Cover Letter of Transmittal

From: SG_STAMP2 Team

Date: 12/8/2023

To: Senior Design Committee
9201 University City Blvd,
Charlotte, NC 28223

Senior Design Committee,

This document describes the progress of the SG_STAMP2 team through the design process. The team was tasked with collaborating with The Schaeffler Group, a large industrial engineering firm who produces needle bearings. Needle bearings are used in many automotive and high force applications which can result in bearing failures if defects are present. The purpose of this project was to produce a device to extract, scan, and analyze multi-sized raceways from the stamping machine, to determine potential part defects. This quality detection checkpoint allows The Schaeffler Group to potentially catch defects earlier in the production process to help with cost and quality control. This team is the second phase of this project.

The final design outlined in this report describes our device that is composed of three primary parts. These parts include a robotic collector mechanism that extends and collects raceways from the assembly line, a camera utilizing artificial intelligence that analyzes the parts and determines if they are defective, and a bin to dump defective parts into.

The collection system will be constructed with two Openbuilds linear actuators and a custom designed collection mechanism powered by Nema-17 stepper motors. The collector will have an outer edge of 7 by 7 inches and an inner edge of 6 by 6 inches to be able to handle a range of needle bearing sizes. The device will be controlled by a raspberry pi 4B microcontroller that will take sensor input from a pixy 2.1 AI camera that will indicate when opportune times to collect parts. This system will attempt a collection on set timer if no detection is received from the pixy 2.1.

The part analysis will be performed by a Keyence VS series AI equipped camera that will scan both faces of the raceways. Once a determination is made on the integrity of the part the camera will signal the control system to return the part to the assembly line or to dump the defective part in the bin.

The SG_STAMP2 will be continuing this work in the spring semester and will produce a functioning version of the device described within this document to implement within the Schaeffler fort mill plant.

Sub-Folder	Content	File Names
BOM and Budget	Bill of Materials and Budget	SG_STAMP2_BOM
Calculations	Weight Analysis of Hinging Mechanism	SG_STAMP2_WeightAnaylsis.pdf
	Weight and Volume Analysis	SG_STAMP2_Weight/Volume.pdf
	Minimum Shaft Diameter	SG_STAMP2_MinimumShaft.pdf
	Hinging Mechanism Forces and Torque	SG_STAMP2_HingeMechanism.pdf
Computer Code	EMPTY	EMPTY
Correspondence	Emails with Industry Supporter	SG_STAMP2_EMAILS
	BiWeekly Meetings with Mentor	SG_STAMP2_WeeklyMeetings
Drawings	3D Printed Part Drawings	SG_STAMP2_3D Printing
	Wiring and Pinout Diagrams	SG_STAMP2_Wiring Diagrams
	CAD Part Files	SG_STAMP2_Part Files
	Final CAD Assembly Model	SG_STAMP2_PDR Assembly.step
Pictures and Videos	Stamping Process Video	Schaeffler_Stamping_Process.mp4
	CAD Render of Final Assembly	PDR_Assembly_render.png
Presentations	CDR Presentation	SG_STAMP2_CDR.pptx
	CDR Revised Design Proposal	SG_STAMP2_CDRRevisedDesign.pptx
	PDR Presentation	SG_STAMP2_PDR.pptx
	Expo Poster	SG_STAMP2_SD1_ExpoPoster
Reports/Documents	Statement of Work	SG_STAMP2_SOW.docx
	Team Contract	SG_STAMP2_TeamContract.docx
	Progress Report 1	SG_STAMP2_ProgressReport_1.docx
	Progress Report 2	SG_STAMP2_ProgressReport_2.docx
	Project Plan	SG_STAMP2_ProjectPlan_Rev03.xlsx
	Timesheet	SG_STAMP2_Timesheet.xlsx
	Final Report	SG_STAMP2_FinalReport.docx
Research	Notes from CDR Presentation	SG_STAMP2_CDR Notes.docx
	Phase 1 Comprehensive Submission	SG_STAMP_Comprehensive_Submission_SD 2.zip
	Combination of Research and Working Documents	SG_STAMP2_ResearchDocs

SG_STAMP2 Project – Final Design Package – Senior Design I

Date	Revision	Author	Comments
12/07/2024	1	SG_STAMP2	

Division of Duties Summary Table

	Joshua Ayers	Aidnen Lamar	Steven Medrano	Slade Garraghty	Alex Bussard	Total (should be 100%)
Collection mechanism design	20%	20%	20%	20%	20%	100%
Acquisition of Phase 1 Prototype	20%	20%	20%	20%	20%	100%
CDR Report	20%	30%	20%	15%	15%	100%
Assessment of new camera system	30%	20%	20%	15%	15%	100%
Wiring diagram	50%	0%	50%	0%	0%	100%
CAD models of flipping mechanism	0%	90%	0%	5%	5%	100%
PDR report and slideshow	20%	20%	20%	20%	20%	100%
Weight and movement analysis	0%	5%	0%	60%	35%	100%
Failure mode and error analysis	5%	10%	5%	75%	5%	100%
Poster	25%	40%	10%	10%	15%	100%
Final design package	20%	20%	20%	20%	20%	100%

Table of Contents

1 Document Overview

This document describes the product that the SG_STAMP2 team has designed, and is planned to build during the Spring 2024 semester. The purpose of this design is to collect circular bearing housings of various sizes and scan them for defects on both sides. This document will describe the process of the design and go into detail about the project overview, specifications needed for the design, description of the design narrative, how the design will adhere to engineering standards as well as the impact the design has in the engineering workplace. The document will also include the initial budget and the bill of materials, which will list all the components of the design with the prices that they were purchased at.

2 Project Overview/Statement of Work Summary

2.1 Project Objective

Senior Design group SG_STAMP2's project is to build a system that collects, analyses, and sorts pre-assembly components at Schaeffler Group's Fort Mill manufacturing plant. The system is required out of the necessity to add component defect detection earlier in manufacturing so as to avoid having to waste time and resources manufacturing faulty products. This system is not meant to replace or improve any existing defect detection systems integrated with Schaeffler manufacturing, but rather it will act as additional security, albeit with potentially lower accuracy, that can be implemented in similar ways though other production lines of the plant. As such, the system outlined in this report is intended to act as a sort of prototype or proof-of-concept for Schaeffler to potentially implement at a larger scale in the future should it prove effective.

The specific task of this design is to collect and analyze two types of housing components for steel needle washer bearings after they are stamped early in production. These parts are all thin and circular, and vary in size. The analysis system will intercept them immediately after they are stamped to perform its inspection. This inspection will be completed via the use of an AI anomaly detection camera system engineered by Keyence Corp., and the system will subsequently place parts flagged with defects in a bin for a plant operator to check. This system is not meant to run in a vacuum, as with the footprint and budget available, it cannot be expected to match the performance of the advanced part inspection systems implemented at the end of the Fort Mill plant's manufacturing process. Therefore, a human operator will be notified when potentially defect parts are found, and if the parts are indeed defective, they will be able to halt production and mitigate the error.

2.2 General Design Solution and Requirements

SG_STAMP2 has designed a system compatible with these general requirements over the course of the 2023 Fall semester. This system occupies a small footprint of around 2ft by 4ft, and stands at just under 2 ft high. It is to be implemented between two conveyors located on the output of the stamping press with the goal of catching bearings intermittently as they call form one belt to the other, and is expected to successfully identify a part as defective or effective at least once every 5 minutes. In order to potentially meet this requirement, the design has been designed to have a projected cycle time of around 1-2 minutes. Each cycle will involve collecting one or more components, filtering these components through a brush, analyzing both sides of the component, and relocating it in correspondence with the results. This system consists of two mirrored mechanical systems, and a stationary camera system for analysis.

2.3 Mechanical Systems

Each mechanical system has two parts: a linear actuator, and a flipper. The flipper is mounted to the linear actuator, and acts as the interface surface for the bearing housings. The linear actuator extends along the entire length of the system, and is used to position the flipper surface at various different stop-points. These stop-points include under the conveyor to catch parts, under the camera for part analysis, and somewhere in the middle to transfer the part to the other mechanical system. While both mechanical systems are identical, one is positioned lower than the other. The high mechanical system is used to initially collect parts, pull them through a filter, and position them under the camera for 1st side analysis. The low mechanical system is used after 1st side analysis for 2nd side analysis, and part relocation. The parts will either be relocated back onto the production belt, or into a discard bin if found defective.

The flipper is the premiere element of the mechanical systems, and exhibits rotation along an outer edge in the same way a book or laptop would. It is composed of two main surfaces, one that is stationary, and one that acts as a lid, rotating via a stepper motor. The lid rests atop the stationary platform, which acts as both a support for the lid, as well as for the motor so that the motor does not have to constantly idle. The top side of this lid is where components are placed, and between the 1st and 2nd side analysis, the high mechanical system flipper will rotate to just beyond 90°, flipping the component onto the other, lower flipper. This will allow both sides of the part to be analyzed by the camera system.

2.4 Camera/Analysis System

The camera system is a stationary section of the design and consists of a mount, the Keyence VS-L500MX AI driven camera, and a circular light used to enable the LumiTrax anomaly detection method in the camera. Each cycle, the camera's analysis system will be used a total of 4 times: twice to check the area of the flippers to verify the part is correctly positioned and is not obscured by another part, and twice to detect anomalies on the surface of that part. The three different anomalies it will look for are called scratches, trash, and deformation. This camera will be trained using Keyence's VS Creator software, and should be able to perform all necessary analysis within 5 seconds, sending a signal to the control computer unit via RJ45 ethernet.

The pixie 2.1 will be used to detect needle bearings coming down the assembly line and signal the control system to . It runs on a 3.3V power supply and is powered either by the cam port or the usb port of the raspberry pi. It is capable of analyzing videos of 1080p at 60fps.

2.5 Control System

The primary control unit used for this design will be Raspberry Pi 4B, which will interface with the camera(s), as well as the motors controlling the flippers and actuators. Adaptive or correctional movement will not be implemented into this design, so all motion will be described by specific positions or distances. The stepper motors allow for this due to their precise and predictable movement. For the majority of the system's active time, the controller will simply be iterating through a list of positional instructions for the motors. As the Keyence camera is the only input to this controller, the only times where it will alter the cycle path is when the flipper area is not clear, or a defective part is found.

3 Design Specifications

3.1 Capabilities

- CAP01: The device should be able to collect needle bearing housings
- CAP02: The device needs to be able to analyze collected raceways
- CAP03: The device needs to be able to sort the scanned raceways into good and bad containers
- CAP04: The device needs to be able to alert the stamp operator of a defective part
- CAP05: The device must not damage the raceways
- CAP06: The device must be able to determine when it is unable to complete its a retraction or extension
- CAP08: The device should have a lifetime of over 2 years
- CAP09: The total price shall not exceed 3000$ excluding the cost of the Keyence camera and its peripherals
- CAP10: The device shall have a reset switch

3.2 Requirements and performance Goals

3.2.1 Requirements

- REQ01: The device shall utilize a raspberry pi model 4 for its control system (CAP 1-10)
- REQ02: The device shall contain a Keyence VS series AI camera for part scanning (CAP02)
- REQ03: The device shall be capable of acurite extension and retraction (CAP01 CAP03)

- REQ04: The device shall utilize a Pixy 2.1 camera for exteroception. (CAP01)
- REQ05: The device shall have a brush to remove extra parts on the collection surface. (CAP05)
- The device shall contain a warning light to indicate a failure.(CAP04)

3.2.2 Performance goals

- REQG1: The device shall attempt to collect part every 1 min
- REQG2: Device shall provide a valid reading every 5 min
- REQG3: The device shall be able to perform a successful scan in 1 min

4 Design Narrative

4.1 Project Initiation

Our first method of preparation for our design was meeting within our industry contact at the kickoff meeting on August 30th. During this meeting, we were shown introductory information on the space we would be designing for, as well as the parts we would be checking for defects. After this, we scheduled a day to drive out to the manufacturing plant to see this space in person, and record information about more specific requirements. During this visit on September 13th, we took video recordings as well as 3D scans of the manufacturing space, and were able to learn more about how the bearing housings are assembled.
We were also able to gain access to Phase 1's design for the catching mechanism at the Schaeffler plant, and promptly stored it in our lab at EPIC. Once we had their design in hand, we began looking it over and determining what we could improve on or transfer over to our designs.

