Toronto Metropolitan University
Department of Mechanical, Industrial, and Mechatronics Engineering
Faculty of Engineering & Architectural Science

Department of Mechanical, Industrial, and Mechatronics Engineering

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Course Number	MEC617
Course Title	Manufacturing System Control
Semester/Year	Fall 2024
Instructor	Vincent Chan
Section Number	03

MEC617 Project

Report Title	Motor Housing Bearing Installer
Group Number	01
Submission Date	November 29, 2024
Due Date	November 29, 2024

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(Note: Remove the first 4 digits from your student ID)

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Introduction

This report details the design and implementation of a specialized electro-pneumatic machine tasked with installing a ball bearing into the housing of an electric motor. The project was tasked with a strict set of requirements, including completing the press-fit operation within a cycle time of 30 seconds, utilizing pneumatic motion and maintaining compliance with safety regulations outlined by OSHA. The client's specifications emphasize precision, worker safety, and operational efficiency, requiring the use of high-quality pneumatic components and a robust PLC-based control system.The mechanism is designed to operate autonomously alongside a worker who will load the motor housing onto the worktable, trigger the sequence using a two-hand push-button and foot pedal system, and unload the housing upon completion. This collaborative operation ensures efficiency while preventing accidental activation through a redundant triggering mechanism. To meet the client's requirements, the system integrates the Festo DSNU line of pneumatic cylinders and the PLC produced through PLCFiddle. The system is designed to pick up the bearing using the inner race, ensuring no damage occurs during the press-fit process by applying force only to the outer race.

In addition to meeting technical specifications, the design prioritizes worker safety by incorporating emergency stop mechanisms, interlocks, and enclosures to prevent injuries during operation. These features are aligned with OSHA safety standards to ensure compliance with industry regulations and maintain a safe working environment for the operator.This report is structured to comprehensively address all aspects of the project, starting with a review of the existing literature and background information relevant to the design of electro-pneumatic systems. The subsequent chapters delve into the design process, analyzing both custom and off-the-shelf components, and providing detailed specifications for each. The design analysis includes calculations for forces, dimensions, and cycle time, ensuring the machine meets all operational requirements. Additionally, the report includes a safety analysis, evaluating potential risks and detailing the measures implemented to mitigate them.The control logic chapter outlines the ladder logic program designed for this project, simulated using PLCfiddle.com. The ladder logic ensures that the machine operates seamlessly, with all sensors, actuators, and interlocks working in harmony.

In conclusion, this report provides a detailed examination of the design and implementation of an electro-pneumatic machine tailored to meet the client's stringent requirements for precision, efficiency, and safety. By integrating high-quality pneumatic components, a robust PLC-based control system, and comprehensive safety features, the proposed design ensures compliance with industry standards while addressing the operational needs of the client.

Literature Review

The development of an electro-pneumatic machine for bearing installation is rooted in several key principles and technologies that underpin modern manufacturing systems. This section reviews the theoretical and practical considerations essential for designing such systems, focusing on pneumatic actuation, industrial automation using PLCs, safety standards, and press-fit operations.

Pneumatic Systems in Manufacturing

Pneumatic systems are a staple of industrial automation since they are simple, economical, and reliable. As they function with compressed air, this enables the control of the motion to be both smooth and accurately specified. The Festo DSNU pneumatic cylinders are the preferred option since they are designed robustly, enabling consistent performance in areas that involve repetitive motion. Literature indicates that pneumatic systems are ideal for press-fit operations due to the rapid actuation and the fact that they can generate the necessary force without resorting to complex mechanisms. Besides, their compatibility with standard industrial components makes integration into an existing setup quite straightforward.

Role of Programmable Logic Controllers (PLCs)

PLCs are widely applicable in the automation of manufacturing systems because they offer reliable means of programming and controlling any process. The Allen Bradley Micrologix 1400 PLC chosen for the project is one of the most popular models widely recognized for its versatility and acceptability. Literature reviews show that PLCs are very useful in managing sequential processes in a very precise and synchronizing manner, such as those used in press-fitting. The possibility of their interfacing with various input and output devices, such as push buttons, sensors, and actuators, makes them indispensable for modern manufacturing equipment.

