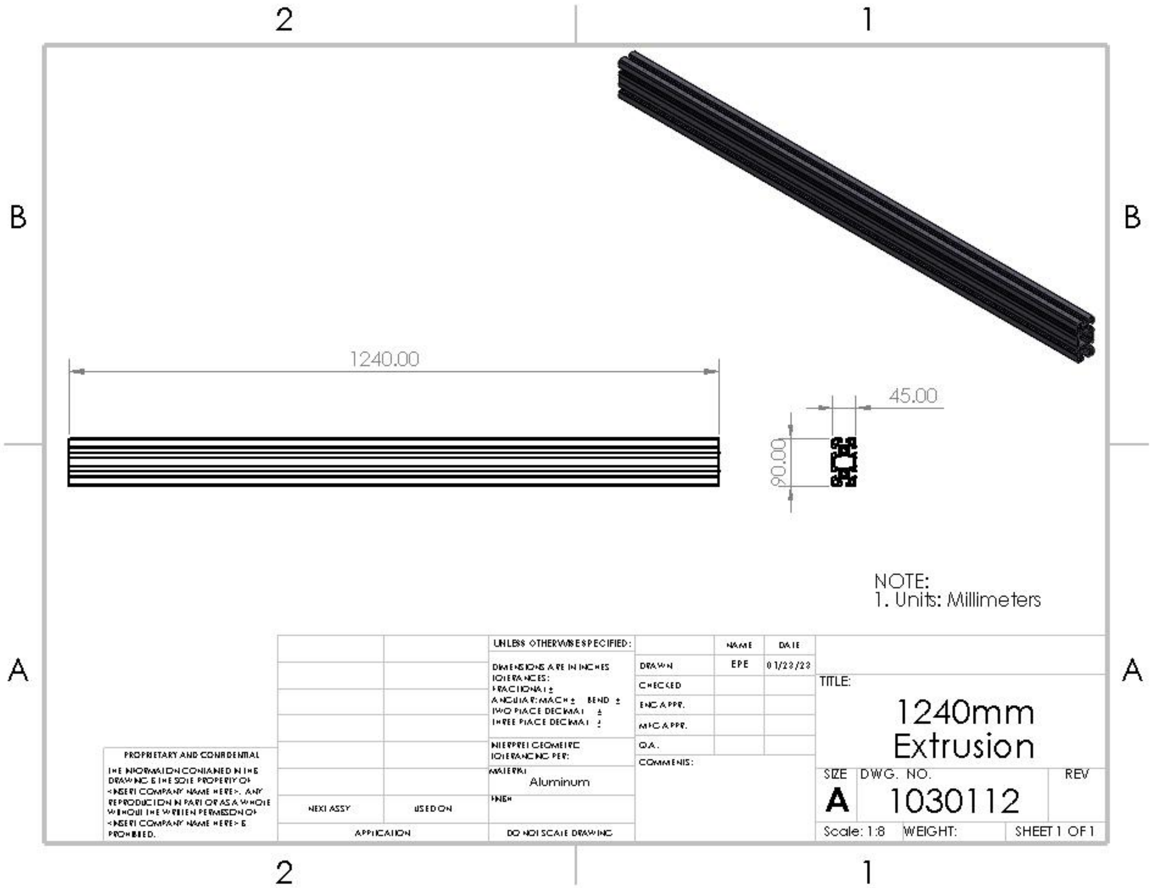

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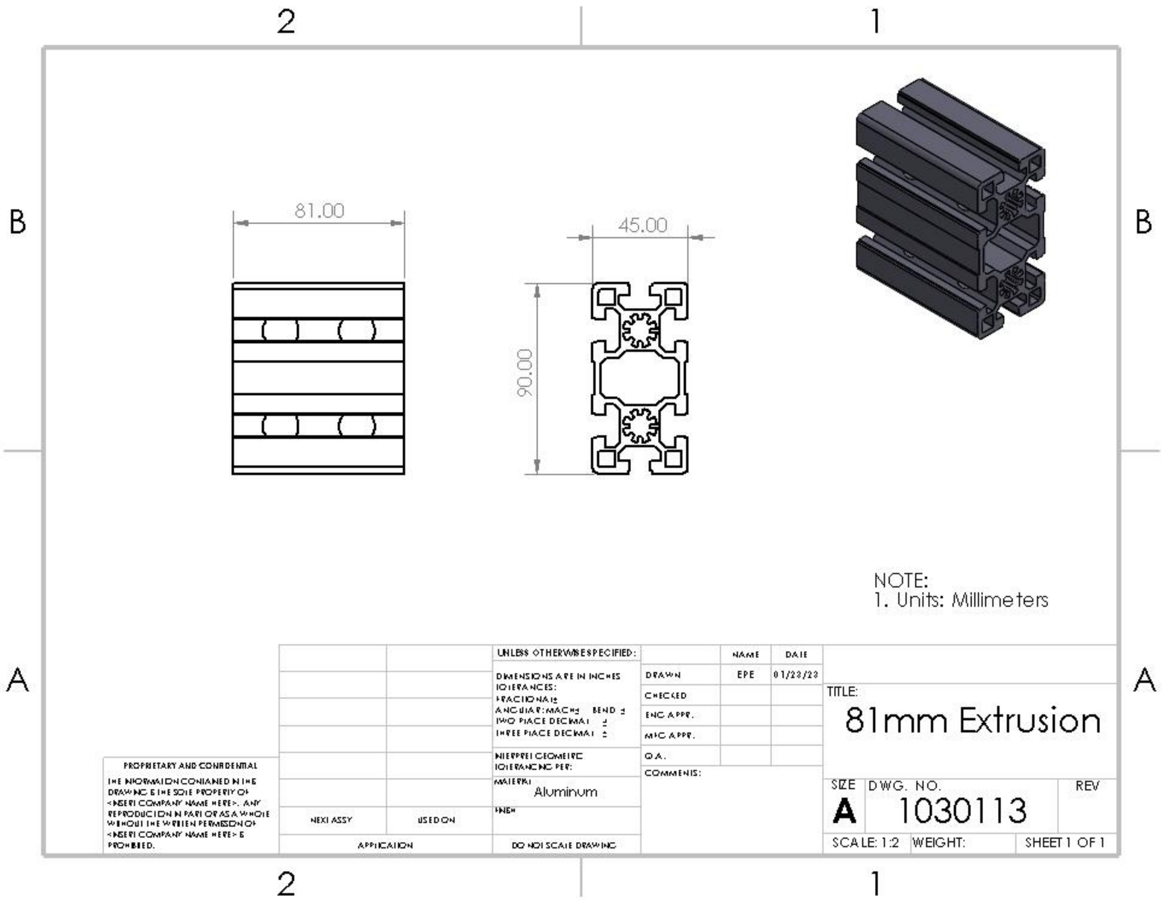
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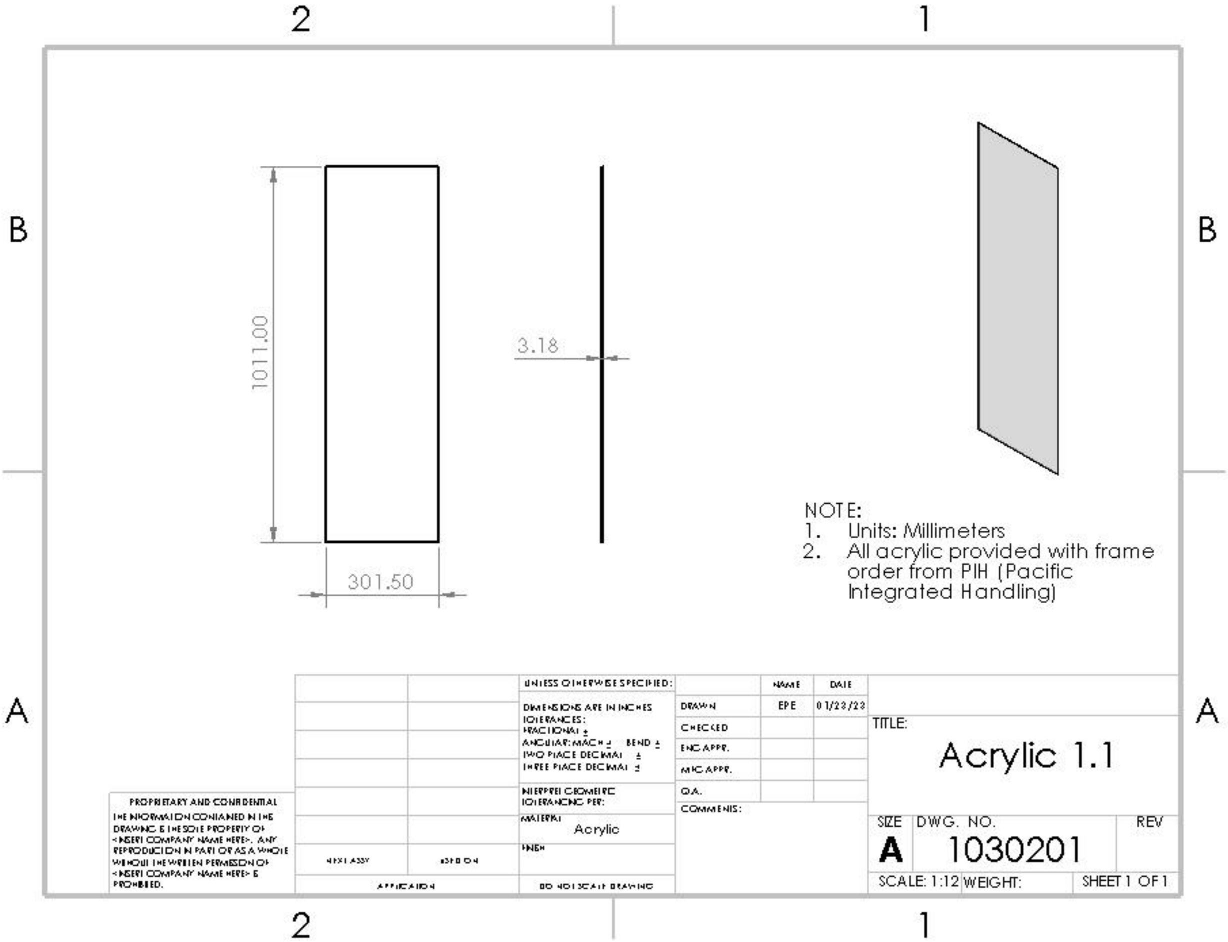