4.2 Research and Initial Design Ideas

4.2.1 Use of Electromagnets

Electromagnets were explored as both a primary and supplementary method of dealing with the raceways. It was determined that implementing electromagnets would not be an effective use of time as electromagnets have the ability to capture raceways efficiently but have very little control over their position or orientation. Another downside to the use of electromagnets is the extensive power and IO load for electromagnets.

4.2.2 Dual Hinging Boxes

Dual Hinged Boxes, as seen in Figure 1, was the design concept that drew the most from the work done by Phase 1. It was intended to not only have the same footprint, but to use the same actuator system utilized by the previous design. Dual Hinging Boxes had the primary goal of improving the most problematic aspect of Phase 1's design, which was their part catching and flipping mechanism. This design replaced the two 3D printed plates on Phase 1's design with two flipping mechanisms that would rotate around an edge axis to drop pieces. These mechanisms would be 3D printed boxes, and were designed to address the primary deficiency in the previous catching mechanism, which was that it had to part control if multiple parts were caught. Dual Hinging Boxes exhibited a small square indent on each of the flippers that was large enough to fit one part, but was not deeper than a single part's height, meaning if another one stacked on top of it, it would not be able to fit into the box. The hinging functionality of this design would both act as the part relocation mechanism, and a filter system, as in theory, tipping the box over the conveyor would cause all except for the bottom part to fall out, ensuring only one part would go through to analysis.

However, this design had two major flaws related to its feasibility from a support standpoint. First, it would likely be difficult to mount the motors necessary to drive the flippers directly to Phase 1's actuators due to the system potentially being too heavy, and second, the flipper motors would have to constantly be running to ensure the flippers would stay in an upright position. The second issue would be solved by adding supporting plates to the flippers, however mounting those would add more weight to the actuators, exacerbating that issue. In summary, Dual Hinging Boxes was a design very similar to Phase 1's design, but that utilized flipping boxes to improve part control.

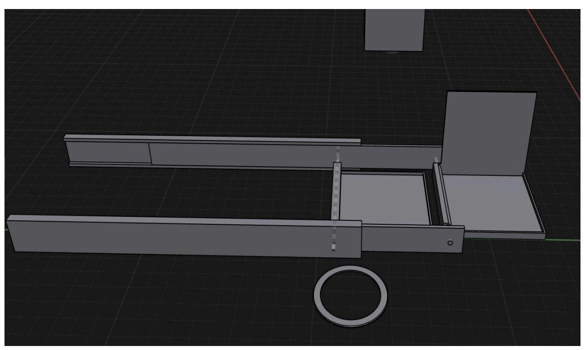


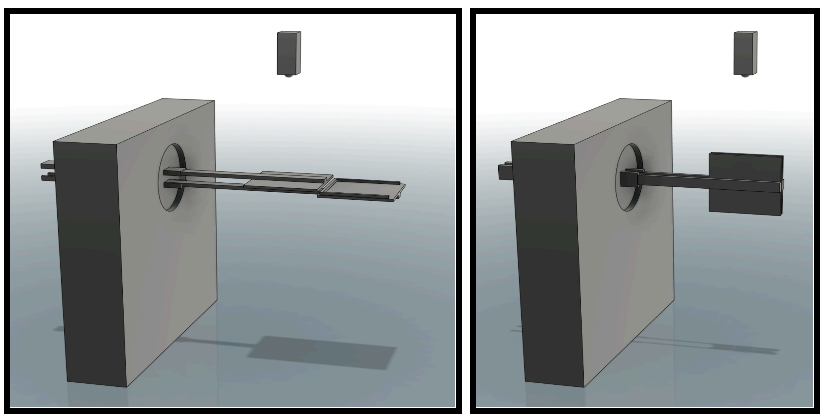
Figure 1: Dual Hinging Boxes Design

4.2.3 Industrial Manipulator Arms

For the initial brainstorming phase, two design possibilities that came up incorporated different process executions. One of the designs would use a hooking mechanism to extend to the conveyor and clamp one of the bearings onto itself. From there the hook would drop the bearing onto a flat surface where the system could then proceed to analyze the bearing. This idea was specifically tailored to the grabbing portion of the system as that was one of the required steps. In other words, the complete layout was not considered in detail. Similarly, the idea of a manipulator arm came to mind when brainstorming catching designs. Like the hook, the arm would reach over to the conveyor belt and grab a bearing at random. At that point, the arm would retract and present itself in an effective manner to the camera. The arm would need to present the part in its entirety without covering any edges. The arm would rotate 180 degrees in order to present the other side of the bearing to the camera. We explored both off the shelf and DIY manipulator options however these were deemed both too complicated and costly to implement.

4.2.4 Two Rotating Plates Design

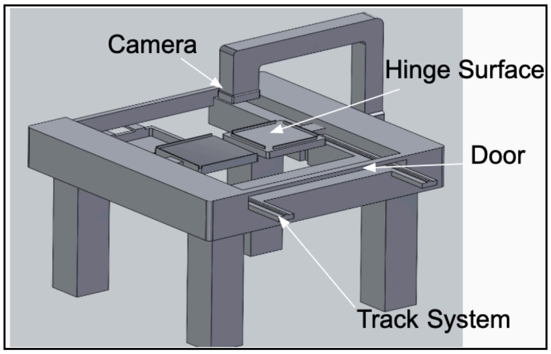
The two rotating plates design, as seen in Figures 2a and 2b, utilized two catching plates with linear extending actuations and a gimbal to rotate the plates. The idea behind this design was to use a similar flat catching surface that was able to be extended to extract a bearing from the assembly line and place it under the camera. The plate would then retract to line up with the second plate, where a gimbal would rotate the two arms to scan the other side of the bearing. The idea would be to use the clamping force of the two plates, as well as exterior walls to eliminate the bearing from sliding out of the plates during rotations. The team's major concerns with this design was its ability to accurately maintain the part between the plates and a lack of force between the plates due to the geometry. The industry supporter also had a concern with the height differences in the bearings produced on the assembly line. The varying height of the bearings would result in a contact force if the bearing height was greater than the distance between the plates, and a loosely held bearing if the part height was less than the distance of the plates.



Figures 2a & 2b: Two Rotating Plates design in different positions

4.2.5 Flat Surface Hinging Mechanism with Doorway

The Flat Surface Hinge Design, as seen in Figures 3a and 3b, was one of the first ideas for a design by the SG_Stamp 2 team. The design would use two linear actuators moving on a track system to move the two flat surfaces. One flat surface would extend to catch the part coming off the conveyor belt, and once the part was extracted, the plate would retract through a doorway to sweep off excess parts and ensure one bearing on the plate. The first side of the part would then be presented to the camera in the middle of the two plates. Once it was scanned, a servo motor would rotate the plate to 95 degrees, allowing the part to flip onto the next flat surface where the second side would be scanned. The second linear actuator would then sort the part back onto the conveyor belt or in a bad parts bind depending on the condition of the part. However, the doorway was determined to cause jamming if the bearings were not flat on the catching plate due to its rigidity. Also, the placement of the design of the side-by-side plates was unable to be seen by the camera system due to its field of view. These factors were determined prior to the CDR which resulted in the need for a new combined design to eliminate these risks.



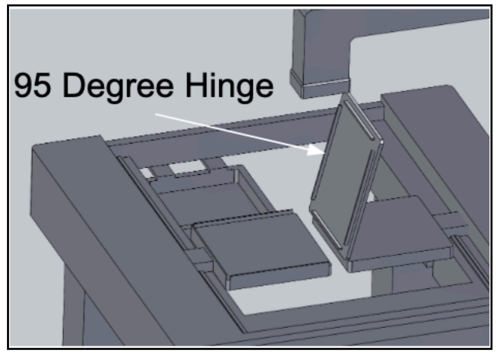


Figure 3a (left): Flat Surface Hinging Mechanism with Detailed Structures
Figure 3b (right): Hinging Mechanism of Design

4.3 Determining Design Finalist

Of the final designs, the Flat Surface Hing and the Dual Hinging Boxes were deemed to be the most effective. This was done via a decision matrix which scored each design relative to its competitors, using weights to delineate which aspects of the design should matter more to our decision (see Table 1). We received positive feedback on the Dual Hinging Boxes design in particular from Alex Perry, our industry sponsor, during the CDR. Thus, we decided to build a second decision matrix (see Table 2), where we could weigh it against improved designs we would develop using other CDR feedback.

The team decided to combine ideas from the two finalist designs and make a design that would perform to the project specifications while reducing risk. By combining the flipping mechanisms in the Dual Hinging Box design with the track system and door-fliter of the linear actuator, the final design was able to minimize wear on the motors while having additional part control.

Weight	1	3	2	1	1	2	1	1.5	0.5	
Designs	Cost	Collection Consistency	Mechanical Complexity	Control System Complexity	Coding Difficulty	Wiring Difficulty	Power Requirements	Work Required of Operator	Ease of Transport	Total
Flat Surface Hinge	4	4	4	5	5	4	3	5	3	54
Dual Hinging Boxes	5	2	5	4	4	3	5	2	4	45
Industrial manipulator	1	5	2	5	2	5	1	3	1	43
Two Rotating Plates	3	3	3	2	3	2	4	4	2	38
Magnetic Manipulation	2	1	1	1	1	1	2	1	5	17

Table 1: Decision Matrix for CDR Presentation

Weight	1	3	2	1	1	2	1	1.5	0.5	
Designs	Cost	Collection Consistency	Mechanical Complexity	Control System Complexity	Coding Difficulty	Wiring Difficulty	Power Requirements	Work Required of Operator	Ease of Transport	Total
Hybrid Hinge Design	1	3	2	1	2	3	2	2	3	29.5
Dual Hinging Boxes	2	2	3	1	1	3	1	2	3	27.5
Phase 1 Prototype	3	1	1	1	3	2	3	3	2	24.5

Table 2: Post-CDR Decision Matrix for Combined Design

4.4 Final Design

The modeling for the final design started by importing CAD files of the two linear actuators into Autodesk Fusion 360, which was the primary software tool used for this project. The actuators were rigged so that the platforms could be slid in a realistic way, and preliminary cad models of the flipping mechanism were assembled and rigged for realistic movement as well. Once all of the moving parts were placed, a frame of 80x20 aluminum was constructed around the actuators, grounding the design. After this, the parts of the flippers went through multiple iterations, and eventually the camera and lighting files were added for the render used for our expo poster which is shown below in Figure 4.