Safety Standards in Machine Design

Safety in the design of industrial equipment, specifically systems that involve high-force operations, is of utmost importance. OSHA guidelines call for the implementation of safety mechanisms such as emergency stop buttons, interlocks, and enclosures to protect workers from accidental injury. The use of two-hand push-button controls and foot pedals in the proposed design is in conformance with such standards because they require positive action by the operator to initiate the process. According to literature, redundancy in safety systems can help minimize risks while operating.

Press-Fit Operations

Press-fitting is a common method within the manufacturing industry, whereby force is applied to insert one component into another with an interference fit. In the installation of the bearing, a force of 100 lbf is required, and this should only be applied to the outer race in order to avoid damage. Studies on press-fit mechanics strongly indicate that precise application and alignment of forces are important for reliable results. Research supports the use of pneumatic actuators in press-fitting, since they can maintain consistent force levels with minimal operational complexity.

Challenges and Innovations in Automation

While pneumatic systems are quite efficient, the problems of precise control and long-term reliability remain. Recently developed adaptive control valves and sensors have overcome these disadvantages of pneumatic systems by offering more accurate monitoring and adjustments of system parameters. In the same way, modern PLC programming has also become easier to implement complex algorithms that improve the performance of an automated system.

Summary

Based on reviewed literature, a suitable bearing electro-pneumatic machine can be designed, using the strengths of pneumatic actuation, PLC-based control systems with the appropriate safety mechanisms, by generally applying the best available practices and meeting client demands in industry. This will eventually lead to the creation of such a machine that is sure and efficient, guaranteeing preciseness, safety, and observance of manufacturing standards.

Design (custom & off the shelf parts, vendor's part #)

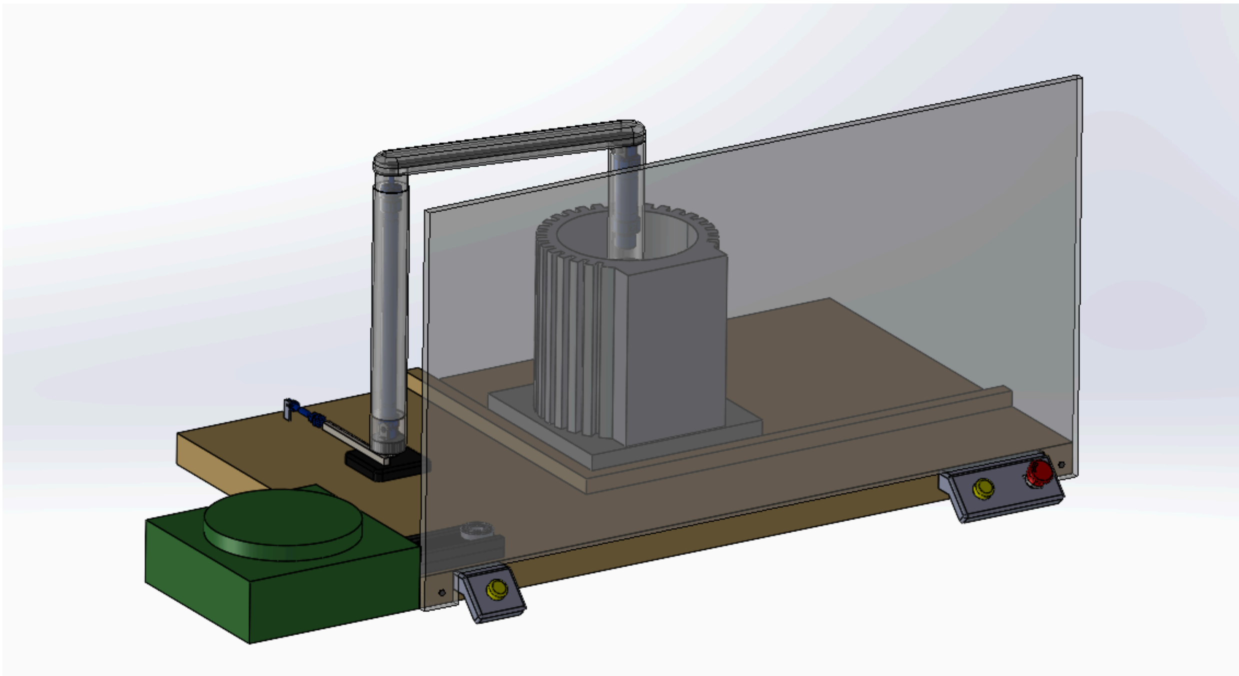

Figure 1. Complete Design Assembly

Various parts were customized and produced to complete the assembly shown in figure 1. To see the visuals of the completed assemblies, components and parts are in Appendix B.