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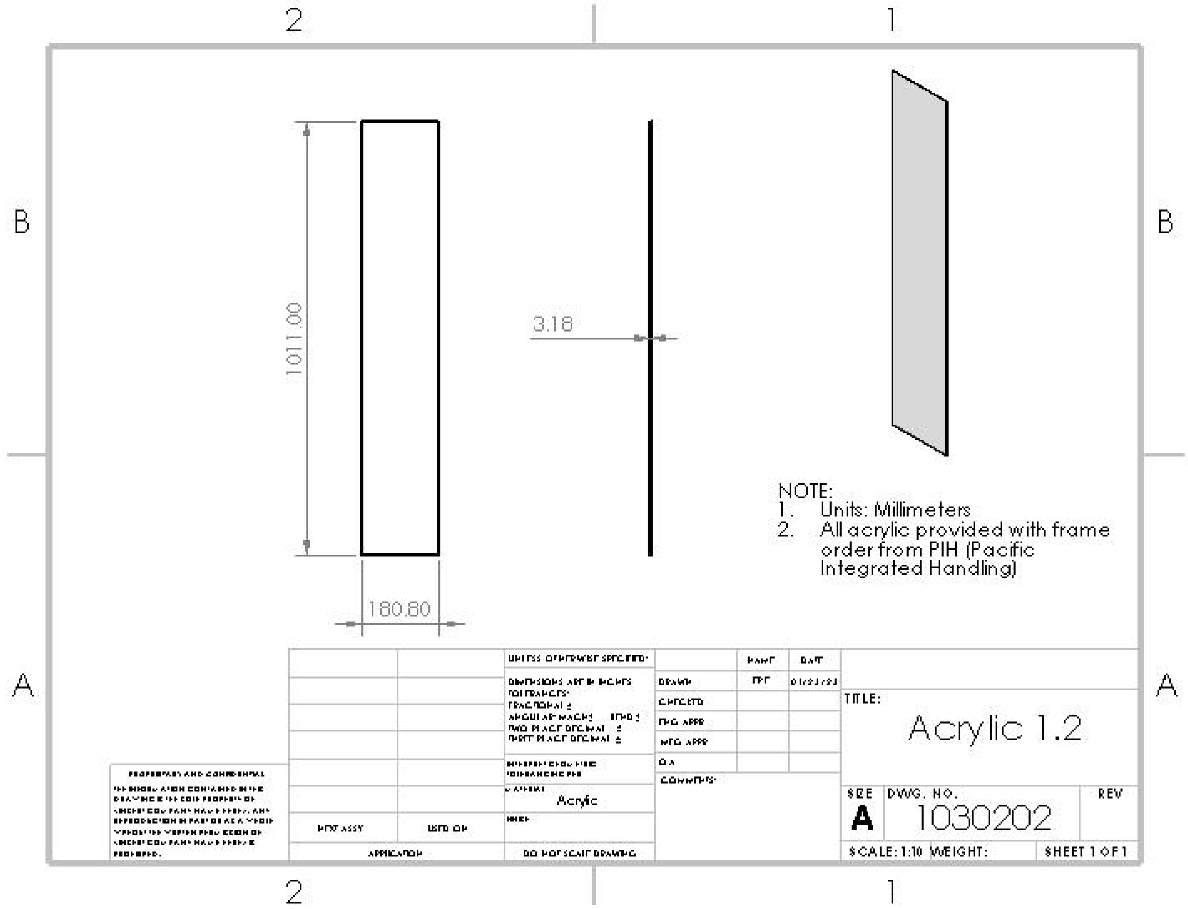
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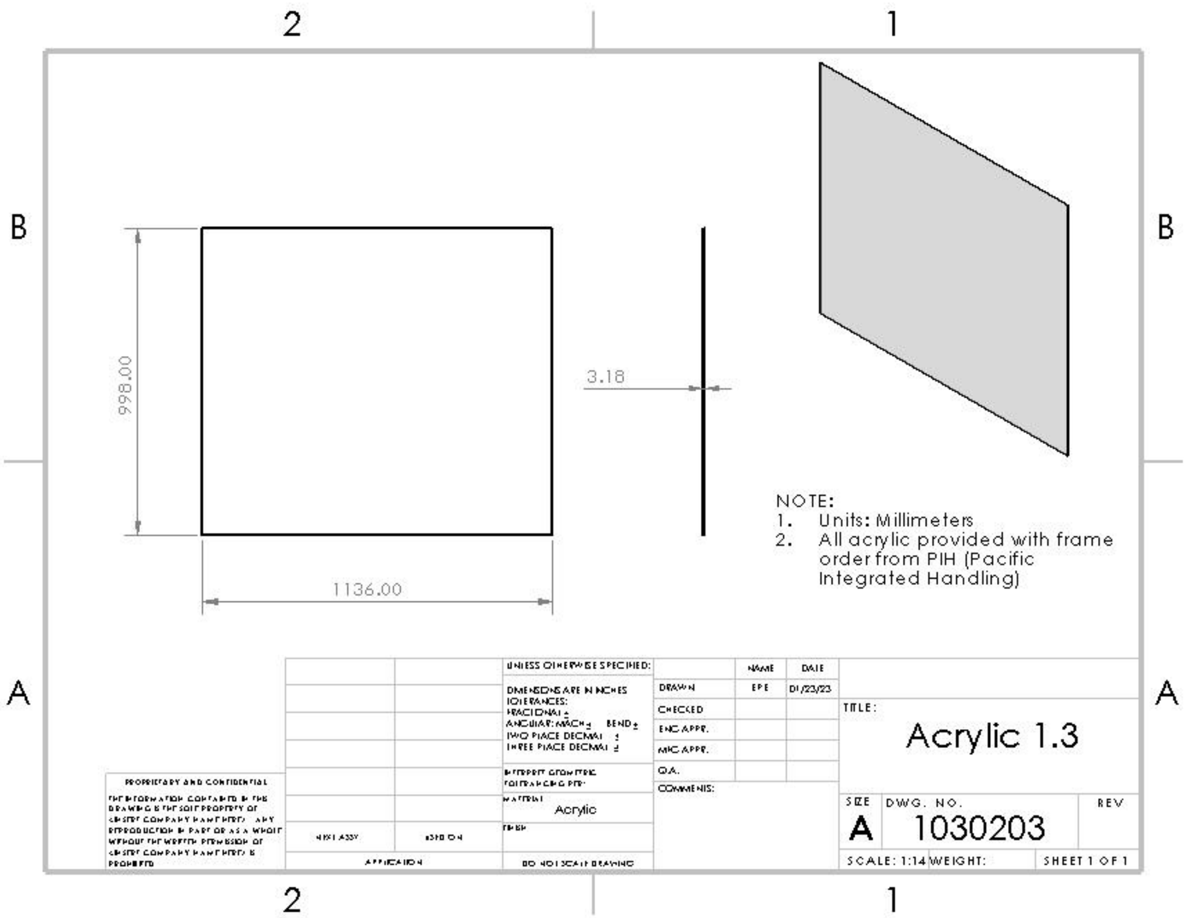
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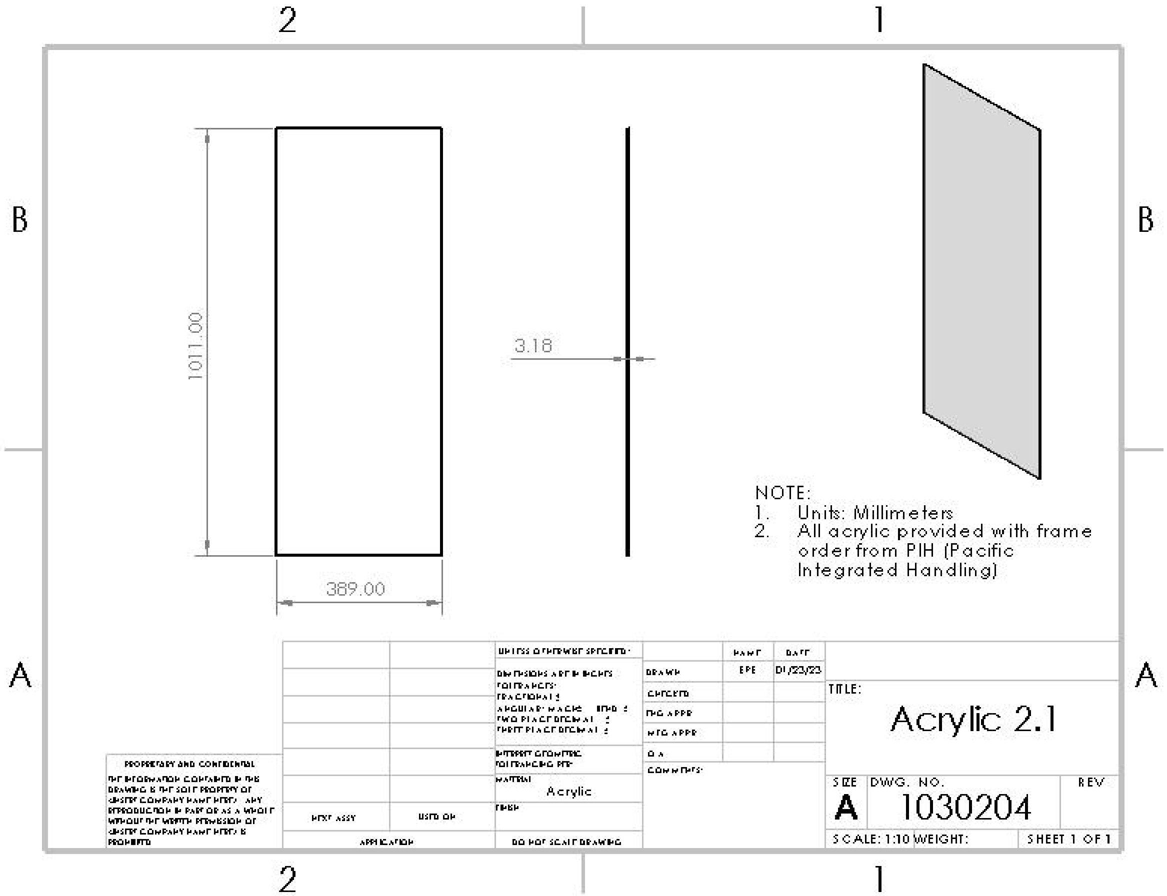
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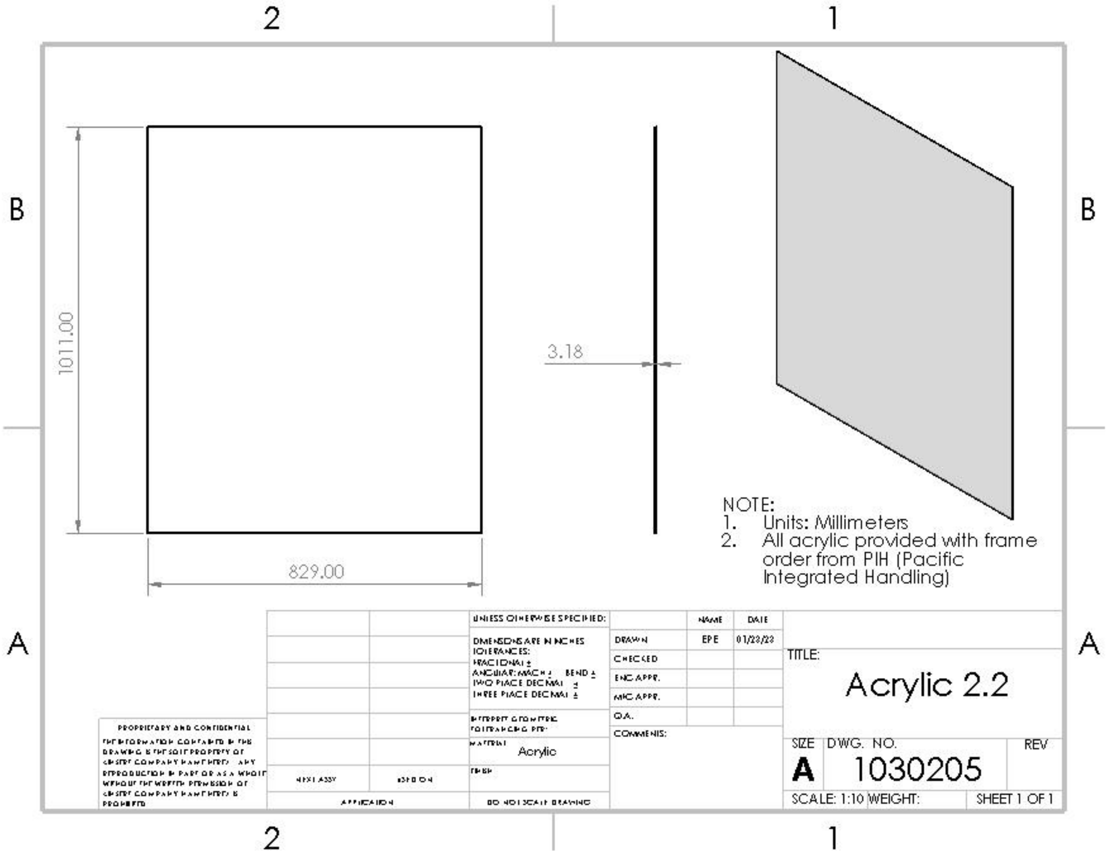

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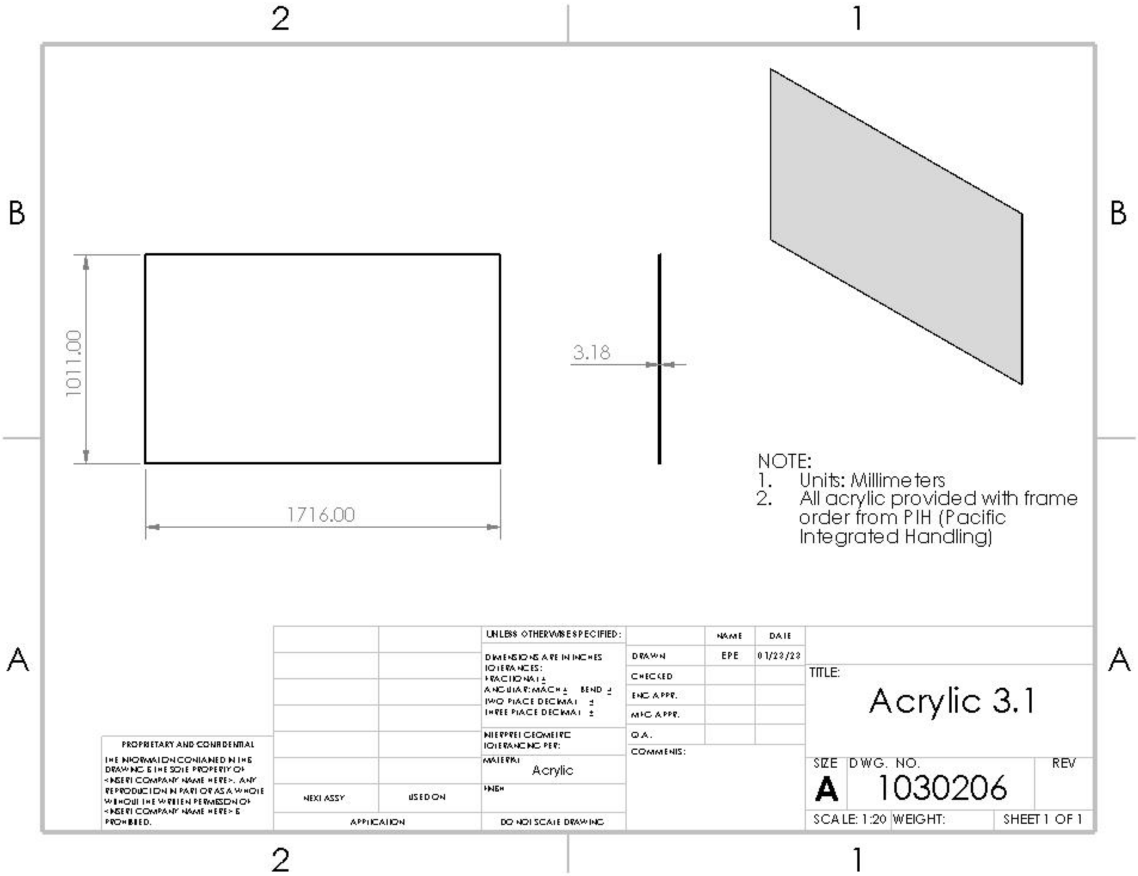
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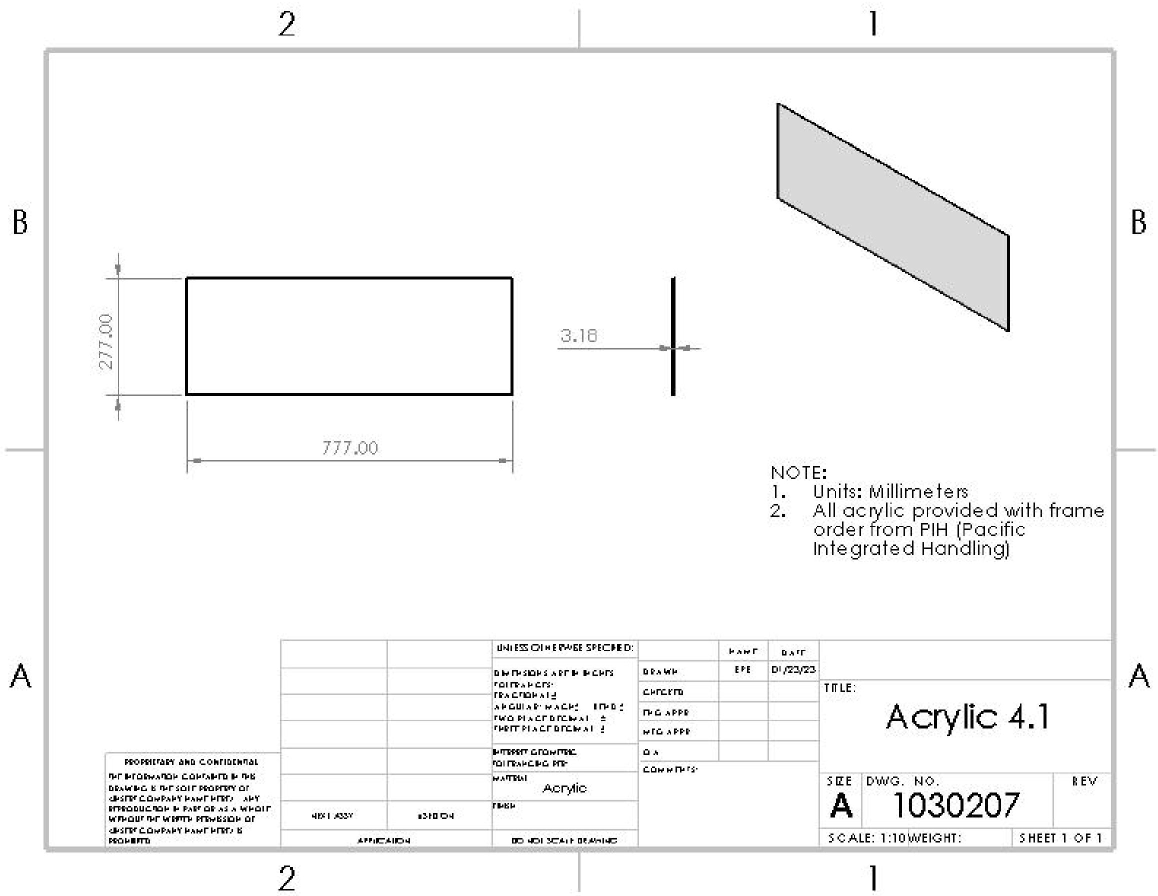