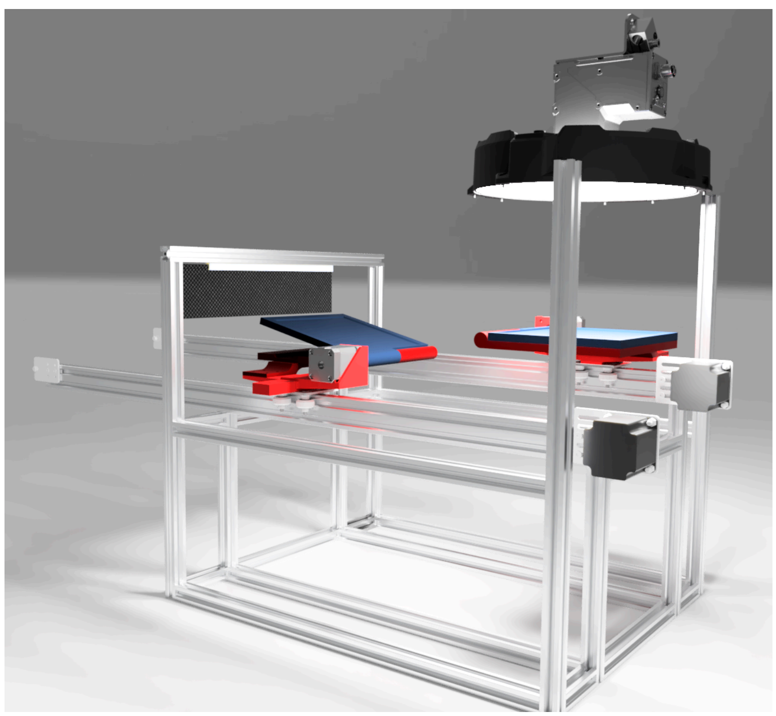


Figure 4: Final Design CAD Render

4.4.1 Included Systems in Model

Every single part of the flipping mechanisms is 3D printed, meaning we had full control over what our parts looked like. The basic design of a baseplate and top plate connected via a bearing stayed constant throughout the modeling process, however the part that underwent the most iteration was the actuator platform. The actuator platform acts as the interface between the flipper and the actuator, and due to this, it has to interface perfectly with both our custom parts, and the prebuilt mounting plate on the actuator. This platform supports the motor mounting solution, as well as a custom bracket designed to support the baseplate. It also could not be flush with the actuator mounting plate, since blots protruded out of the plate, so it had to be designed with an envelope that left room for those bolts. This ment it could only be connected to the plate via two locations, and so pins would have to be used to help it slot into the plate in a stable way. We also choose to taper the underside of this platform to give it more structural integrity against bending, as it will likely have to support weight changes from side to side frequently due to the uneven load across it. Finally, on the side of this platform that faces outside of the design, we added an extrusion to hold a counterweight to help balance out the flipper hanging off one side of it. This addition is important so that the actuator wheels have even contact with the track. The complete assembly of the hinging mechanism is shown below in Figure 5. The part drawings for each component listed below are shown in Appendix A.

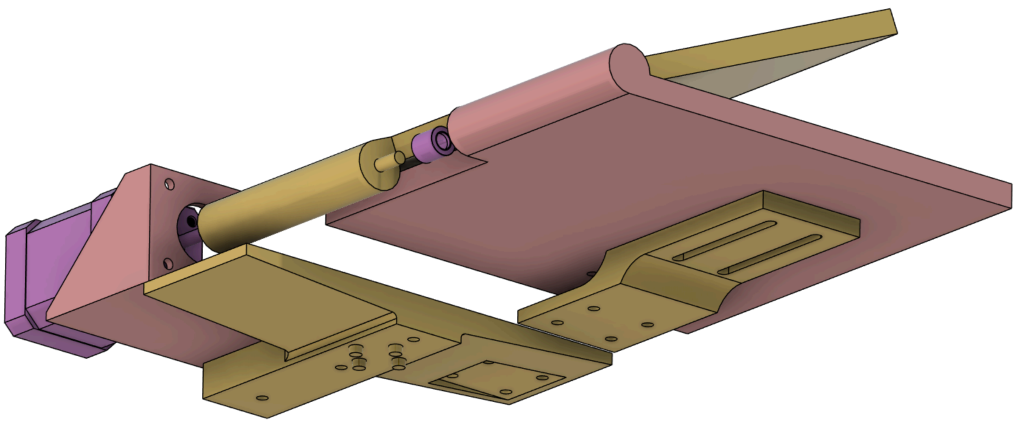


Figure 5: Exploded Assembly of the Hinging Plate Mechanism

4.4.1.1 Motor Mount

The Motor mounting solution was relatively simple, and has only been altered twice. It is a plate with two walls, one of which has the profile of the motor’s holes cut into it. Due to our motors' small size, the mounting can be relatively light and thin, although depending on results from early testing, we may need to add additional connection features, since it is currently only affixed via two fasteners.

4.4.1.2 Platform to Plate Bracket

The bracket connecting the bottom plate to the platform is integral for our design's main strength, which is how it can minimize stress on the motor. This bottom platform and bracket act as a surface that the flipper can rest on while it is not moving, and the bracket acts as the part keeping that platform rigid and level. The corners of this bracket are curved to minimize the effect of any tensile force on it, and the reason it couldn't have been a simple block is because it has to be out of the way of the bottom flipper when the top flipper passes over it. While there are other, simpler solutions to designing a bracket like this, we found this design to be sufficiently strong, while also being very light, and minimally intrusive. The final design choice of this bracket was to have the connection feature between it and the bottom plate be a slot and not a hole. This was so that the distance between the motor and our flipper could be adjusted as needed, and since this piece in particular is critical to holding the flipper together, using slots allows more flexibility in what the position is, so that it can be fine tuned and optimized during real world application.

4.4.1.3 Bottom Stationary Plate

The bracket directly interfaces with the bottom plate, which is a simple rectangle with an intent to allow fasteners to be inserted from the top. Together with the top plate, it makes up the rotational axis that is driven by the motor, and the bottom plate in particular, acts as the outer half of this axis. The reason for this is that since it is fastened to the platform via the bracket, and therefore can be used to lock the motion of the bottom plate so that it cannot slide off the motor. This part will likely be optimized later on to reduce overall weight and part footprint, since making it a full square is unnecessary, however this does not need to be implemented until rapid prototyping begins.

4.4.1.4 Top Flipping Plate

The final element of the flipper system is the top flipper. This part is the same size as the bottom plate, and interfaces with both a bearing within the axle of the bottom plate, and the motor. The top surface of the flipper will have an intent that is sufficiently large enough to hold the biggest part, but not large enough to hold two of the smallest parts. This intention is slightly shallower than the height of the tallest part so that as the flipper passes underneath the brush, all parts that are not in the indent can slide off of the flipper. Initially, our indent design incorporated tapered edges to help parts slide out during the part filtration process outlined by the Dual Hinging Boxes design, however this may end up changing in the future depending on how effective the brush design is, and whether or not it inhibits our ability to flip pieces over, as they might slide out instead of flip.

4.4.2 Excluded Systems From Model

While the CAD design is intended to be representative of our final product, there are certain elements of the design we did not choose to implement in the model. The reasoning behind these exclusions vary and the following paragraphs will outline this reasoning.

4.4.2.1 Actuator Belt, Wiring, and Control Board

Including the belt would have been possible, however it would have clipped through the platform as it moved along the track, and so we decided to not include it for design clarity. The wiring and control board could have been very difficult to model accurately, and since they depend solely on the placement of our other components, and no components depend on their placement, it did not make sense to add them.

4.4.2.2 Discard Bin and Schaeffler Conveyor

The placement of these items should be the last thing factored into the design, since it can be changed, and our design should be as modular as possible since it is meant to be a proof of concept that could be improved upon and replicated for different production lines.

4.4.2.3 Camera and Lighting Mounts

While these would have been useful to include into the design design, we are planning to use a mounting solution built by SwivelLink, and the cad models provided from that website of the arm we would use is not editable in Fusion 360, and therefore we would not be able to position it properly. We do plan to add in the lighting mount later, however since our lighting system was finalized recently, we have not had time to implement its mount into the model, although we do know the method we will use.

4.4.3 Rapid Prototyping

We decided to use PLA filament for 3D printing the stationary and flipping plates, as well as the bracket and motor mount. PLA was chosen because of its durability, cost effectiveness, and ease of use. At first, the team wanted to use personal 3D printers due to ease of access. However, Schaeffler offered the team access to the 3D printing software at their facility. To decide where to print, we decided to do test prints at both locations.

Using the personal 3D printer called the Ender-3, the team noticed that Hatchbox PLA at 1.75 in diameter was printing more solid parts, while still having perfect shapes for where the parts would connect with fasteners. In order to print the part at first, the layout of the part on the printer bed was planned using Ultimaker's Cura software. The parts would contain 20% infill with 3 walls which would reduce print time while ensuring part integrity.

While printing at the Schaeffler location, the team used a different brand of 3D printing filament called Bambu with the X1-Carbon printer. The printer had faster print times compared to the Ender-3, while also having decent accuracy with the same print parameters. However, the Bambu filament did not seem as durable as Hatchbox filament, and also sagged around holes. These shortcomings resulted in us printing all parts in-house.

4.5 Risk Mitigation and Failure Analysis

Prior to the Preliminary Design Report, the team analyzed the final design to determine the risks and possible failure modes. From this analysis, a Failure Mode and Error Analysis (FMEA) was completed to analyze the severity of the risk, and possible ways to mitigate from the design. Table 3 shows the color key and meaning of the severity values of each failure mode.Table 4 shows the resulting FMEA from the team's analysis.

Probability	Severity			
	1	2	3	4
	Catastrophic	Critical	Marginal	Negligible
A-Frequent	1A	2A	3A	4A
B-Probable	1B	2B	3B	4B
C-Occasional	1C	2C	3C	4C
D-Remote	1D	2D	3D	4D
E-Improbable	1E	2E	3E	4E

Table 3: Failure Mode and Error Analysis Severity Determination

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC
Jamming of Bearing	Hard Brush; not enough clearance for parts to fall correctly off of catching tray	Catching Tray could potentially fracture, or actuator motor could break due to excess force	1A	Flexible Brush, Higher Clearance between sliding mechanism to act as a secondary, Manipulate electrical system to power off if excessive voltage is determined	Design Change, Electrical System	3D
Moment Load on Hinging Mechanism Motor	No Support for Catching Tray	Lead to motor failure, or decreased life of motor	2B	Change to Stepper Motor with a higher holding torque, Add bottom plate and holding arm to eliminate moment loads	Design Change	4C
Moment Load on Linear Actuator	Catching Plate Design would lead to moment load on the device	Slower motion of actuation or Possible Failure of the Actuation System	1A	Counter weight added to the hinging plate mechanism to balance load along the centerline of actuation	Weight Analysis	4C
Flipping of Bearing	Low coefficient of friction between plate and bearing during rotation	Part does not correctly flip, camera will be unable to scan both sides of part	1B	Sliding Friction Analysis to determine angle of slip, Deeper catching tray to ideally cause part to flip, add rubber strip to tray to flip instead of slide	Analysis and Design Change	3C
Camera Incorrectly Scans Part	Lighting Errors, very small defects, Incorrect Part placement	Faulty part added back to assembly line	1A	Camera Experimentation, could add all parts scanned to a box instead of assembly line	Experimentation	4B
Incorrect Positioning of Catching Plates	Complex cycle of positioning could lead to additive error over time, Stretching Pulleys lead to inconsistent movement	Device no longer catches accurately, Pulley needs to be tightened	2C	Analyze life cycle of pulley system, calibration if positioning is incorrect	Life Cycle Analysis	4C
Depletion of productivity by the electrical system	Extended use over time. Not a high risk hazard leading to substantial consequences.	Wear or minor malfunctions of the electronic devices	2D	One way to alleviate or have a better idea of this risk would be to extensively research the likelihood of it happening. Depending on the life cycle, repairs or replacement of the devices may be necessary.	Life Cycle Analysis. Minor Maintenance	4D

Table 3: Failure Mode and Error Analysis Results

From the FMEA, the team was able to successfully determine the failure modes of the current design. The team then worked to address each failure mode (see Table 3) on the design. After completing the FMEA, all failure modes were determined to be negligible except the flipping of the bearing and incorrect scans by the camera. For the flipping of the bearing, the theoretical motor speeds and friction were determined to allow the part to flip to the second actuator rather than sliding down the hinging surface. We believe this could be a potential issue experimentally, but will work with motor speed and surface contact to help alleviate this risk. As for incorrect scans by the camera, the risk is likely low, but this could result in faulty parts added back to the assembly line. We believe through experimentation, this risk could be eliminated by placing all scanned parts in a box for secondary processing by an operator until the camera system is working properly.

5 Adherence to Engineering Standards and Codes

Before the SG_Stamp 2 team could begin on the design part of the project, engineering standards and codes had to be researched to allow safety regarding installing, operating and maintaining to take place. The first code researched was IEC 60204-1: Safety of Machinery Including Electrical Equipment which states safety of persons and property, consistency of control response, and ease of operation and maintenance. This code will make sure that no damage will come to any person or property in the workplace and will have a controlled response to any electrical failure.

The engineering code IEEE 2755.1-2019: Taxonomy for Intelligent Process Automation Product Features and Functionality was also structured into this project for the software that would be used in the Keyence camera and catching mechanism. This code is used as a guideline to allow participants to have a better understanding of SBIPA and to rely on a product manufactures functionality claims used to produce those functions.

Code IEEE P3110: Standard for Computer Vision (CV) - Technical Requirements for Algorithms Application Programming Interfaces (APIs) of Deep Learning Framework was used for the data set of the algorithm development that the software from Keyence will be using.

6 Impact

While our project seems to be relatively distant from a substantial or widespread impact, the mission behind it is one that drives decisions that do often impact industry in larg ways. Our product is a quality control system, and more specifically, it is an early stage defect detection system. Many companies like Schaeffler vertically invest large sums of resources into end of the line quality control, where they test parts at the end of manufacturing with rigorous and precise tests to make sure bad parts do not get shipped to customers. On the surface this seems like it would be enough, since often, like is the case at Schaeffler's Fort Mill 1 plant, this system is able to catch any and all defects. However, if it does catch a defect, it is important to realize the effects that those parts have already had on your company's resources. Those parts may have spent days or weeks in production getting assembled and treated, processes which can be very costly. While a consumer and reputation crisis is averted, there is still a major blindspot of end of the line systems. Early stage systems like ours help fill this blindspot, and do not need to have the same levels of investment or quality control strength to be effective. Systems like ours will be able to make an impact in the following ways:

6.1 Consumer Safety

Our device adds an extra layer of protection for the end user of needle bearings. These parts are used in power distributors and transmissions of vehicles and are placed under extreme loads. A failure of one of these parts would put the passenger in harm's way thus a redundant check on the integrity of these parts ensures that no defective part reaches an application point.

6.2 Resource Efficiency

The Schaeffler Group produces thousands of these parts per day and they are put through a rigorous treatment process. This process is both time consuming and expensive to perform. Our system has the potential to prevent wasting of time resources on defective raceways.

6.3 Company Reputation

A company's reputation is its life as such our device protects Schaeffler's reputation with their clients by preventing them from receiving parts that are out of spec.

7 Bill of Materials (BOM)

The complete Bill of Materials (BOM) for this project is outlined below in Table 5. This table splits the materials needed for this project into their respective subsystems. The resulting parts combine to a final cost of $744.50, excluding the camera and lighting system provided by Schaeffler. The camera and light used for this project will be the Keyence VS-L500MX camera and CA-DRM20x light. The final cost for the camera, lighting system, and key operating components will be $18,800. The final cost for all components will be $19,544.30 including all components purchased by the team and provided by Schaeffler.

Hinging/ Movement Mechanism				
Item	Quantity	Unit Cost	Total Cost	Vendor
V-Slot NEMA 23 Linear Actuator Bundle (1000mm, Silver)	2	$150.00	$300.00	Openbuild

Top Catching Plate - 136g (PLA)	2	$0.02/gram	$5.17	Amazon
Bottom Plate - 158g (PLA)	2	$0.02/gram	$6.00	Amazon
Base Plate - 36.3g (PLA)	2	$0.02/gram	$1.38	Amazon
Hinge Motor Mount - 27.2g (PLA)	2	$0.02/gram	$1.05	Amazon
Support Bracket - 46g (PLA)	2	$0.02/gram	$1.75	Amazon
Roller Bearing	2	$13.28	$26.56	McMaster Carr
NEMA 17 Stepper Motor	2	$76.25	$152.50	McMaster-Carr
Base to Gantry Plate Screws	10	$0.79	$7.91	McMaster-Carr
Support Bracket Screws	25	$0.54	$13.50	McMaster-Carr
M5 Hex Nuts	100	$0.04	$3.56	McMaster-Carr
M5 Washers	100	$0.04	$3.52	McMaster-Carr
Electrical/Camera Components				
Item	Quantity	Unit Cost	Total Cost	Vendor
Raspberry Pi	1	$66.00	$66.00	Amazon
Pixy2 Camera	1	$75.00	$75.00	adafruit
12V Power Supply	1	-	-	Phase-1
Wires	1	$15.95	$15.95	Amazon
PWM/Servo HAT	1	$17.50	$17.50	Adafruit
Channel Relay Module	1	-	-	Pre-purchased
Boost Converter 12V to 24V	1	$6.99	$6.99	Amazon
Camera Power Cable	1	-	-	Keyence
Frame/Mounting Components				
Item	Quantity	Unit Cost	Total Cost	Source
T-slotted Frame Structural Bracket	1	$8.29	$8.29	McMaster Carr
T-Slotted Framing Rails	1	$8.67	$8.67 / 1ft	McMaster Carr
T-Slotted Framing Levels	1	$27.94	$27.94	McMaster Carr
Sweeping Brush	1	$10.81	$10.81	McMaster
Total Cost w/o Camera System			**$744.30**	
Total Cost w/ Camera System			**$19,544.30**	

Table 5: Final Bill of Materials from Senior Design 1

8 Budget

Table 6 below includes the resources and miscellaneous that have been or may be used within the completion of this project. This gives an idea of what it would cost someone (outside education privileges) to recreate this project. In our position, most of these resources have cost little to nothing due to being a student which is why it is not taken into consideration in our bill of materials or costs. That's not to say, however, that there are still some other costs that are important to include in the budget.

Resources/Miscellaneous	**Cost of Purchasing/Licensing**	**Cost for the Team**
AutoCAD Software	$245/month * 8 months	$0
EasyEDA Software	$19.9/month * 8 months	$0
Coding Software/Training	$3000-$5000	$0
Keyence Software Training	$100	$0
3D Printer	$250-$3000	$0
Tools	$100-$300	$0
Trips to Schaeffler	Varies	$20/trip * 4 trips
Keyence Camera and Lighting System	$20,000	$18,800

Table 6: Budget of Resources and Softwares Needed and the Respective Costs

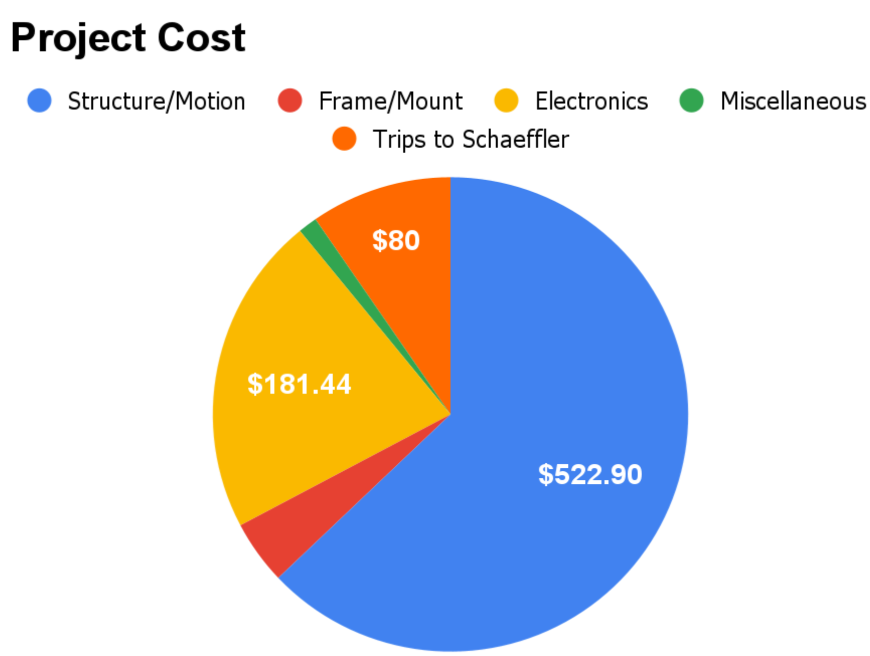


Figure 1: Project Cost w/o Keyence Camera

Total Cost: **$831.38**

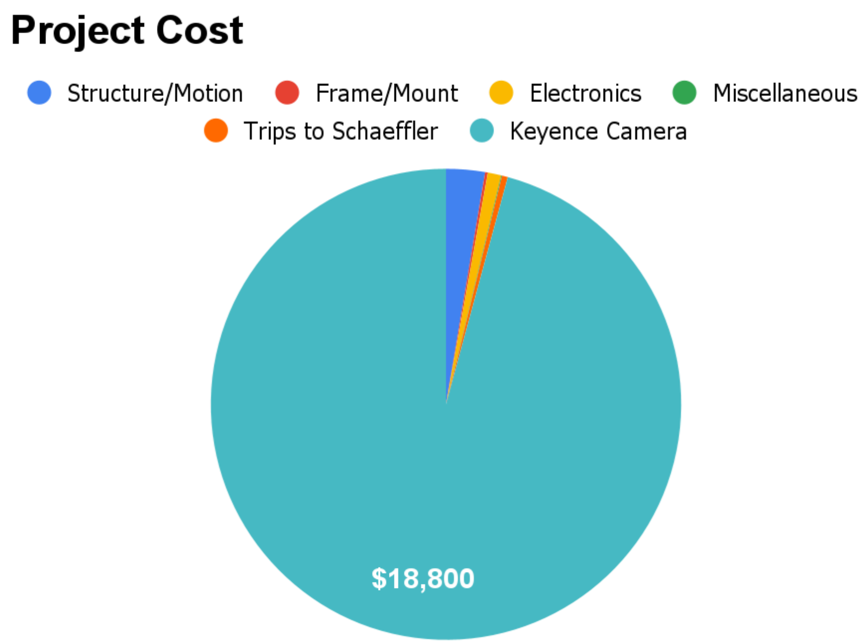


Figure 2: Project Cost with Keyence Camera

Total Cost: **$19,631.38**

9 Conclusion

Following the SOW(Statement of work) and specifications needed for the project, the SG_Stamp 2 has successfully designed the catching mechanism with the Keyence camera attached while staying within the budget limits. The bill of materials includes all parts that will be ordered or have been ordered at the price quoted. A full analysis of the project has been completed impacting the workplace in terms of safety, financially, and reputation in the engineering community. The project also adheres to engineering standards and code through multiple codes that affect the software, automation and safety of machinery. Following the design expo on December 8th, 2023, the team will retrieve the components ordered from ISL and begin prototyping the project.

10 References

1. Adams, Max. *Keyence Camera Quotation*. Document. KEYENCE CORPORATION OF AMERICA, *2023* (accessed December 2023).
2. Ayers, Josh, & Bussard, Alex, & Garraghty, Slade, & Lamar, Aiden, & Medrano, Steven. *Bill of Materials*. Excel Spreadsheet. SG_STAMP2, *2023* (accessed December 2023).
3. Ayers, Josh, & Bussard, Alex, & Garraghty, Slade, & Lamar, Aiden, & Medrano, Steven. *Project Plan*. Formal Documentation. SG_STAMP2, *2023* (accessed December 2023).
4. Ayers, Josh, & Bussard, Alex, & Garraghty, Slade, & Lamar, Aiden, & Medrano, Steven. *Progress Report 2*. Formal Documentation. SG_STAMP2, *2023* (accessed September 2023).
5. *Canvas Additional Resources Page: CMS Guidelines*. https://canvas.instructure.com (accessed September 27, 2023).
6. Mercer, Cameron, & Vujicic, Borna, & Hagler, Kevin, & Pruitt, Blake, & Taraz Ali, & Medina, Alan. *Final Report*. Formal Documentation. SG_STAMP1, *2022* (accessed December 2023).
7. Perry, Alex. Direct communication with the team leader via email. August-September 2023. “Selecting Stepper Motors.” *UNC Charlotte Engineering Tool Kit*, eng-resources.charlotte.edu/unccengkit/mechanical/motors/selecting-stepper-motors/. Accessed 31 Oct. 2023.