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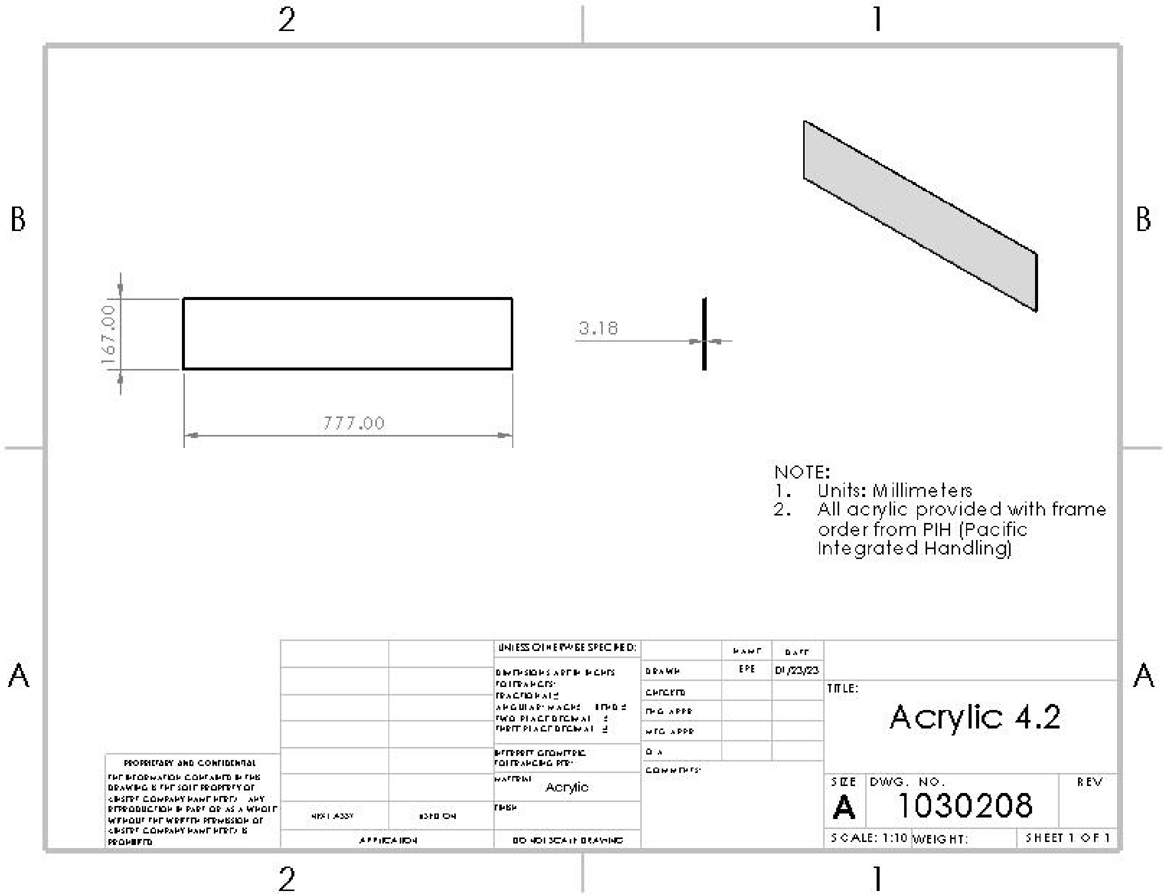

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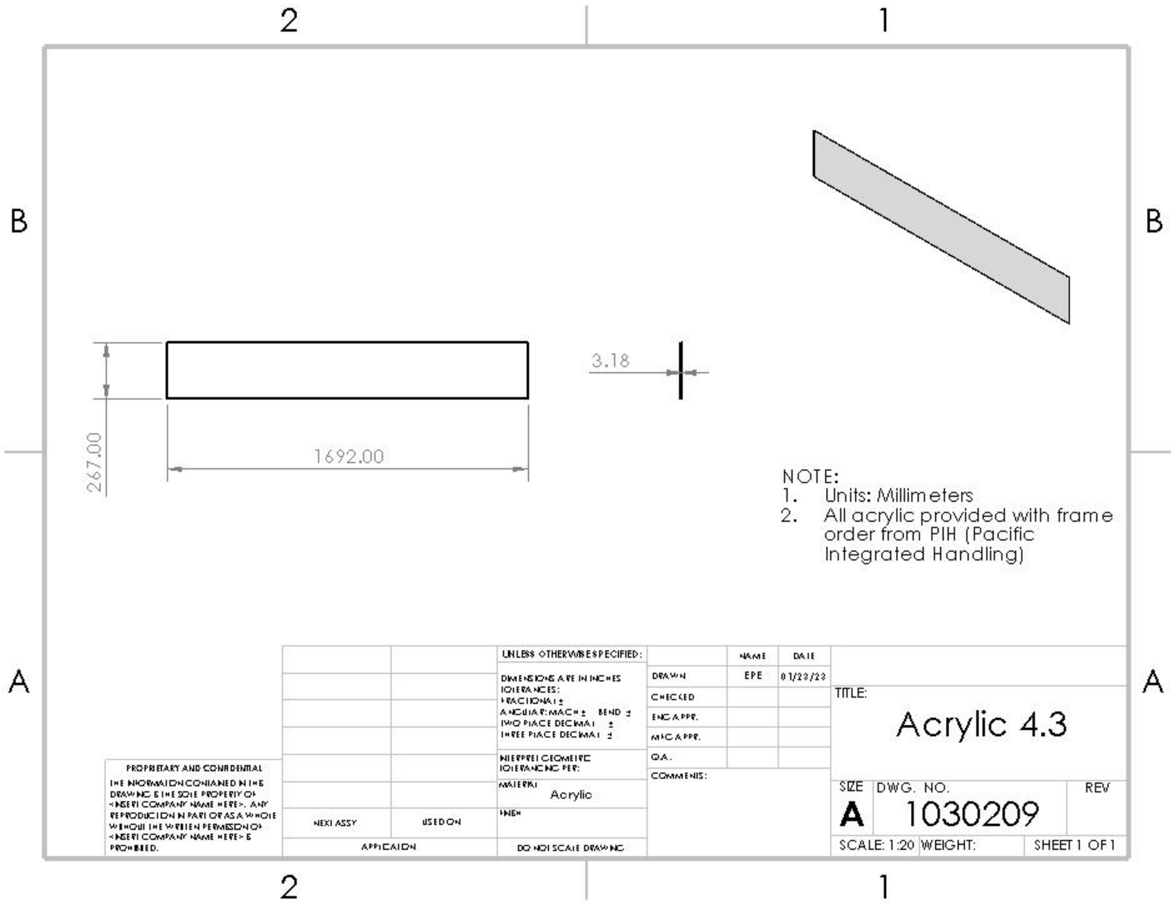
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B
A
A
2
1
3.18
267.00
1692.00
NOTE:
1. Units: Millimeters
2. All acrylic provided with frame order from PIH (Pacific Integrated Handling)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Acrylic
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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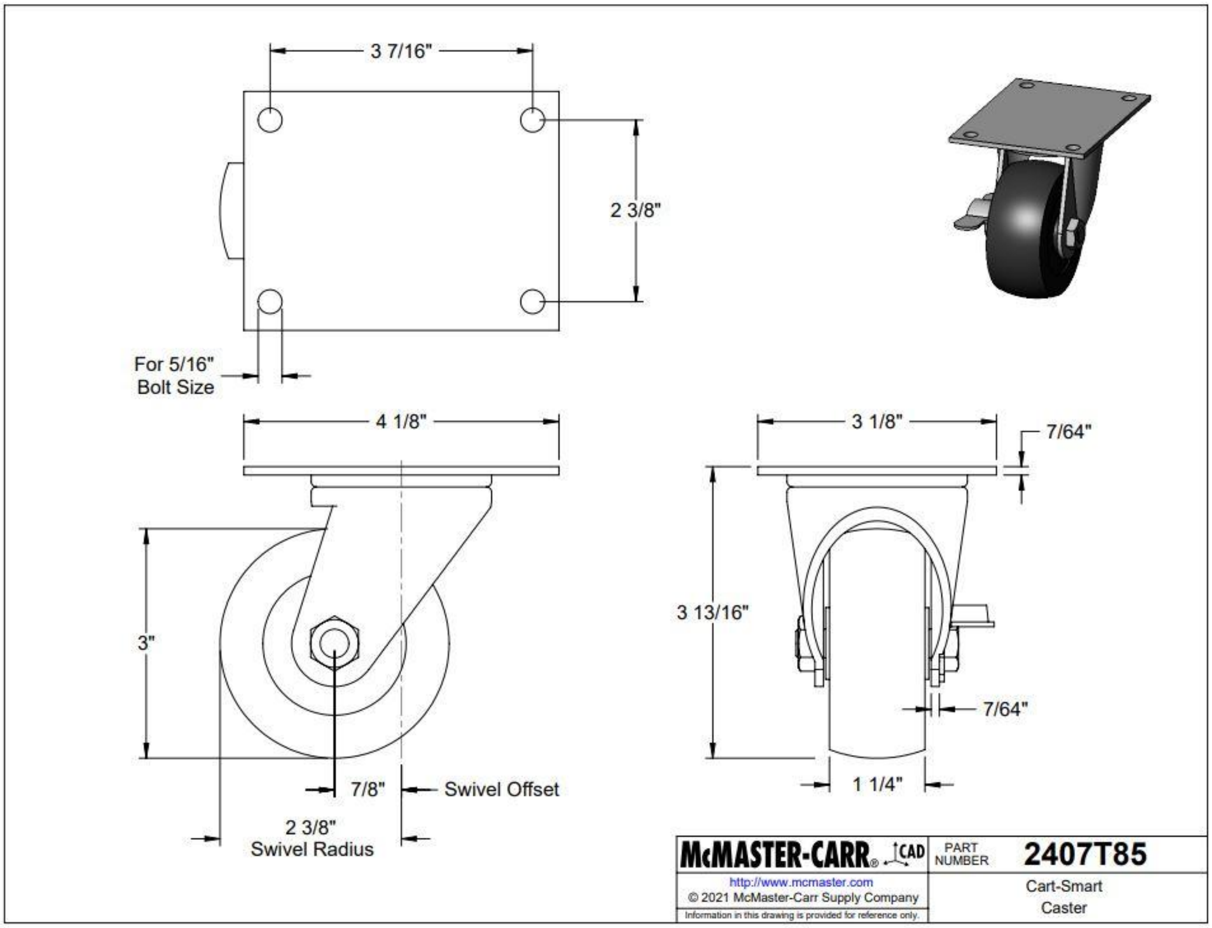
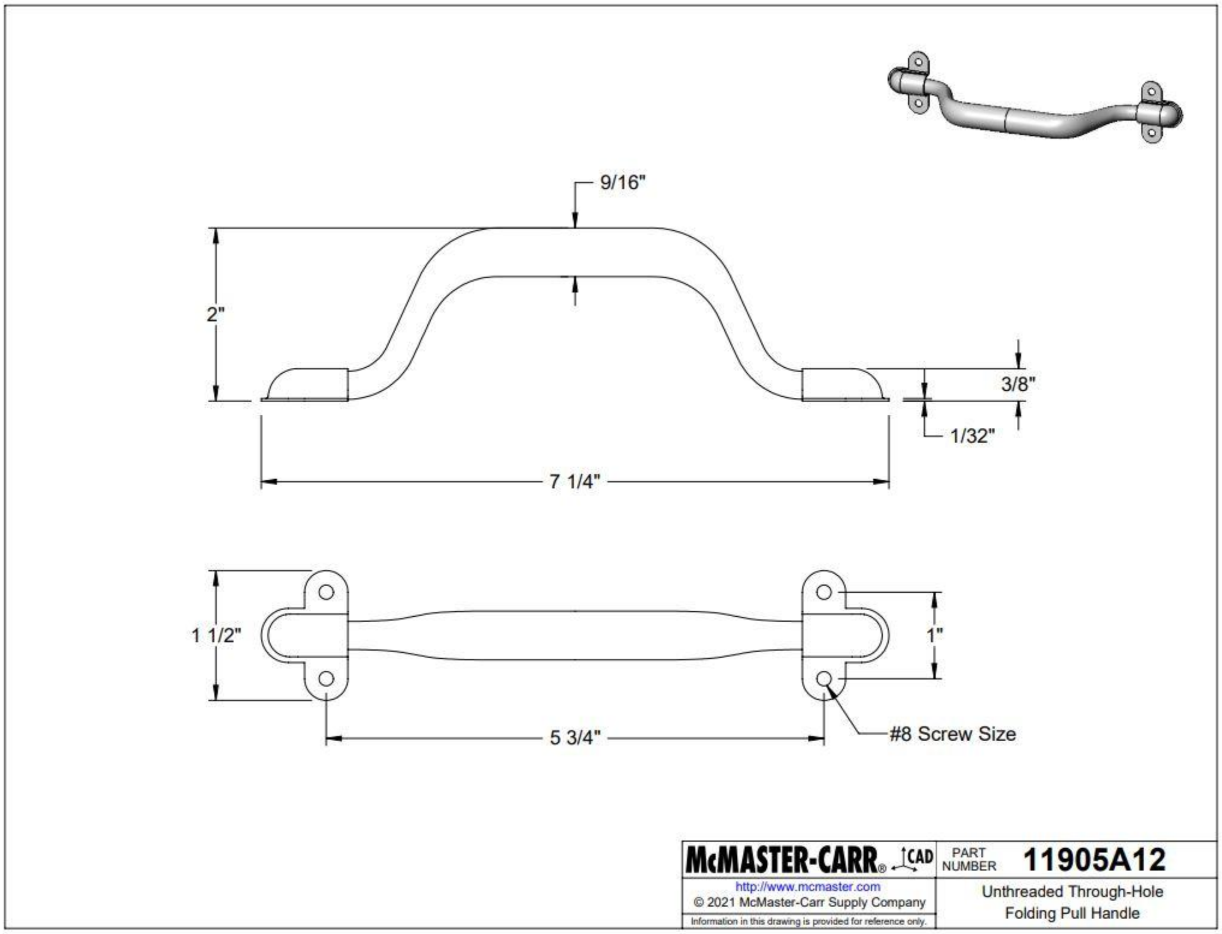
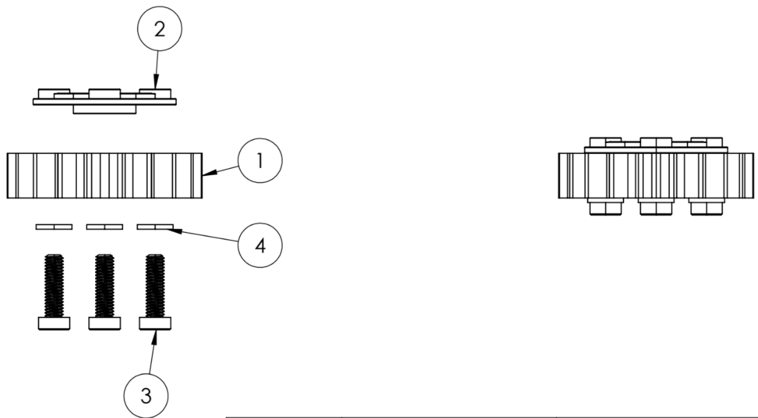
NAME
DATE
DRAWN
EPE
01/23/23
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Acrylic 4.3
SIZE
A
DWG. NO.
1030209
REV
SCALE: 1:20
WEIGHT:
SHEET 1 OF 1


3 7/16"
2 3/8"
For 5/16"
Bolt Size
4 1/8"
3"
7/8"
Swivel Offset
2 3/8"
Swivel Radius
3 1/8"
7/64"
3 13/16"
7/64"
1 1/4"
McMASTER-CARR
CAD
PART NUMBER
2407T85
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Cart-Smart
Caster



Gripper Part Drawings:



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1040202	Gripper Pinion Gear Rev2	1
2	1906-0025-0032	Low Profile Servo Hub	1
3	2804-0004-0014	Low Profile Steel Screw	4
4	2801-0004-0008	Steel Washer	4

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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

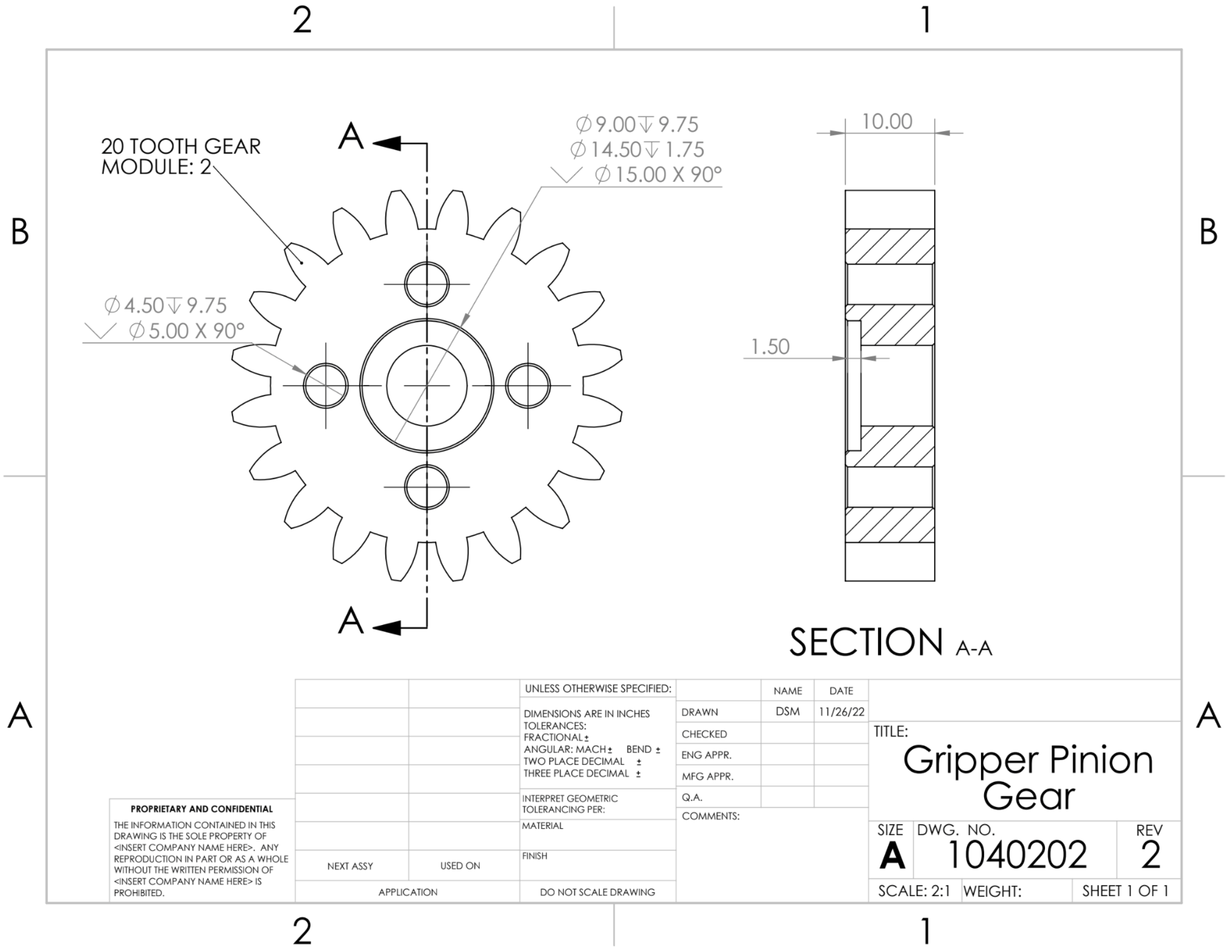
	NAME	DATE
DRAWN	DSM	1/24/23
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Gripper Pinion Gear Assembly

SIZE A | DWG. NO. 1040220 | REV 2

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



20 TOOTH GEAR
MODULE: 2
A
A
∅9.00 ↧ 9.75
∅14.50 ↧ 1.75
⌵ ∅15.00 X 90°
∅4.50 ↧ 9.75
⌵ ∅5.00 X 90°
10.00
1.50
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN DSM 11/26/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gripper Pinion Gear
SIZE A
DWG. NO. 1040202
REV 2
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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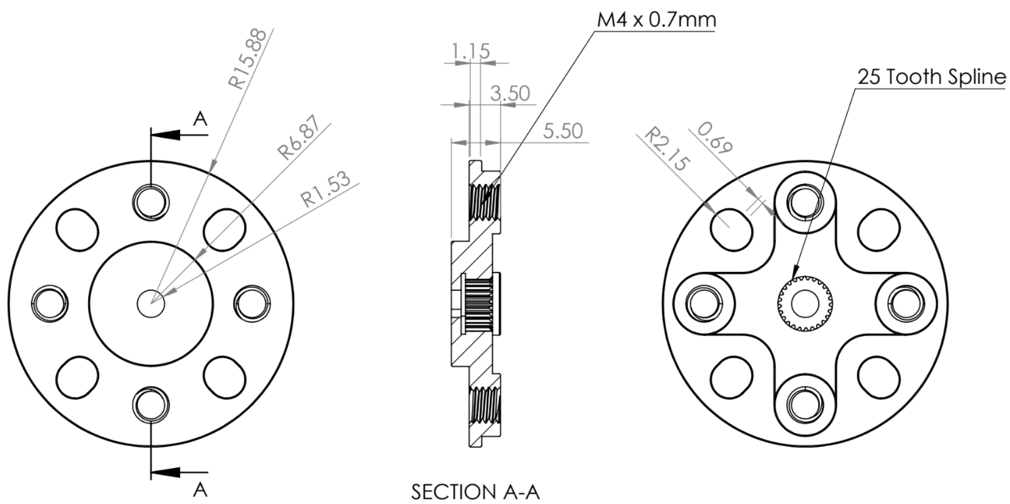
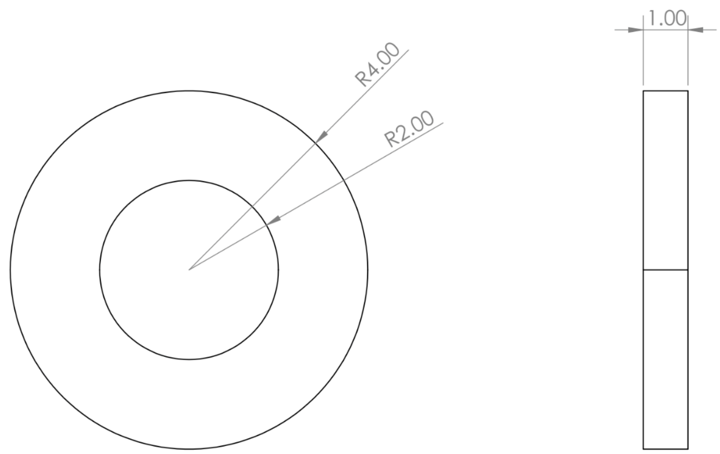


		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DSM	1/24/23	TITLE:
			CHECKED			Low Profile Servo Horn
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. 1906-0025-0032 · REV 1
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1 · WEIGHT: · SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DSM	11/26/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

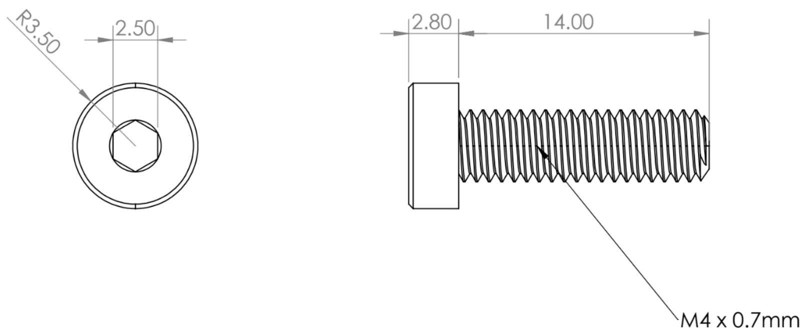
COMMENTS:

TITLE:

Steel Washer

SIZE	DWG. NO.	REV
A	2801-0004-0008	1

SCALE: 10:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DSM	11/26/22	TITLE:	
	CHECKED			Low Profile Steel Screw	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL	COMMENTS:			SIZE A	DWG. NO. 2804-0004-0014 — REV 1
FINISH					
DO NOT SCALE DRAWING				SCALE: 2:1	WEIGHT: — SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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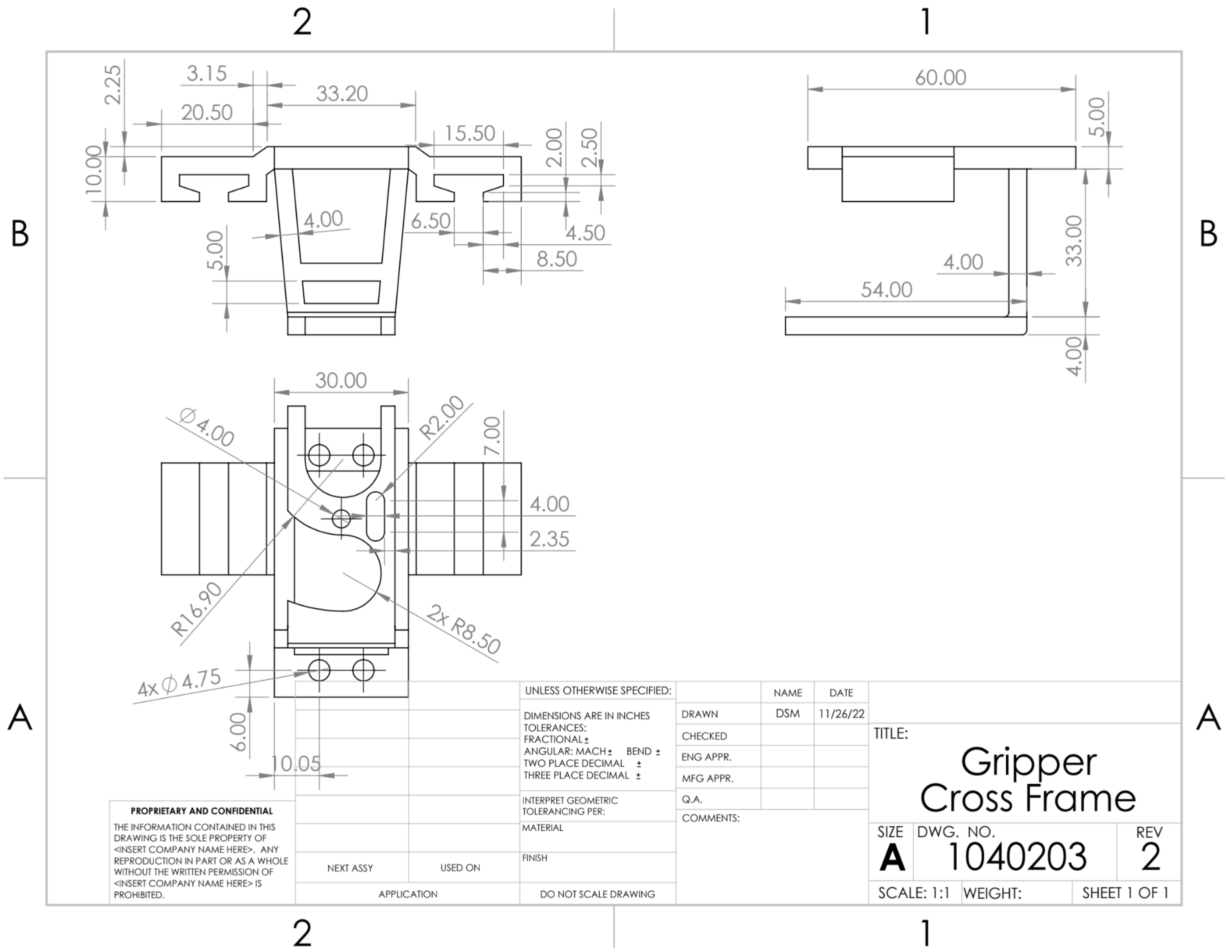

3.15
33.20
20.50
2.25
10.00
15.50
2.00
2.50
4.00
6.50
4.50
8.50
5.00
60.00
5.00
33.00
4.00
54.00
4.00
30.00
∅4.00
R2.00
7.00
4.00
2.35
R16.90
2x R8.50
4x ∅4.75
6.00
10.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
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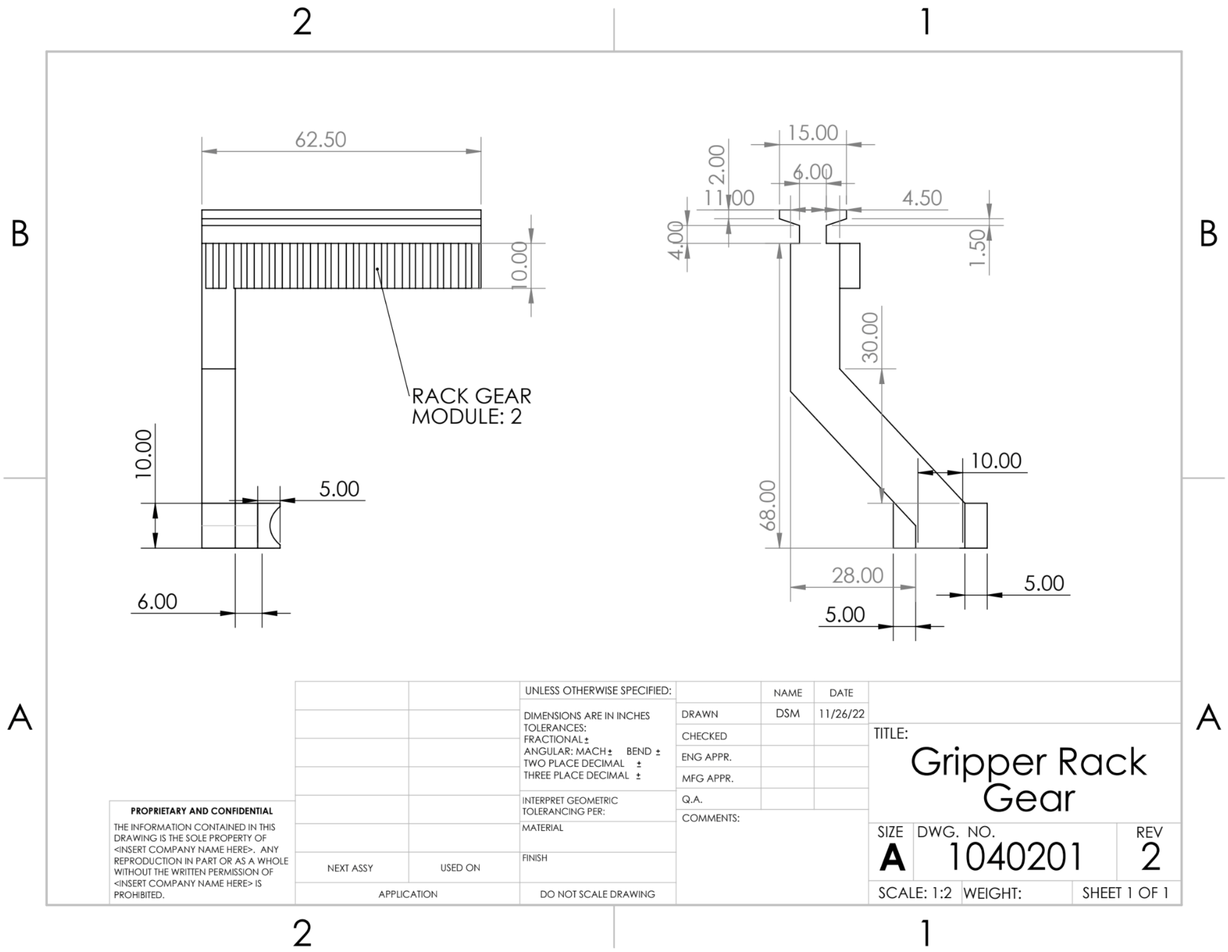
NAME
DATE
DRAWN
DSM
11/26/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gripper Cross Frame
SIZE
A
DWG. NO.
1040203
REV
2
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


2
1
B
A
62.50
10.00
RACK GEAR
MODULE: 2
10.00
5.00
6.00
15.00
2.00
6.00
11.00
4.50
4.00
1.50
30.00
10.00
68.00
28.00
5.00
5.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
DSM
11/26/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gripper Rack
Gear
SIZE
A
DWG. NO.
1040201
REV
2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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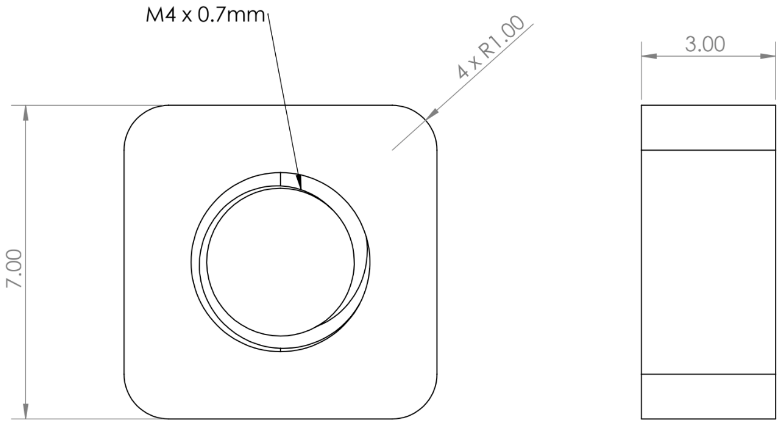

		UNLESS OTHERWISE SPECIFIED:	NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN DSM	11/26/22
			CHECKED	
			ENG APPR.	
			MFG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	
		MATERIAL	COMMENTS:	
NEXT ASSY	USED ON	FINISH		
APPLICATION		DO NOT SCALE DRAWING		

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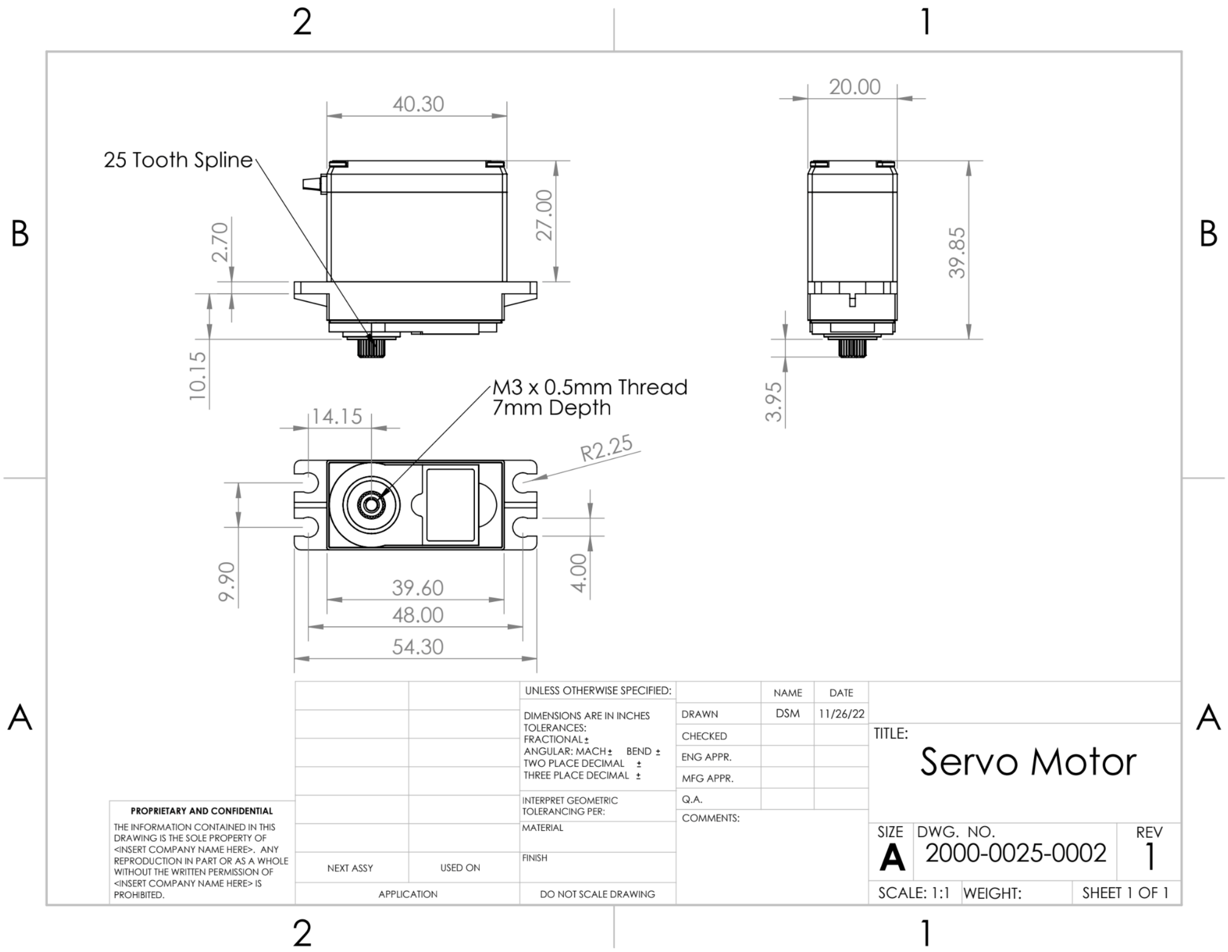
TITLE: Square Nut