11 Appendices

Appendix A: Drawings

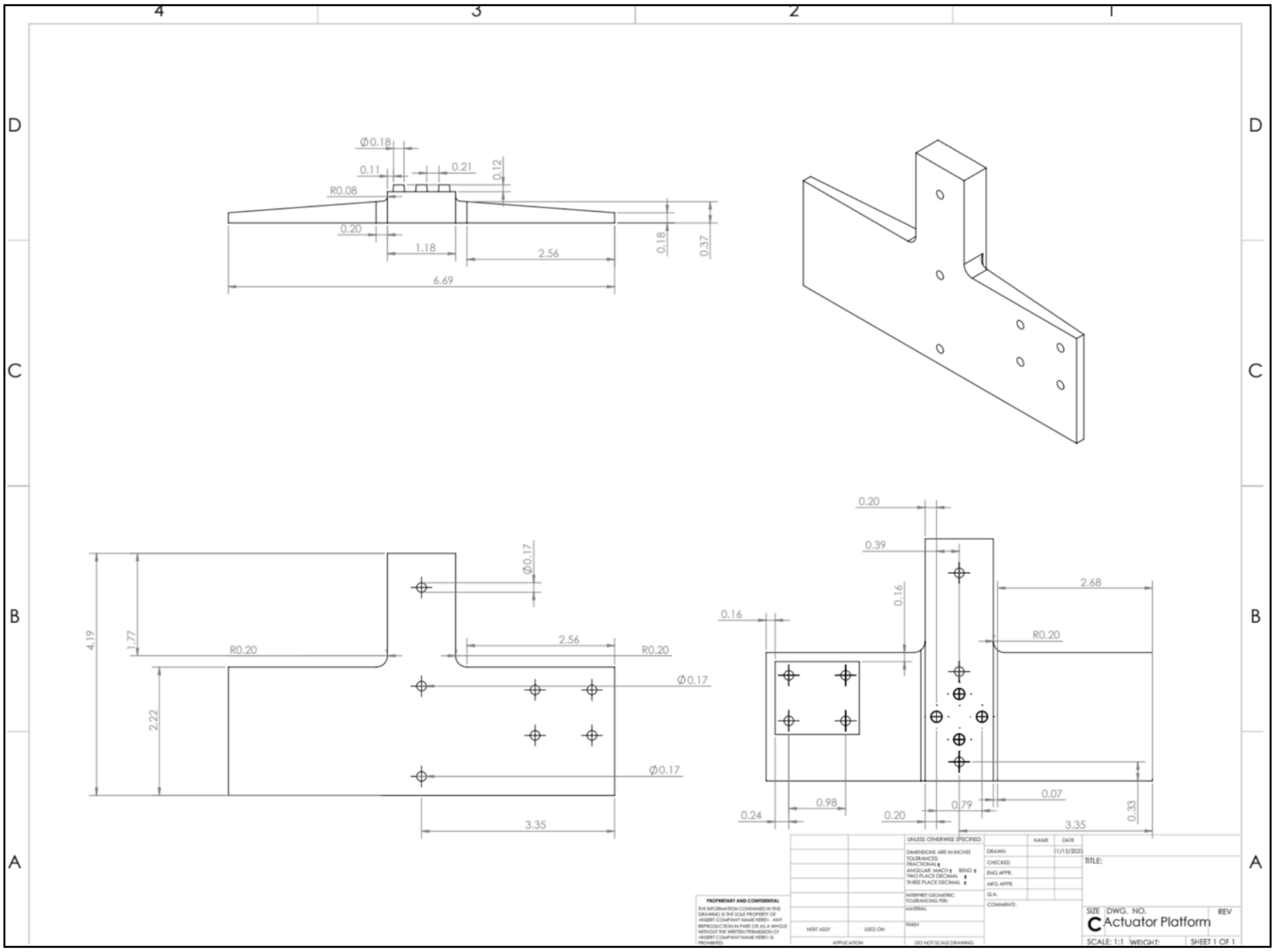


Figure A1: Part Drawing for the Connecting Platform to the Linear Actuator

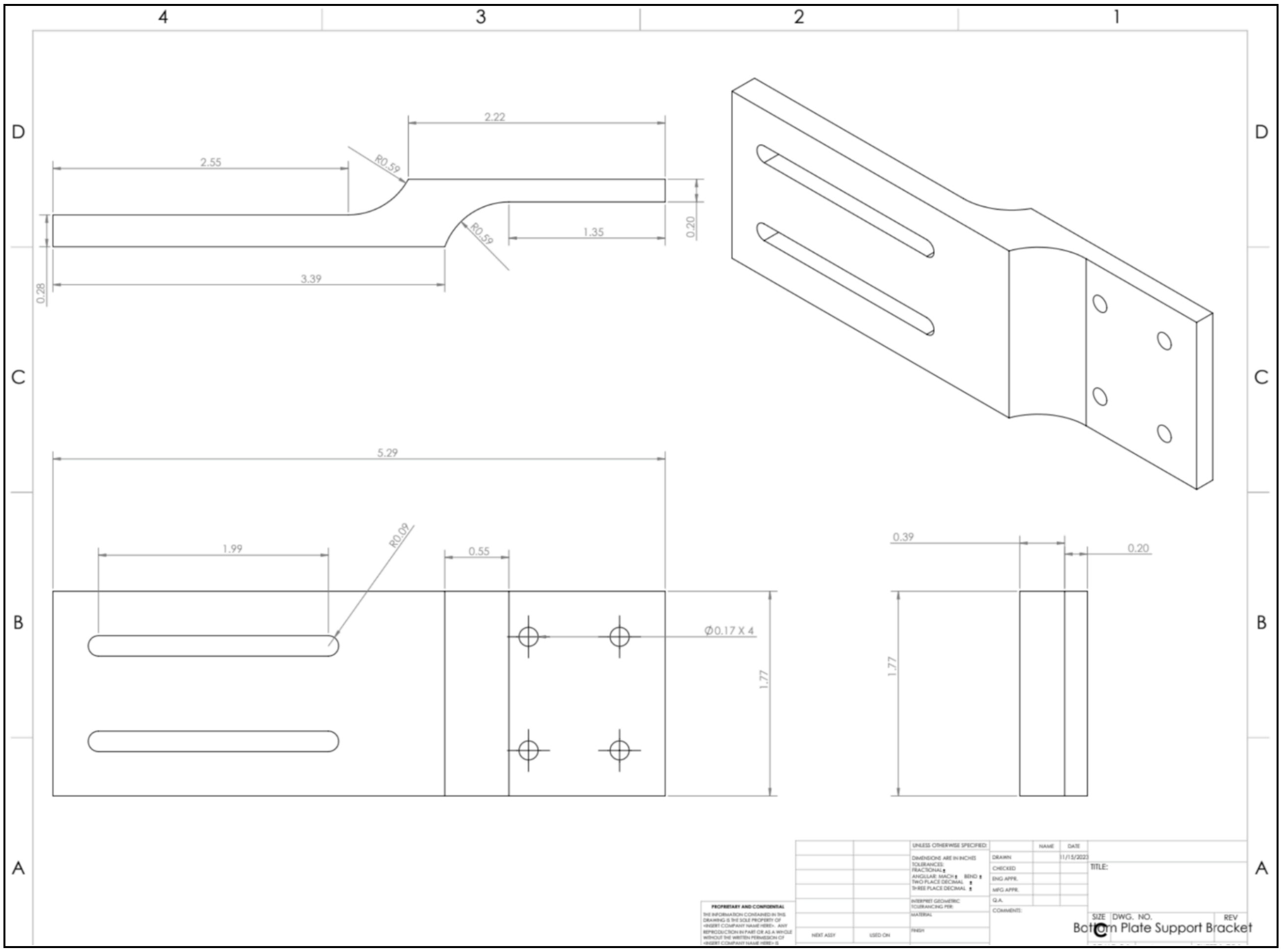


Figure A2: Part Drawing for the Plate Support Bracket

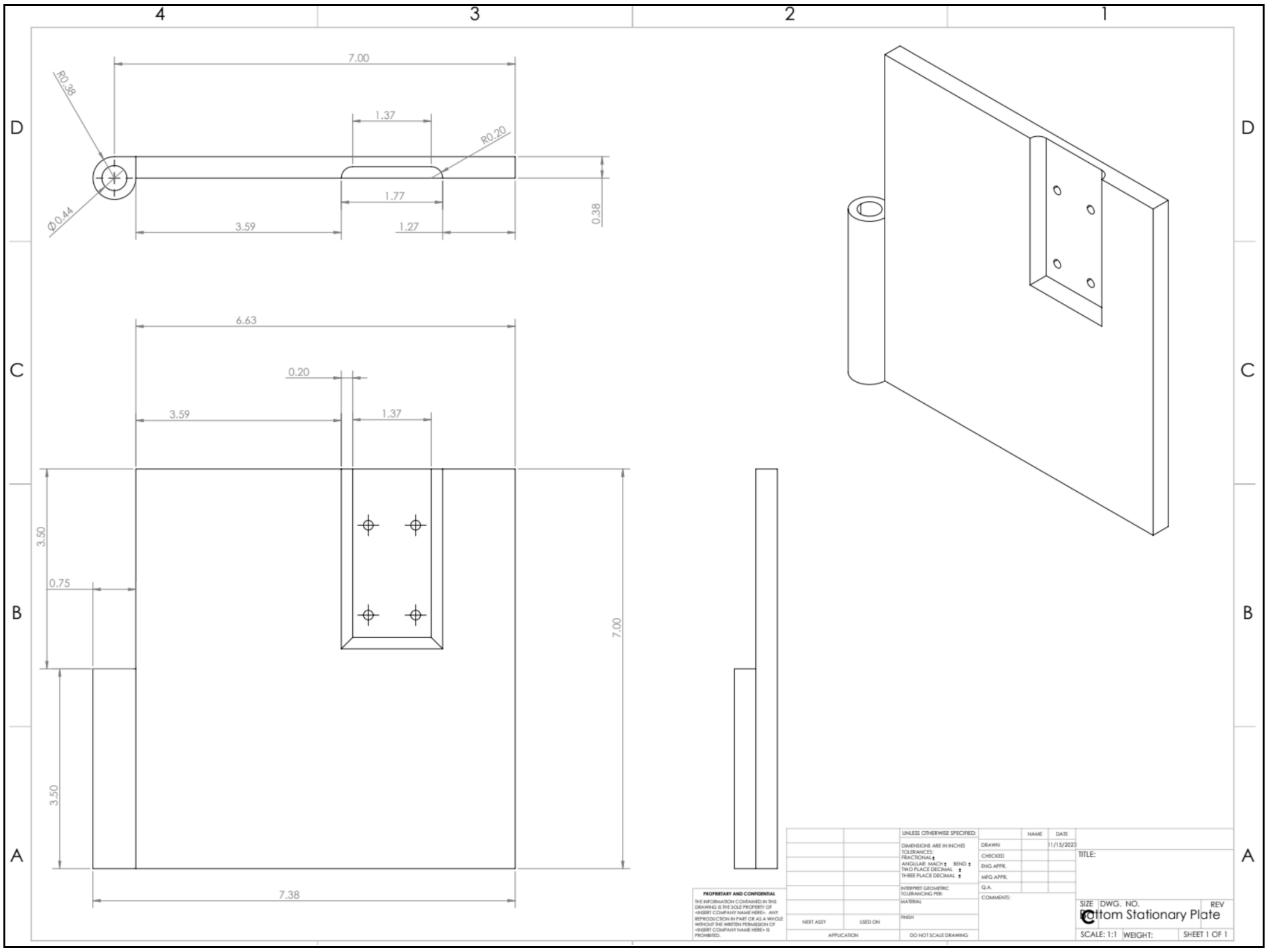


Figure A3: Part Drawing for the Bottom Stationary Plate

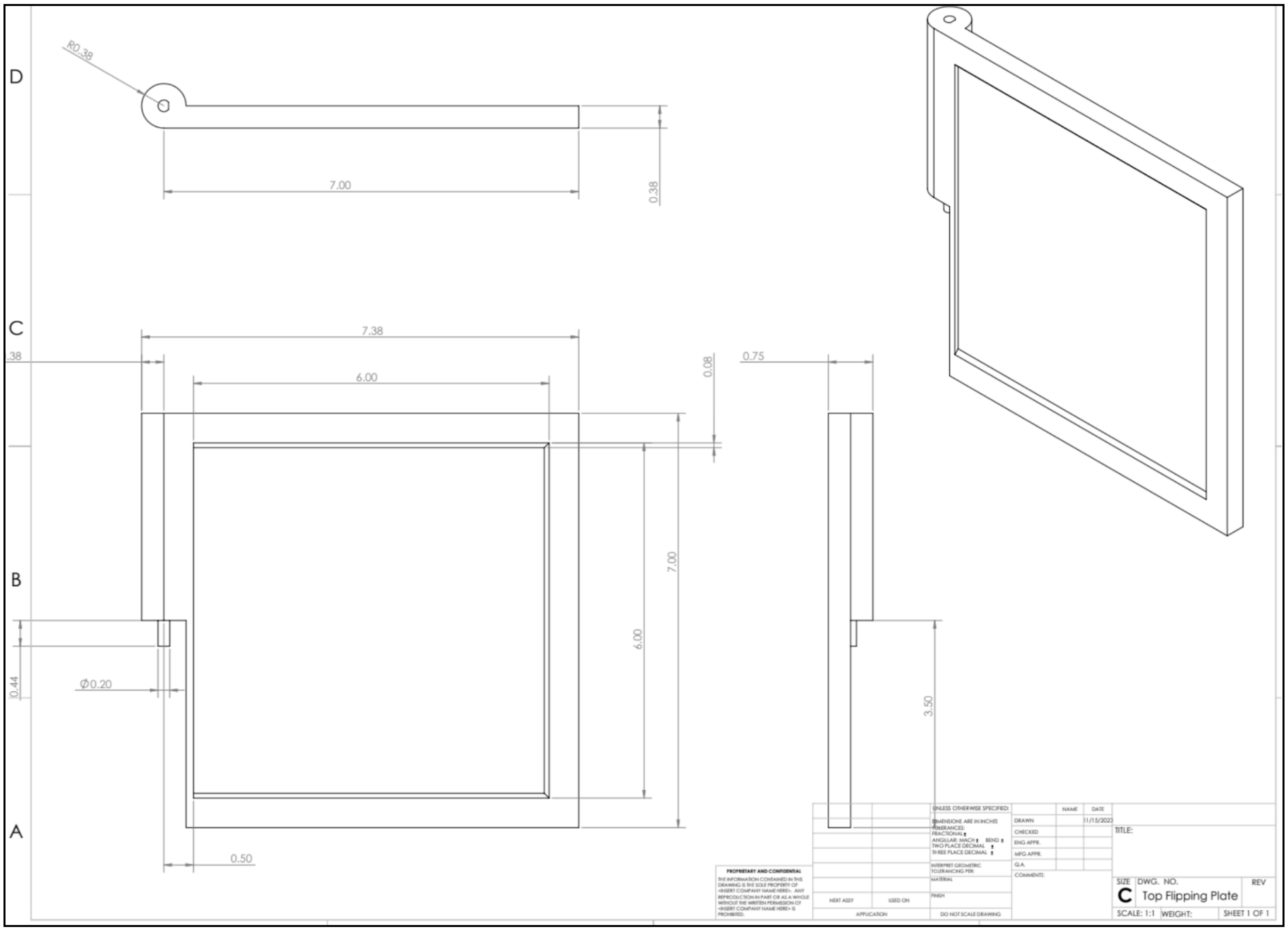


Figure A4: Part Drawing for the Top Hinging Plate

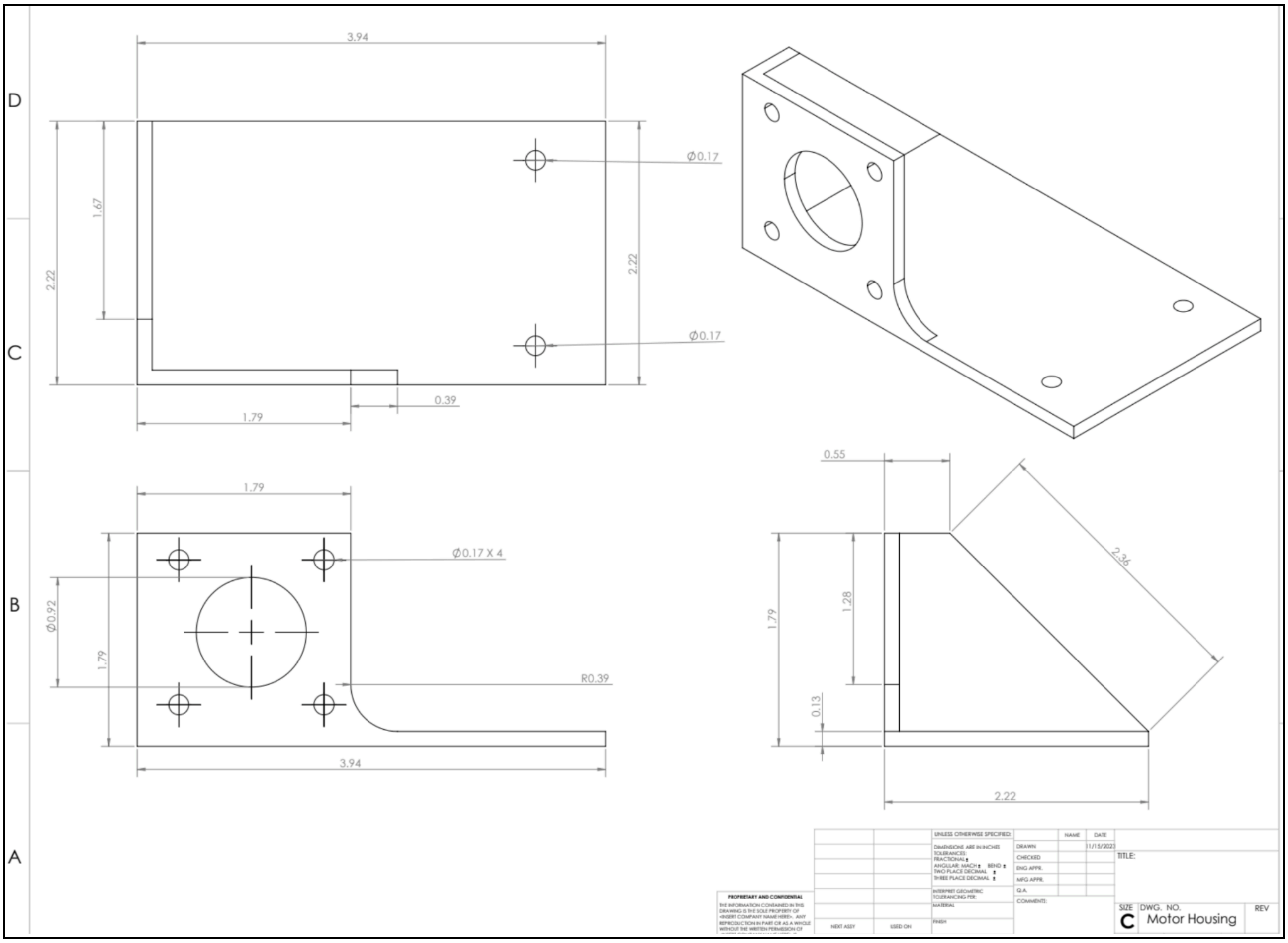


Figure A5: Part Drawing for the Motor Housing

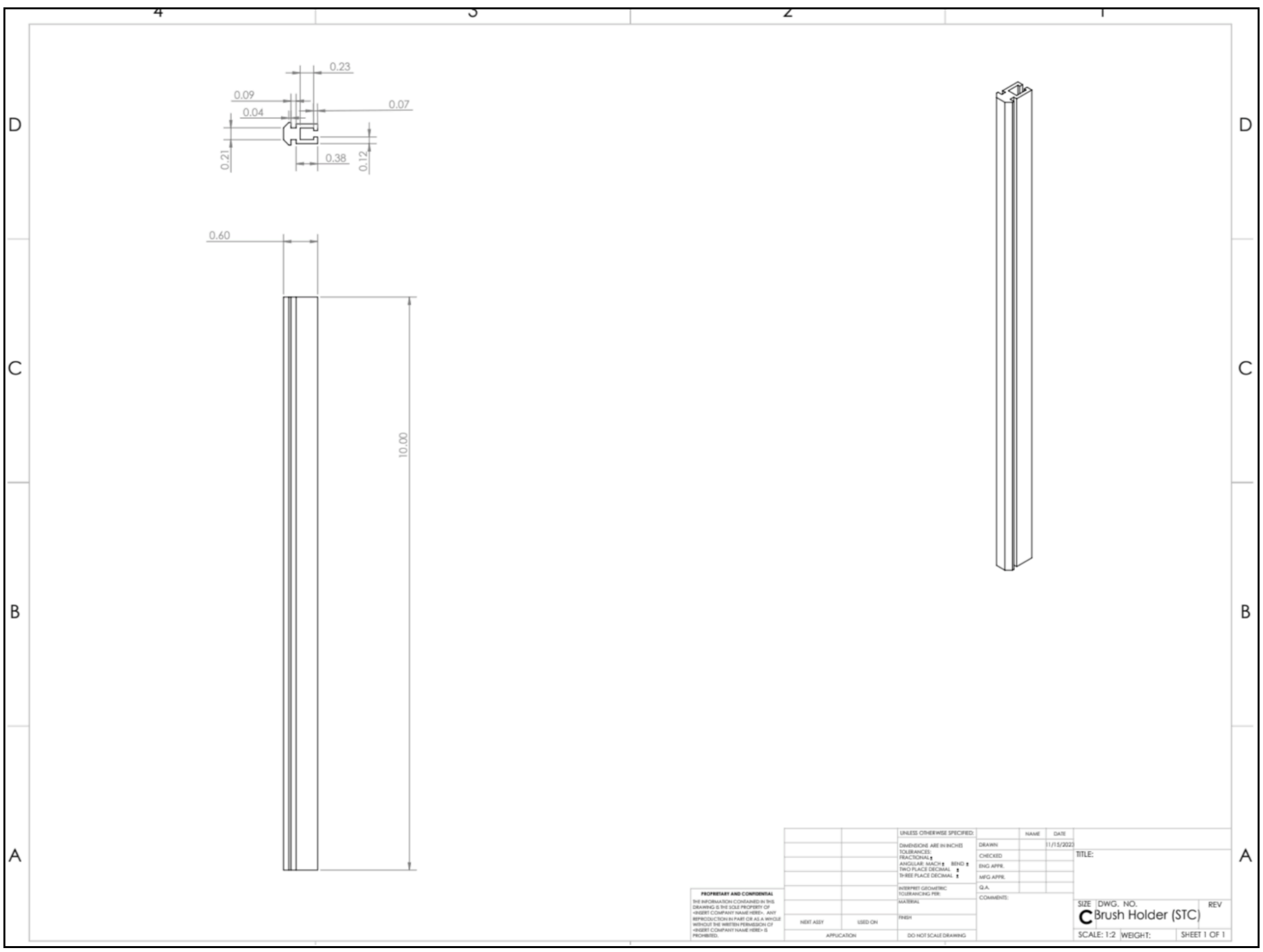


Figure A6: Part Drawing for the Brush Holder Connection

Appendix B: Calculations

Torque Calculations for Motor

$m_{tp} := 0.3482\ lb$ $\quad m_b := 0.9\ lb$ $\quad \Delta w := 5.254\ \frac{rad}{s}$ $\quad r := 0.3\ in$