SIZE	DWG. NO.	REV
A	2803-0007-0007	1
SCALE: 10:1	WEIGHT:	SHEET 1 OF 1



2
1
B
A
40.30
20.00
25 Tooth Spline
27.00
2.70
39.85
10.15
3.95
M3 x 0.5mm Thread
7mm Depth
14.15
R2.25
9.90
4.00
39.60
48.00
54.30
PROPRIETARY AND CONFIDENTIAL
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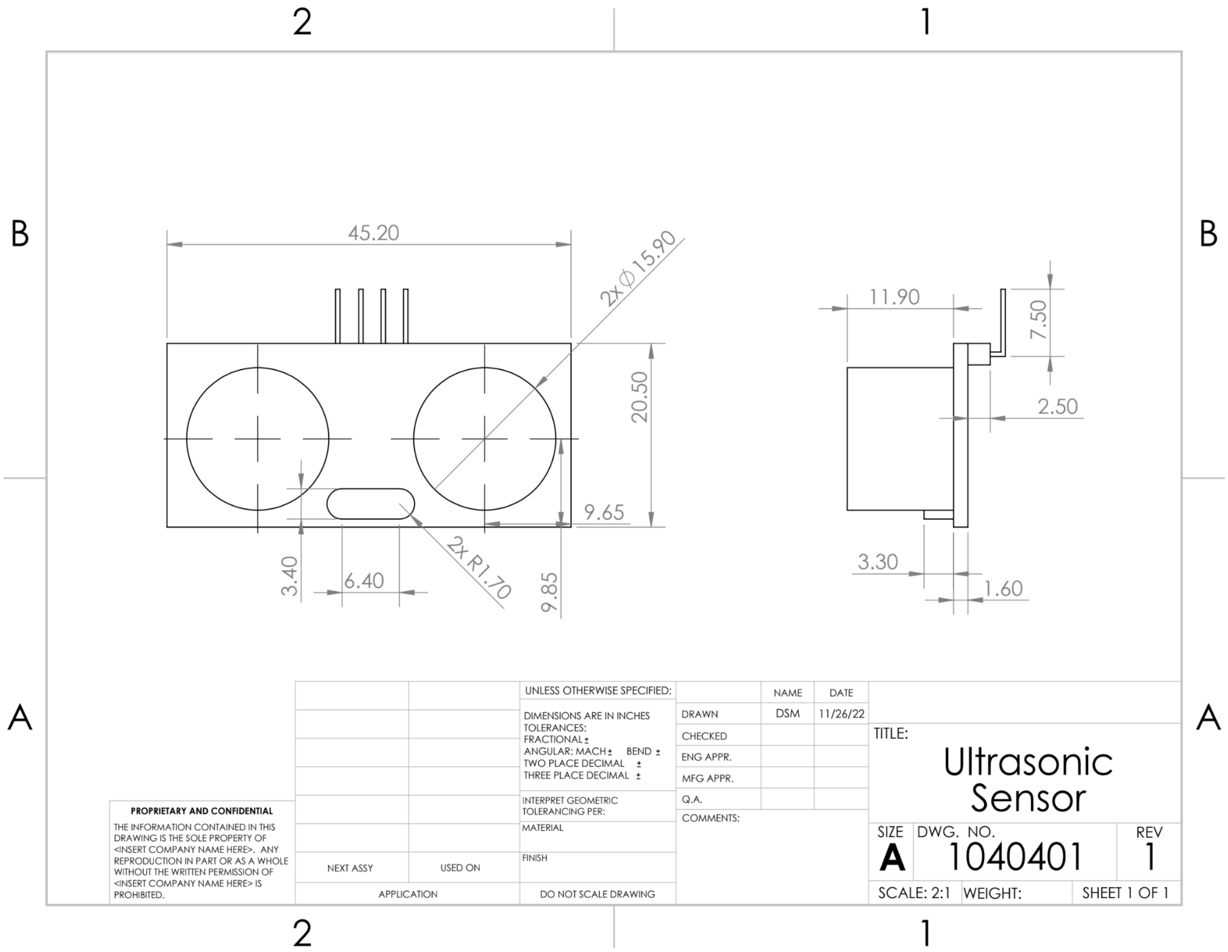
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
DSM
11/26/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Servo Motor
SIZE
A
DWG. NO.
2000-0025-0002
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



2
1
B
A
45.20
2x ⌀15.90
20.50
9.65
3.40
6.40
2x R1.70
9.85
11.90
7.50
2.50
3.30
1.60
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
DSM
11/26/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Ultrasonic Sensor
SIZE
A
DWG. NO.
1040401
REV
1
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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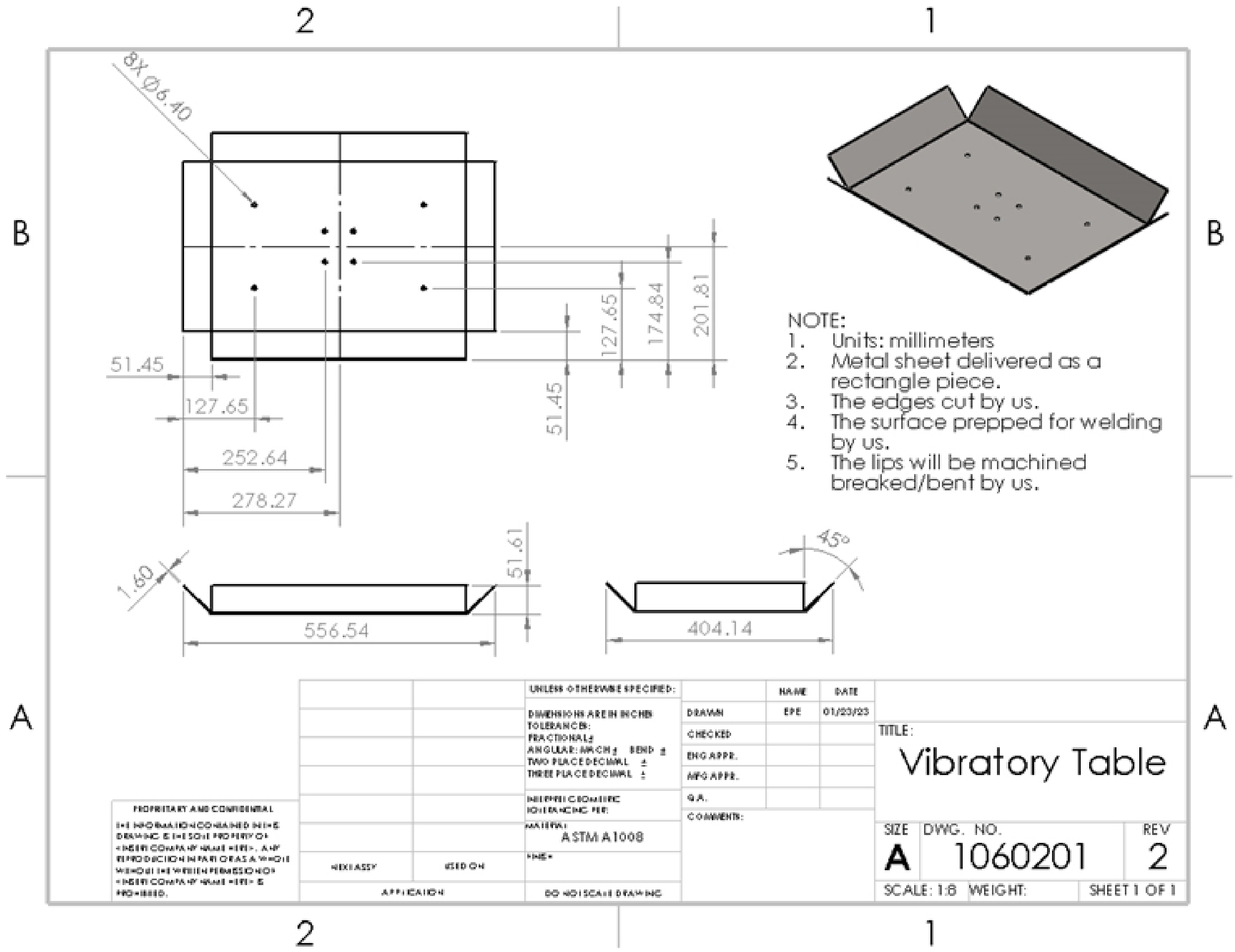
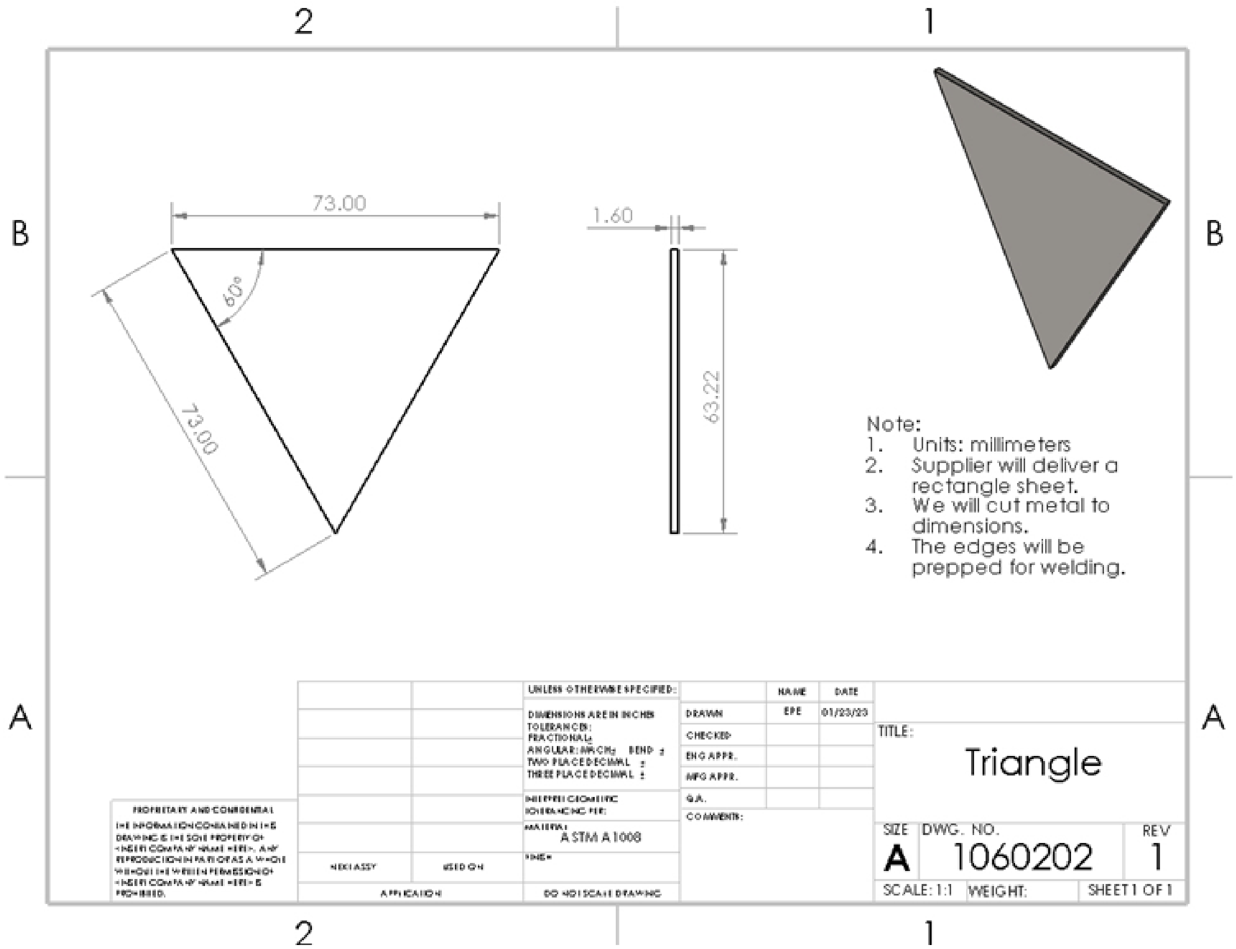
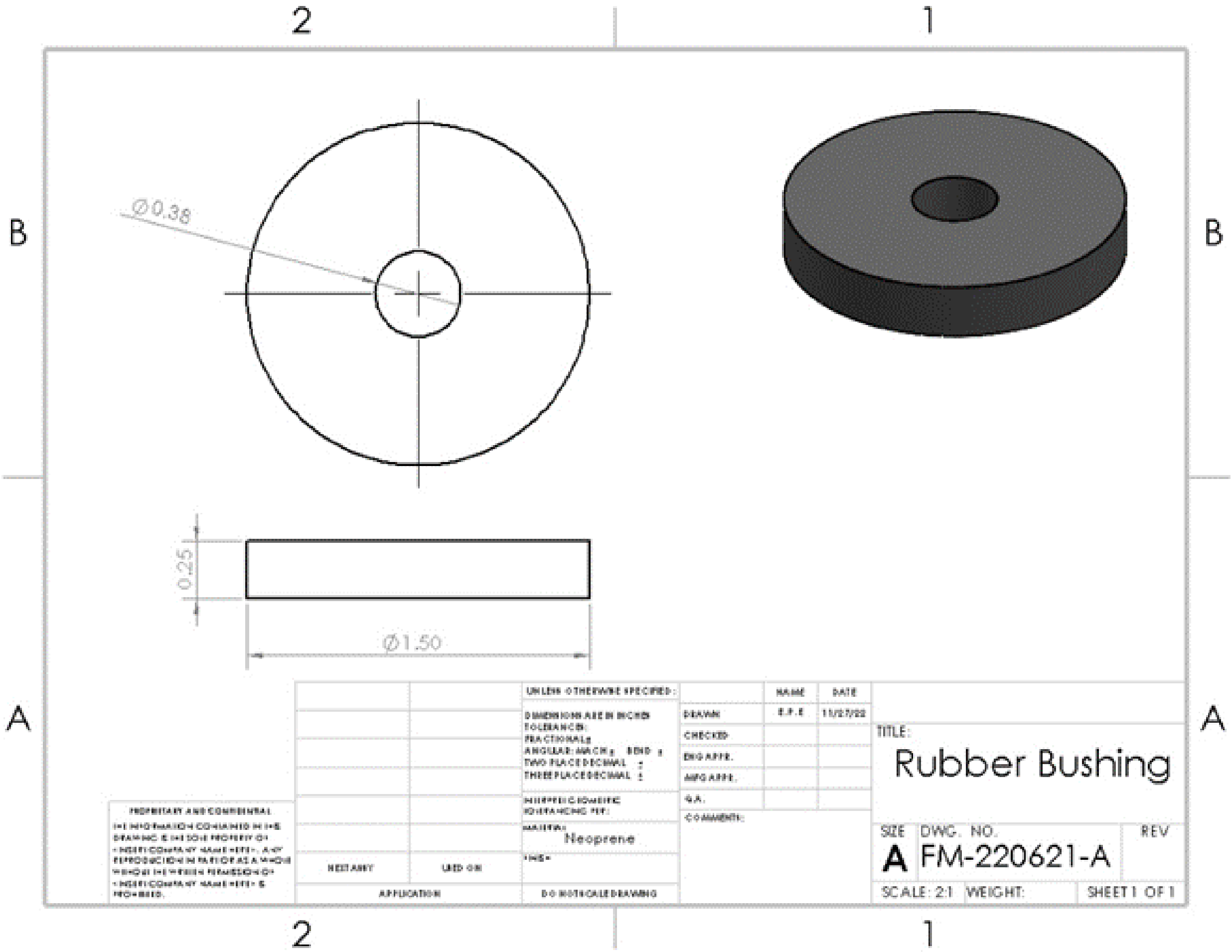
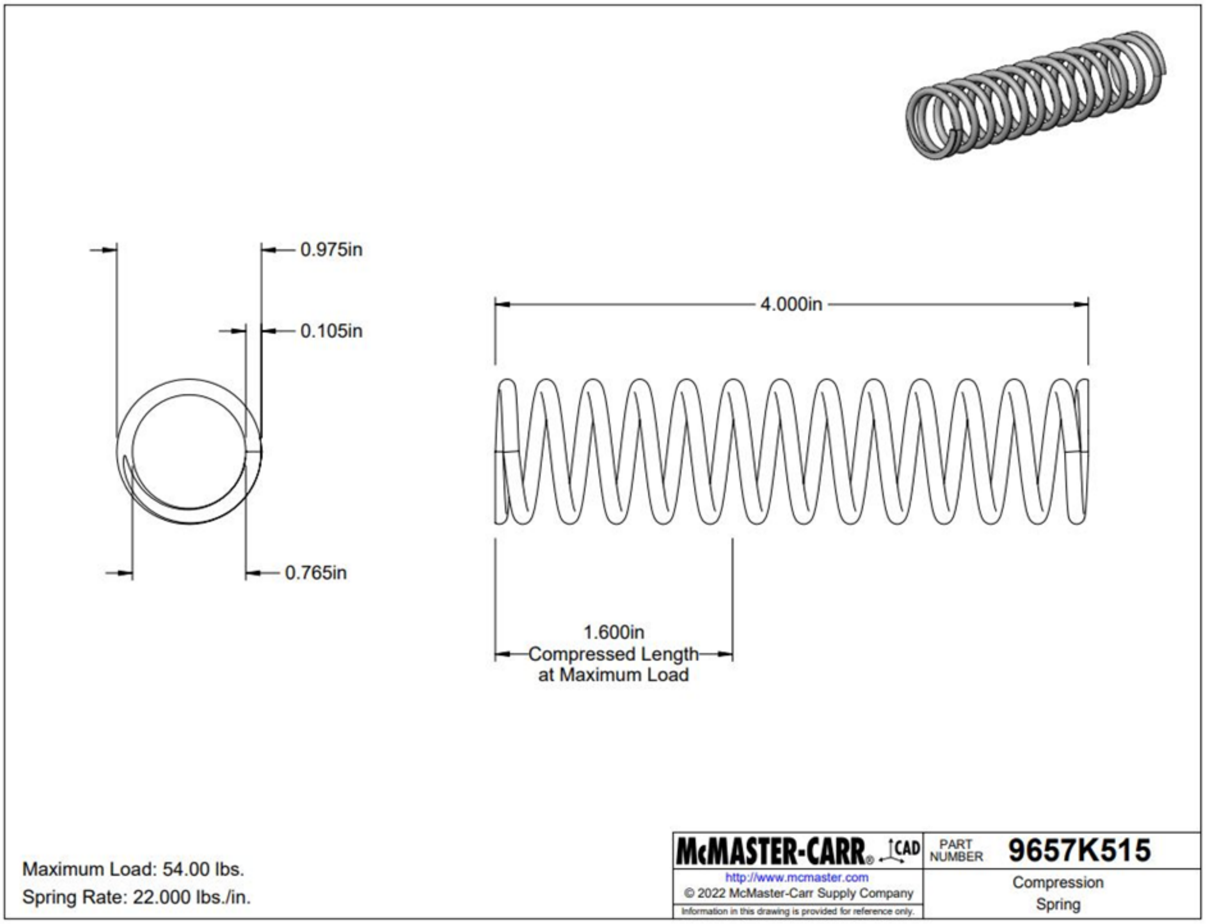
Vibratory Assembly Part Drawings:




73.00
60°
73.00
1.60
63.22
Note:
1. Units: millimeters
2. Supplier will deliver a rectangle sheet.
3. We will cut metal to dimensions.
4. The edges will be prepped for welding.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
NAME
DATE
DRAWN
EPE
01/23/23
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
ASTM A1008
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Triangle
SIZE
A
DWG. NO.
1060202
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


2
1
B
A
Ø0.38
0.25
Ø1.50
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
11/27/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Neoprene
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Rubber Bushing
SIZE
DWG. NO.
REV
A
FM-220621-A
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1



0.975in
0.105in
0.765in
4.000in
1.600in
Compressed Length
at Maximum Load
Maximum Load: 54.00 lbs.
Spring Rate: 22.000 lbs./in.
McMASTER-CARR
CAD
http://www.mcmaster.com
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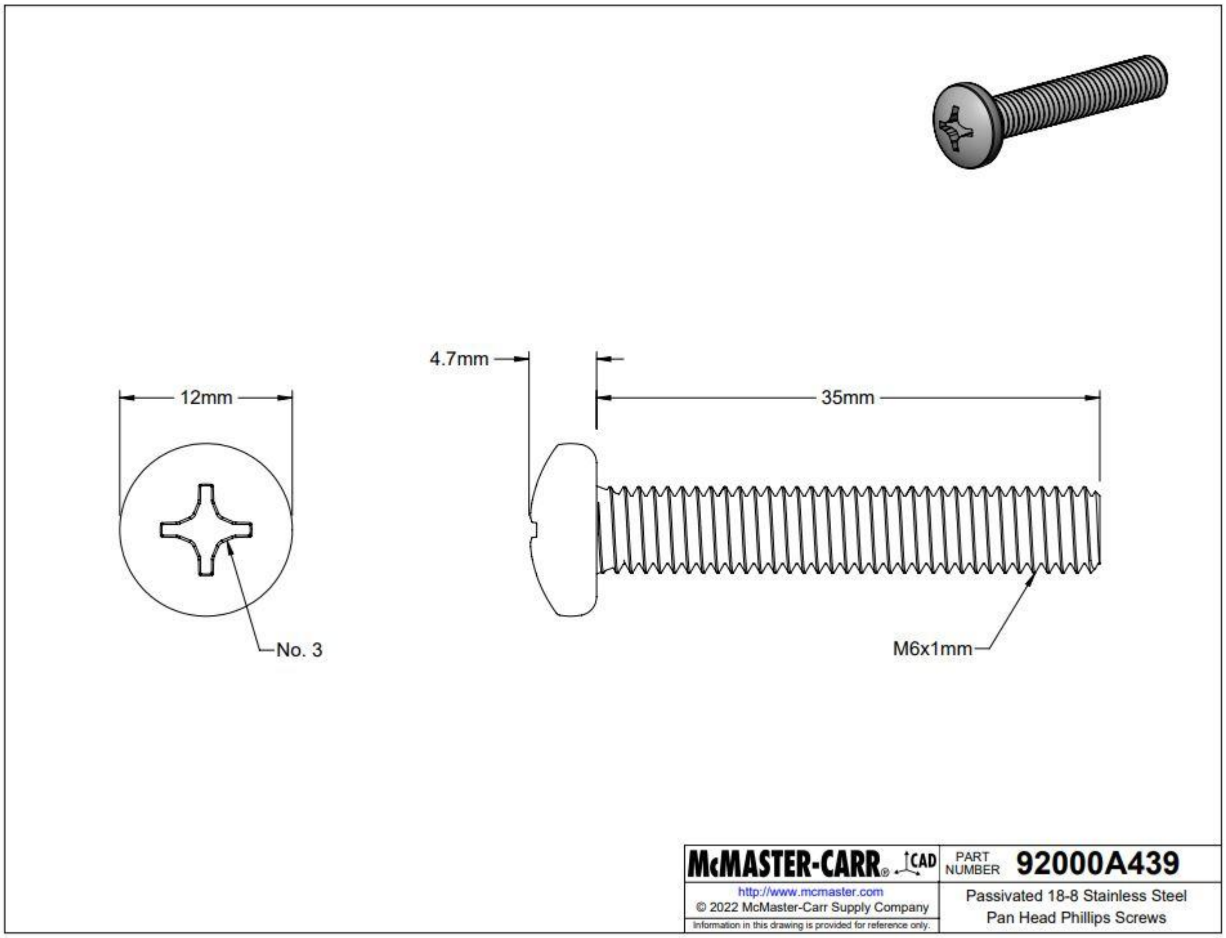
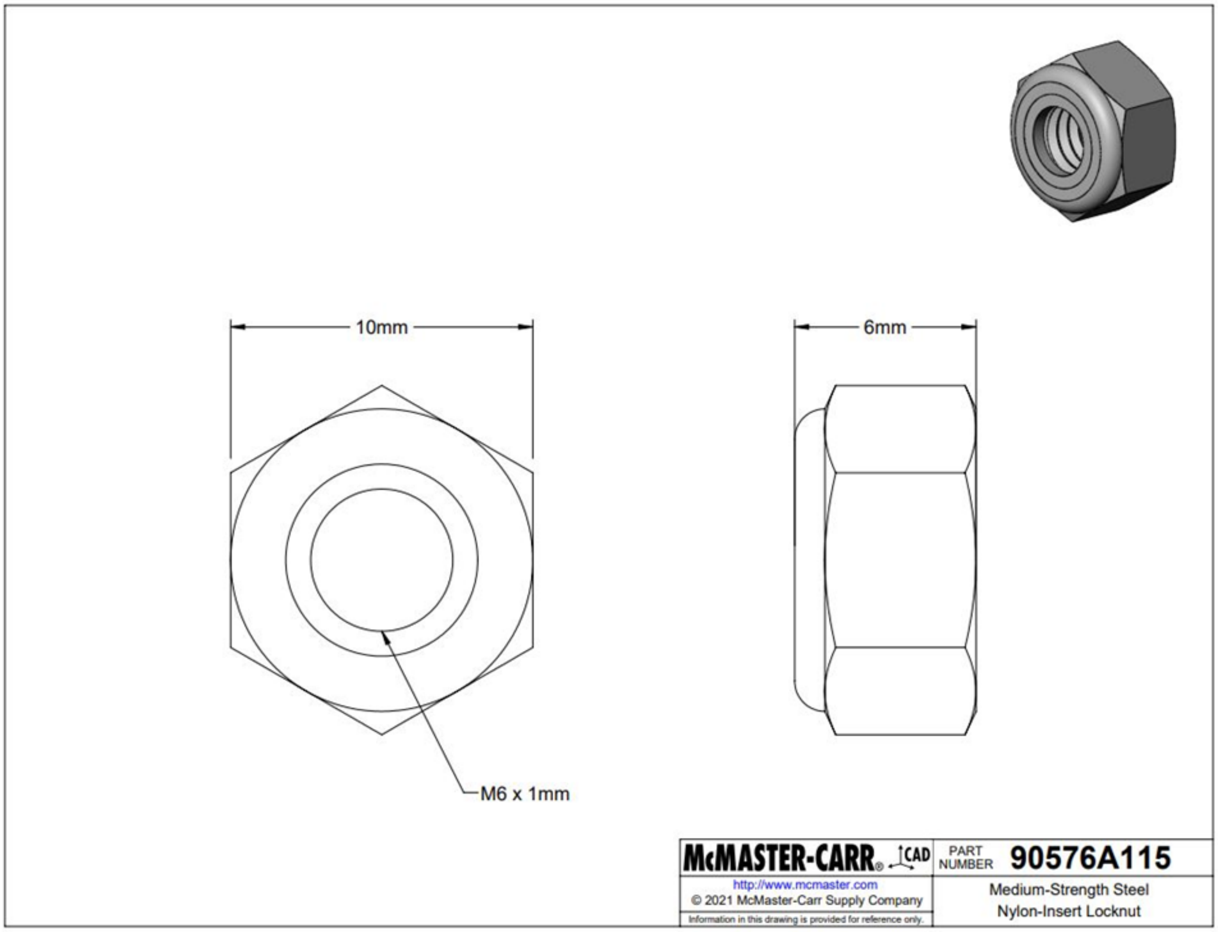
Information in this drawing is provided for reference only.
PART NUMBER
9657K515
Compression Spring