$m_{total} := m_{tp} + m_b = 1.248\ lb$

$\alpha := \frac{\Delta w}{1\ s} = 5.254\ \frac{rad}{s^2}$

$a := r \cdot \alpha = 0.04\ \frac{m}{s^2}$

$F_{hinge} := m_{total} \cdot a = 0.005\ lbf$

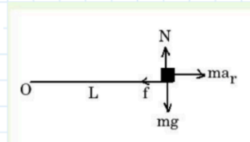
$$r_{mass} := \frac{(m_{tp} \cdot 3.25\ in) + (m_b \cdot 3.5\ in)}{m_{total}} = 3.43\ in$$

$T_{hinge} := F_{hinge} \cdot r_{mass} = 0.001\ lbf \cdot ft$

Max Speed of Motor before Bearing Slides instead of Flipping

$\mu_s := 0.25$ Static Friction between Steel and ABS

$g := 32.2\ \frac{ft}{s^2}$ $\quad r_b := 3.5\ in$



$\omega_{max} := \sqrt{\frac{\mu_s \cdot g}{r_b}} = 5.254\ \frac{rad}{s}$ Max Speed of Motor is 50 RPM to prevent slipping

Figure B1: Hinging Mechanism Calculations

Life of Stepper Motor

$L := 10000\ hr$ Assumed Life of Stepper Motors from https://printingit3d.com/how-long-do-3d-printer-stepper-motors-last-facts-explained/

$L_{days} := \frac{L}{24\ hr} = 416.667$ Life Assumed to be 1.15 years (24 hours a day) or 3.5 years (8 hours a day)

$Run\_Time := 1.5\ min$

$N_{cycles} := \frac{L}{Run\_Time} = 4 \cdot 10^5$

Life of Press Fit

$S_{ut} := 30$ $\quad S_f' := 19$ Units: MPa

$S_l' := 0.29 \cdot S_{ut} = 8.7$ $\quad S_e' := 0.72 \cdot S_{ut} = 21.6$

$b_s := \frac{-1}{3} \log\left(\frac{S_l'}{S_e'}\right) = 0.132$

$C := \log\left(\frac{S_l'^2}{S_e'}\right) = 0.545$

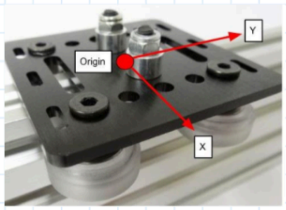
$N := \left(S_f' \cdot 10^{-C}\right)^{\frac{1}{b_s}} = 3.775 \cdot 10^5$ Life of Press Fit is estimated as 550000 cycles or 1.5 years

$Life_{days} := \frac{N \cdot Run\_Time}{24\ hr} = 393.205$

Fatigue Strength Source: https://www.scientific.net/MSF.1051.137?utm_source=researcher_app&utm_medium=referral&utm_campaign=RESR_MRKT_Researcher_inbound#:~:text=The%20shaft%20fatigue%20strength%20of,S%2DN%20curve%20is%2016.25%20MPa.

Figure B2: Hinging Mechanism Calculations Continued

Loaded Configuration (Static)



Weight	Center of Gravity		
$m_{bp} := 0.3\ lbf$	$y_{bp} := 1.75\ in$	$x_{bp} := 5.1\ in$	Bottom Plate
$m_{tp} := 0.3\ lbf$	$y_{tp} := 1.75\ in$	$x_{tp} := 4.7\ in$	Top Plate
$m_{b} := 0.1\ lbf$	$y_{b} := 1.5\ in$	$x_{b} := 5\ in$	Bearing
$m_{m} := 0.9\ lbf$	$y_{m} := -2.22\ in$	$x_{m} := -0.35\ in$	Motor
$m_{arm} := 0.11\ lbf$	$y_{arm} := 2.24\ in$	$x_{arm} := 1.11\ in$	Resting Plate
$m_{cw} := 0.75\ lbf$	$y_{cw} := 0\ in$	$x_{cw} := -3\ in$	Counter Weight

$$x_{cg} := \frac{(m_{bp} \cdot x_{bp}) + (m_{tp} \cdot x_{tp}) + (m_b \cdot x_b) + (m_m \cdot x_m) + (m_{arm} \cdot x_{arm}) + (m_{cw} \cdot x_{cw})}{m_{bp} + m_{tp} + m_b + m_m + m_{arm} + m_{cw}} = 0.41\ in$$

$$y_{cg} := \frac{(m_{bp} \cdot y_{bp}) + (m_{tp} \cdot y_{tp}) + (m_b \cdot y_b) + (m_m \cdot y_m) + (m_{arm} \cdot y_{arm}) + (m_{cw} \cdot y_{cw})}{m_{bp} + m_{tp} + m_b + m_m + m_{arm} + m_{cw}} = -0.22\ in$$

Treat the center of the plate attached to the pulley as the origin to make center of gravity along the centerline (Ideal COG will be around (0,0)in)

Figure B3: Hinging Plate Weight Analysis Calculations

$$m_{total} := m_{bp} + m_{tp} + m_b + m_m + m_{arm} + m_{cw} = 2.46\ lbf$$

$$m_{all} := 7.5\ lbf$$

$$SF_{actuator} := \frac{m_{all}}{m_{total}} = 3.049$$

Deflection of Resting Arm

$$M_{arm} := (m_{bp} + m_{tp} + m_b + m_{arm}) \cdot 3\ in = 2.43\ lbf \cdot in$$

$$I_{arm} := 0.113906\ in^4 \qquad E_{abs} := 2\ GPa \qquad l_{arm} := 3\ in$$

$$\delta_{arm} := \frac{M_{arm} \cdot {l_{arm}}^2}{2 \cdot E_{abs} \cdot I_{arm}} = 0.008\ mm$$

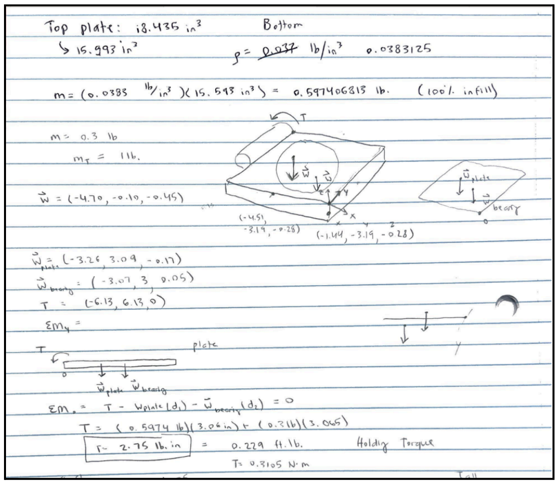
Deflection Due to Counterweight

$I_{cw} := 0.0656\ in^4$ $\quad l_{cw} := 4\ in$ $\quad M_{cw} := 2.25\ lbf \cdot in$

$E_{cw} := 2\ GPa$

$$\delta_{cw} := \frac{M_{cw} \cdot l_{cw}^{\ 2}}{2 \cdot E_{cw} \cdot I_{cw}} = 0.024\ mm$$

Figure B4: Hinging Plate Weight Analysis Calculations Continued


Top plate: 18.435 in³ Bottom
↳ 15.993 in³
ρ = ~~0.037~~ lb/in³ 0.0383125
m = (0.0383 lb/in³)(15.593 in³) = 0.597406815 lb. (100% infill)
m = 0.3 lb
m_T = 1 lb.
W = (-4.70, -0.10, -0.45)
W_plate = (-3.26, 3.09, -0.17)
W_bearing = (-3.07, 3, 0.05)
T = (-6.13, 6.13, 0)
ΣM_y =
ΣM_o = T - W_plate(d₁) - W_bearing(d₂) = 0
T = (0.5974 lb)(3.06 in) + (0.3 lb)(3.065)
T = 2.75 lb.in = 0.229 ft.lb. Holding Torque
T = 0.3105 N·m

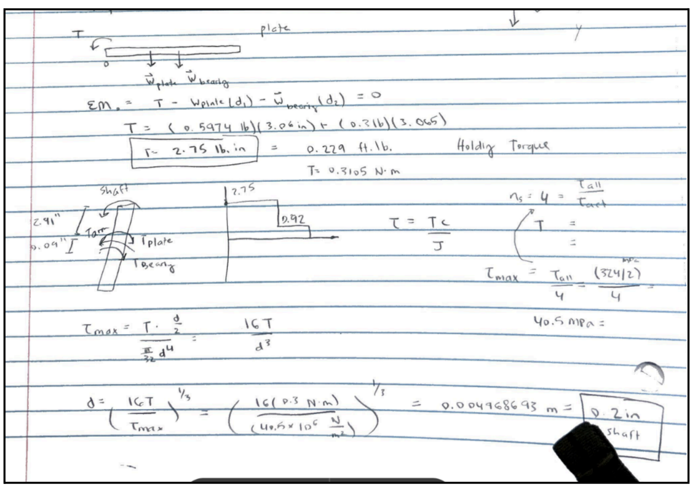

ΣM_o = T - W_plate(d₁) - W_bearing(d₂) = 0
T = (0.5974 lb)(3.06 in) + (0.3 lb)(3.065)
T = 2.75 lb.in = 0.229 ft.lb. Holding Torque
T = 0.3105 N·m
τ = Tc/J
n_s = 4 = τ_all/τ_act
τ_max = τ_all/4 = (324/2)/4
40.5 MPa
τ_max = T·(d/2)/((π/32)d⁴) = 16T/d³
d = (16T/τ_max)^(1/3) = (16(0.3 N·m)/(40.5×10⁶ N/m²))^(1/3) = 0.004968693 m = 0.2 in shaft

Figure B5: Minimum Diameter Shaft Calculations

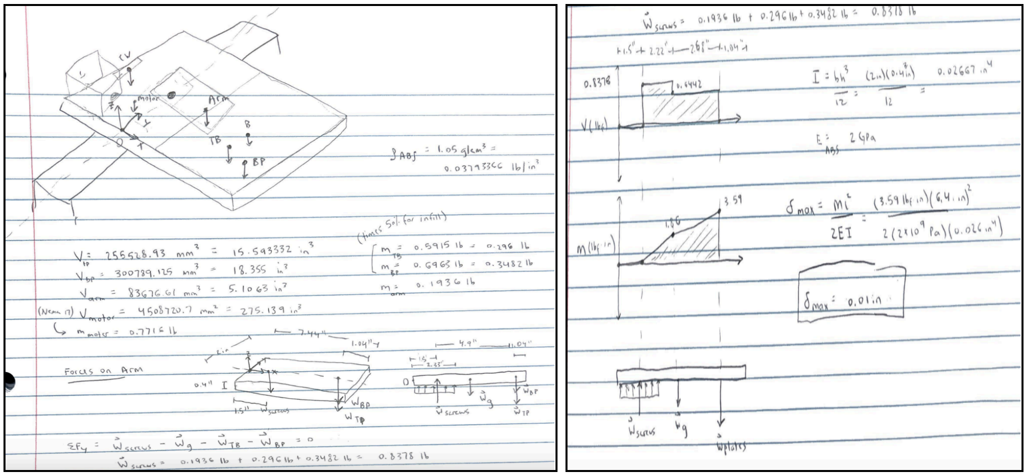


Figure B6: Weight and Volume Analysis Calculations

Appendix C: Computer/Electrical Diagrams

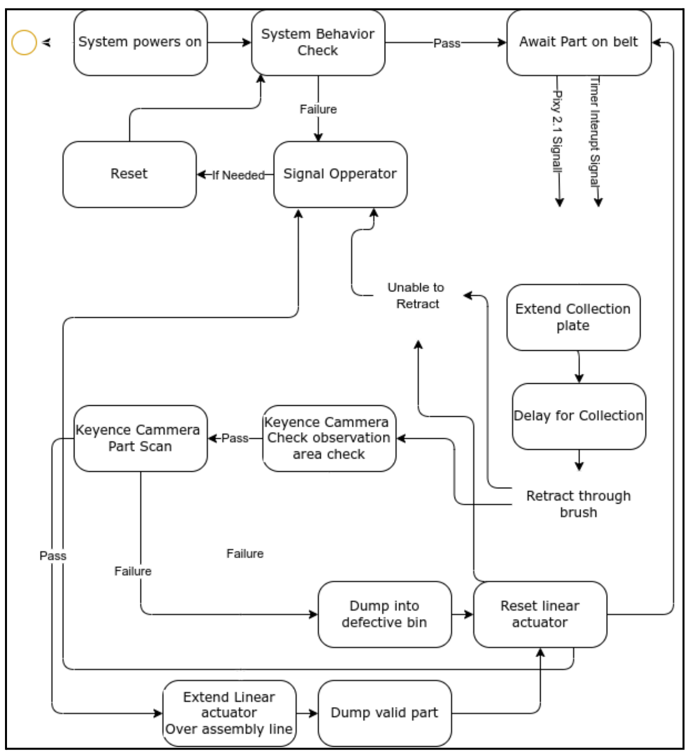


Figure C1: Code Flow Diagram

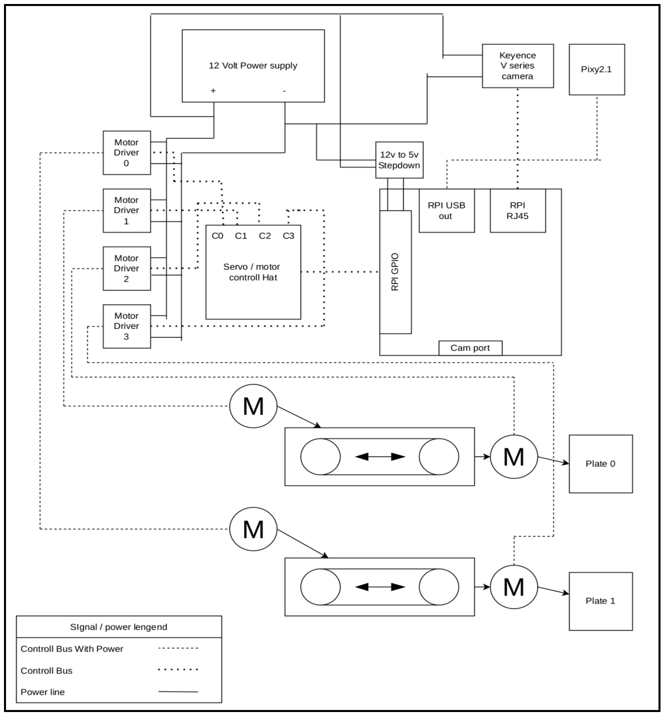


Figure C2: Schematic Diagram

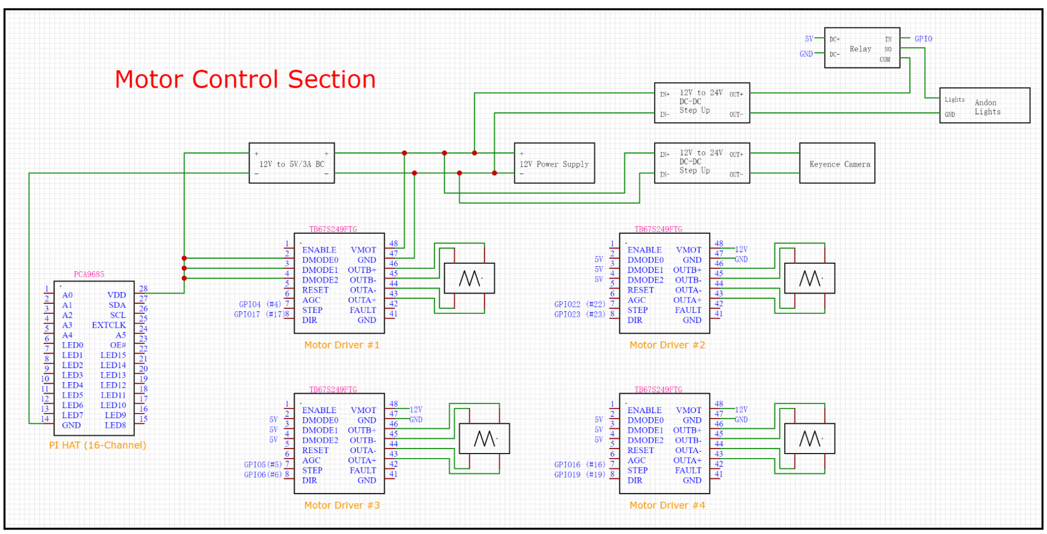


Figure C3: Wiring Diagram

Appendix D: Keyence Camera

KEYENCE CORPORATION OF AMERICA
Headquarters: 500 Park Boulevard Suite 200 Itasca IL 60143 PHONE: 888-539-3623

Quotation

Attn : Alex Perry
Dept :
Fax :
Email : perryaex@schaeffler.com
Quoted to : Schaeffler Group USA
308 Springhill Farm Road
FORT MILL, South Carolina 29715

Quotation : 12894316
Quote Date : 10/23/23

Your Reference :

Thank you for the opportunity to provide you a quotation for the following product(s).
*****Please reference the Keyence Quotation number 12894316 when placing your order!**

Reference : **This is the proper quote for the defect on ring inspection**

Sales Contact : ADAMS, MAX (SAM-CLT)
Tel : 1-888-KEYENCE Ext : 88688
Fax : 855-539-0123
Email : Max.Adams@keyence.com

Line	Item	Item Description	Taxable Unit	Unit Price	Qty	Ext Price
1	VS-L500MX HS Code: 9031494000	Smart Camera - Vision System Zoom, 5MP, Monochrome	pcs	12,000.00	1	12,000.00
2	CA-DRM20X HS Code: 9405428440	LED Lighting for Vision Systems Multispectrum Light 200mm	pcs	2,609.00	1	2,609.00
3	OP-88807 HS Code: 9002208000	Accessory - Vision System Polarizing Filter for Smart Light	pcs	125.00	1	125.00
4	OP-88832 HS Code: 8544429090	Cable - Vision System Ethernet Cable, M12-M12, 5m	pcs	220.00	1	220.00
5	OP-88836 HS Code: 8544429090	Cable - Vision System Ethernet Cable, M12-RJ45, 5m	pcs	220.00	1	220.00
6	OP-88811 HS Code: 8544429090	Cable - Vision System Power & I/O Cable, M12 12-pin, 5m	pcs	115.00	1	115.00
7	CA-D1MXE HS Code: 8544429090	Lighting Cable - Vision System 1m Extension Cable for Light	pcs	200.00	1	200.00

Figure D1: Parts List for the VS-L500MX Keyence Camera

KEYENCE

KEYENCE CORPORATION OF AMERICA
Headquarters: 500 Park Boulevard Suite 200 Itasca IL 60143 PHONE: 888-539-3623

Quotation

Attn : Alex Perry
Dept :
Fax :
Email : perryaex@schaeffler.com
Quoted to : Schaeffler Group USA
308 Springhill Farm Road
FORT MILL, South Carolina 29715

Quotation : 12894316
Quote Date : 10/23/23

Your Reference :

Thank you for the opportunity to provide you a quotation for the following product(s).
*****Please reference the Keyence Quotation number 12894316 when placing your order!**

Reference : **This is the proper quote for the defect on ring inspection**

Sales Contact : ADAMS, MAX (SAM-CLT)
Tel : 1-888-KEYENCE Ext : 88688
Fax : 855-539-0123
Email : Max.Adams@keyence.com

HS Codes provided for general information purposes only. Keyence is not responsible for any custom clearance issues if HS codes used by a third party for import purposes.

Sub Total	15,489.00
Misc. Charges	0.00
Shipping & Handling	0.00
Tax	0.00
Total (USD)	15,489.00

DELIVERY : 2-3 Business Days
Shipping : UPS GRD Exempt
F.O.B Point : Itasca, IL
Terms : NET 75
Quote Expires: 12/22/23
Quoted shipping & handling cost is an estimate based on quantities and method of delivery. Prices, Availability and Terms are subject to Change.

FOR ORDERS & CUSTOMER SUPPORT,
PLEASE CONTACT:
CUSTOMER SERVICE
TEL: 1-888-KEYENCE(539-3623) EXT.28761
FAX: 855-539-0123
EMAIL: CustomerService@Keyence.com

Figure D2: Quotation for the VS-L500MX Keyence Camera

Appendix E: Project Plan

Phase 1: Foundation/Conceptual Design				
Research standards and scope	Team	100%	8/21/23	9/7/23
SOW and Team Contract	Team	100%	8/25/23	9/6/23
Brainstorm and Research	Team	100%	8/30/23	9/1/23
Site Visit	Team	100%	9/1/23	9/25/23
Camera Movement Mechanism Design	Alex, Slade	90%	9/1/23	9/25/23
Camera Selection	Joshua, Aiden	100%	9/1/23	9/25/23
Electrical Design/Schematics	Steven, Aiden	0%	9/1/23	9/25/23
CDR Presentation	Team	100%	9/25/23	10/6/23

Figure E1: Phase 1 Plan

Phase 2: Preliminary Design				
Revist and Update Design	Team	100%	10/4/23	10/11/23
CAD Drawings for Movement Mechanism	Slade, Alex	100%	10/11/23	11/13/23
CAD Drawings for Catching/ Flipping Mech.	Alex, Aiden	100%	10/11/23	11/13/23
CAD Drawings for Camera Mount	Josh, Aiden	100%	10/11/23	11/13/23
Wiring Diagrams/Schematics	Steven	100%	10/11/23	11/13/23
Calculations for Movement Mechanism	Slade	100%	10/11/23	11/13/23
Motor Selection and Calculations	Alex, Josh	100%	10/11/23	11/13/23
Bill of Materials	Josh	100%	10/11/23	11/17/23
PDR Presentation	Team	100%	11/6/23	11/17/23
Purchase Materials, Prepare for Expo	Team	80%	11/18/23	12/7/23
Update Design from PDR Feedback	Team	100%	11/18/23	12/1/23
Design Expo and Poster	Team	100%	12/8/23	12/8/23

Figure E2: Phase 2 Plan

Phase 3: PSR				
Email to Re-engage Supporter	Josh	0%	1/10/24	1/12/24
Order and Recieve All Materials	Team	50%	1/10/24	1/19/24
Prototype and Test Hinging Mechanism	Slade, Alex	50%	1/15/23	2/5/24
Assembly of Subsection Systems	Slade, Alex	0%	1/15/23	2/5/24
Motor Integration and Speed Control	Slade, Steven	0%	1/15/23	2/5/24
Initial Coding of Camara	Aiden, Josh	0%	1/15/23	2/5/24
Coding Movement System	Steven	0%	1/15/23	2/5/24
Project Status Review	Team	0%	2/5/24	2/16/24

Figure E3: Phase 3 Plan