4.7mm
12mm
35mm
No. 3
M6x1mm
McMASTER-CARR® CAD
PART NUMBER 92000A439
http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Passivated 18-8 Stainless Steel
Pan Head Phillips Screws


10mm
6mm
M6 x 1mm
McMASTER-CARR
CAD
PART NUMBER
90576A115
http://www.mcmaster.com
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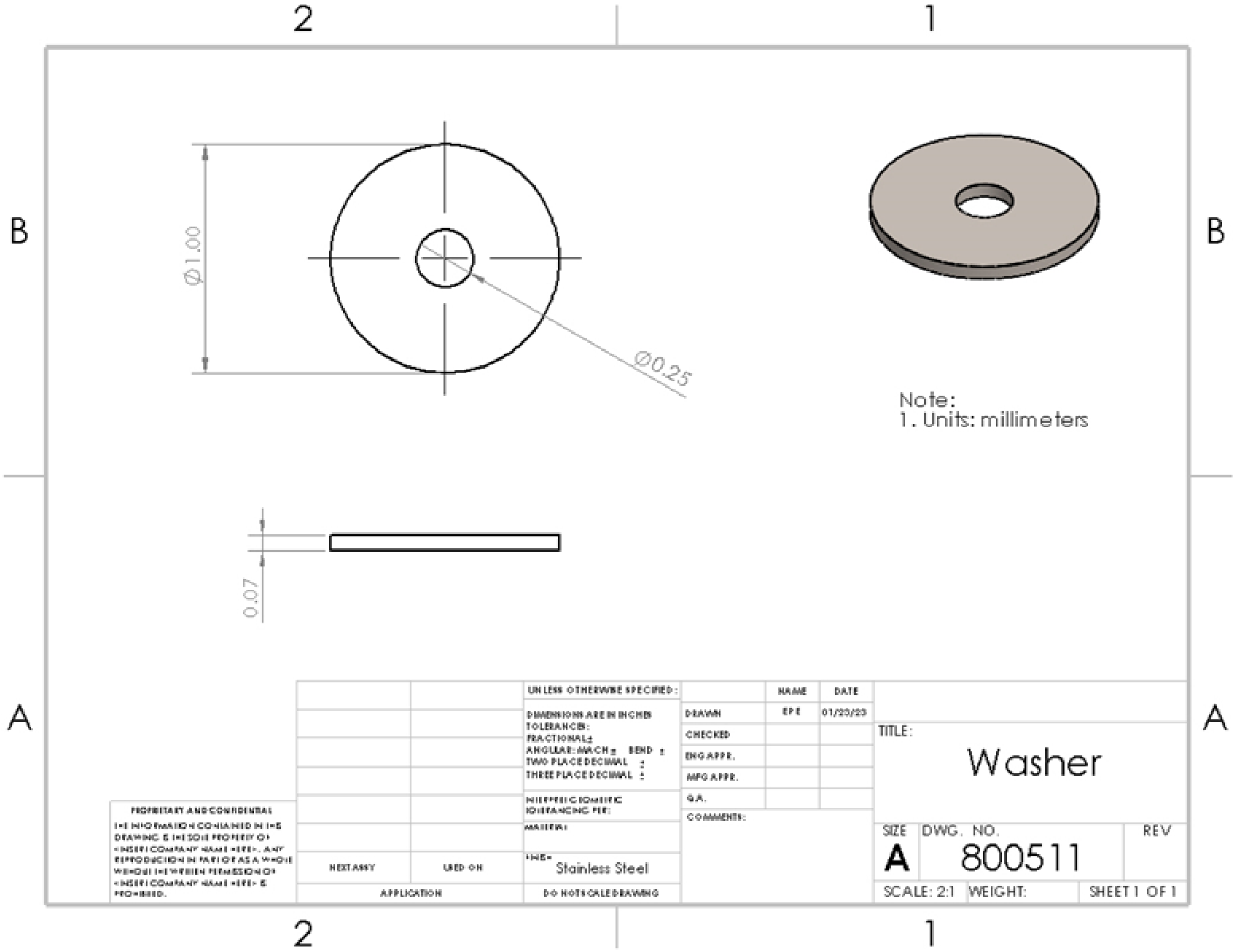
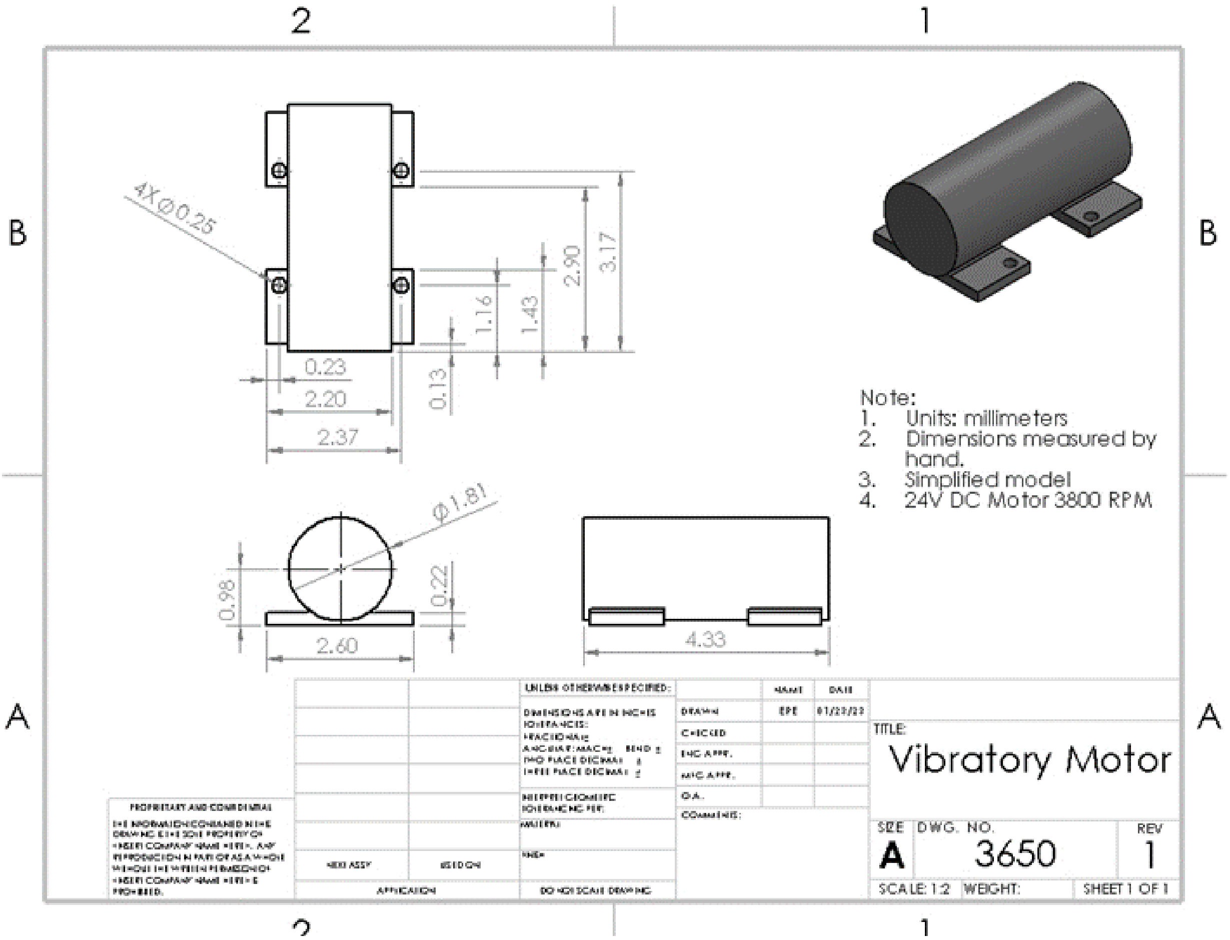
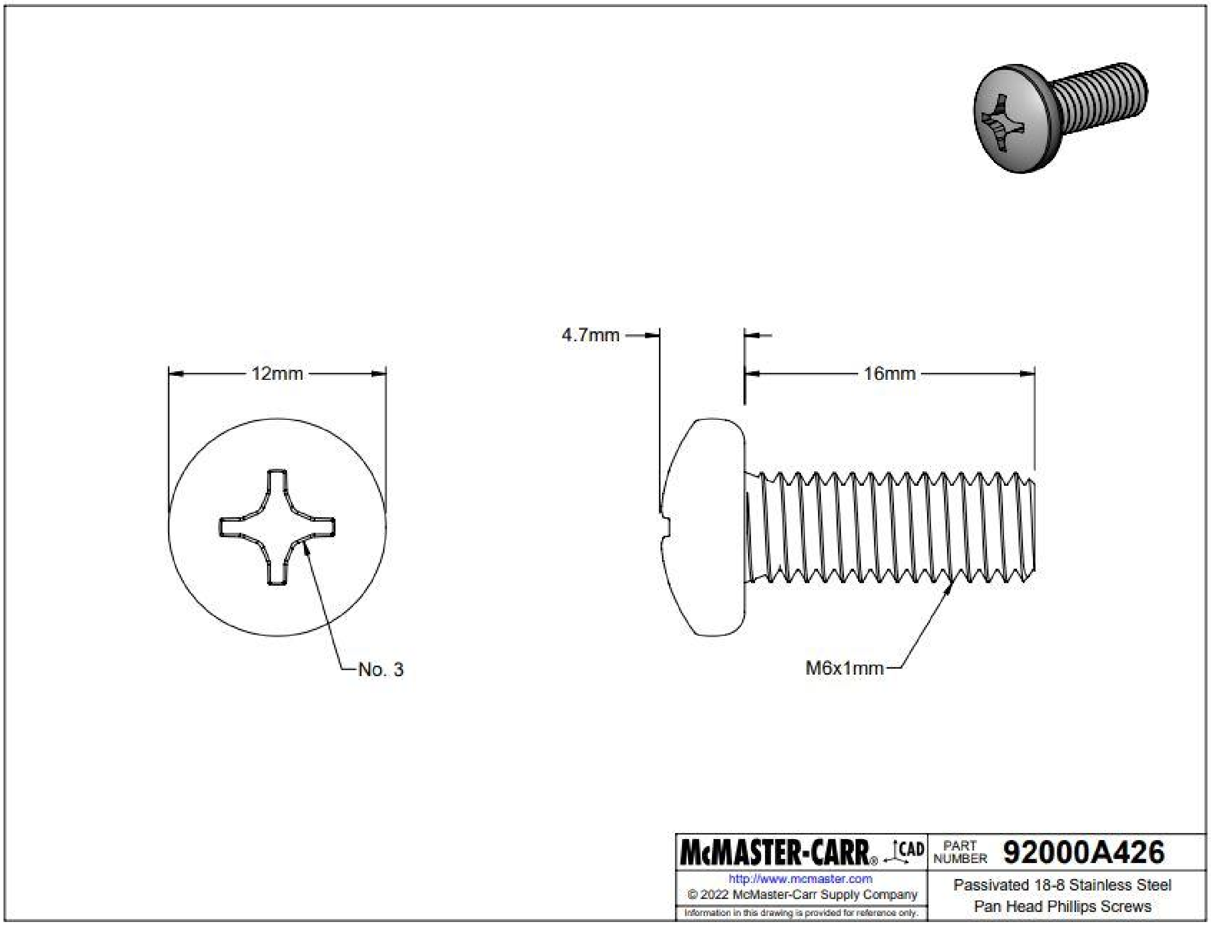
Information in this drawing is provided for reference only.
Medium-Strength Steel
Nylon-Insert Locknut



Ø1.00
Ø0.25
0.07
Note:
1. Units: millimeters
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
EPE
01/20/23
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Stainless Steel
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Washer
SIZE
A
DWG. NO.
800511
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1


4X Ø0.25
3.17
2.90
1.43
1.16
0.13
0.23
2.20
2.37
Ø1.81
0.98
0.22
2.60
4.33
Note:
1. Units: millimeters
2. Dimensions measured by hand.
3. Simplified model
4. 24V DC Motor 3800 RPM
TITLE:
Vibratory Motor
SIZE A
DWG. NO. 3650
REV 1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


12mm
No. 3
4.7mm
16mm
M6x1mm
McMASTER-CARR®
CAD
PART NUMBER
92000A426
http://www.mcmaster.com
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Information in this drawing is provided for reference only.
Passivated 18-8 Stainless Steel
Pan Head Phillips Screws