Table 1. Custom Parts

Part Name	Qty
Base	1
End Arm Housing	1
Lift Arm Case 1	1
Lift Arm Case 2	1
Link Arm	1
Linkage Arm Casing	1
Pressing Arm	1
Rotation Piston Mount	1

Table 2. Shelf Parts

Part Name	Qty	Vendor #
DSNU 8 25 P A	2	19178
DSNU 8 25 P A	1	19178
DSNU 20 300 P A	1	19217
Metric Rack - Spur Rectangular	1	NA
Metric Spur Gear	1	NA
1/4"-20 Screws	2	012520WF100
M5-0.8 x 20mm Flanged Hex Head Bolts	2	B083LRH8GZ

Challenges Encountered:

One of the big challenges during the design process was how to take care of the dimensional mismatches between custom-designed components and off-the-shelf parts. Ensuring compatibility, mainly in mounting brackets and matching fasteners, was crucial for a perfect fit. Small discrepancies in dimensions often resulted in parts not aligning correctly, requiring several design iterations to resolve these issues. Similarly, clearance and interference with moving parts, like the pneumatic cylinder rods, gripper mechanism, and motor housing, was very tricky to manage. That required careful planning in the CAD model to make sure everything was sufficiently spaced without over-constraining the system to eliminate conflicts.

This was a complication to the design as this was to be fitted within a limited-dimension existing workstation. Every component had to be placed with consideration such that the design stays in the available space while allowing good functionality: pneumatic cylinders, mounting brackets, spacers, and everything involved. Moreover, accurate position and alignment between the gripper, bearing, and motor housing had to be obtained so that press-fitting may result successfully. Any misalignment could have led to uneven force application or system inefficiencies, making tolerance control a critical part of the design process. These challenges required iterative adjustments and attention to detail to ensure all components worked harmoniously within the design constraints.

Design analysis

The produced design operates in a sequential manner. The sequence consists of four pistons. The figure above showcases how the system should appear at its initial start point. Below, the sequence to follow that initial position is listed:

1. B Extends
2. A Extends
3. B Retracts
4. D Extends
5. B Extends
6. A Retracts
7. B Retracts
8. C Extends
9. D Retracts
10. C Retracts

Force Calculation

There is a requirement of a 100 lbf force to provide capability to press-fit the bearing into the motor-housing. The force calculation can be completed using the formula: $P = \frac{F}{A}$

To complete, we know that the pressing arm will complete the task of press-fitting . This cylinder has a diameter of 50.8 mm. It is said that 90 PSI of plant air is available to assist with the press-fitting. Solving this by plugging in the known values and rearranging for force:

$$F = (90\,PSI)(\pi(25.4\,mm)^2) = 1258.7\,N$$
$$F = 1258.7\,N = 282.96\,lbf$$

Stress Calculation

The presser consists of 2 screws (¼" - 20), making it possible for the force to be distributed amongst them equally. The force is the indication of the force which the screws must withstand in order for the design to function appropriately and without quick wear and tear.

$$F = 282.96\,lbf\,/\,2 = 141.48\,lbf$$

Thus, the determined force per screw is 141.48 lbf.

Functional Analysis of Design

The final design utilizes 4 pistons to allow for the desired goal of press fitting the bearing into the engine housing bore. This is done by piston B fully extending to allow for clearance of rotation of the arm. The arm is then able to rotate 90 degrees due to the placement of the base in a position that creates a ¼ arc from the position of the latest bearing on the bearing assembly and the bore position. Rotation occurs from extension of piston A allowing for piston B to then retract and piston D extending to allow for the magnet assembly to pick up the bearing from the inner diameter. Piston B is then able to extend to once again clear the machine housing and piston A can retract to rotate 90 degrees once again aligning the bearing with the bore. Piston B then retracts allowing lowering the arm positioning closer to the bore allows for piston C which is assembled to the bearing press fit to extend pressing the bearing into place. The nature of the design should allow for the bearing to be aligned in position to prevent the bearing from still being attached to the magnet after extension of piston C which would lead to a line stop causing delays. Once press fit piston C and D can retract, returning the arm to its starting position which would trigger a delay before the cycle repeats if the operator requires.

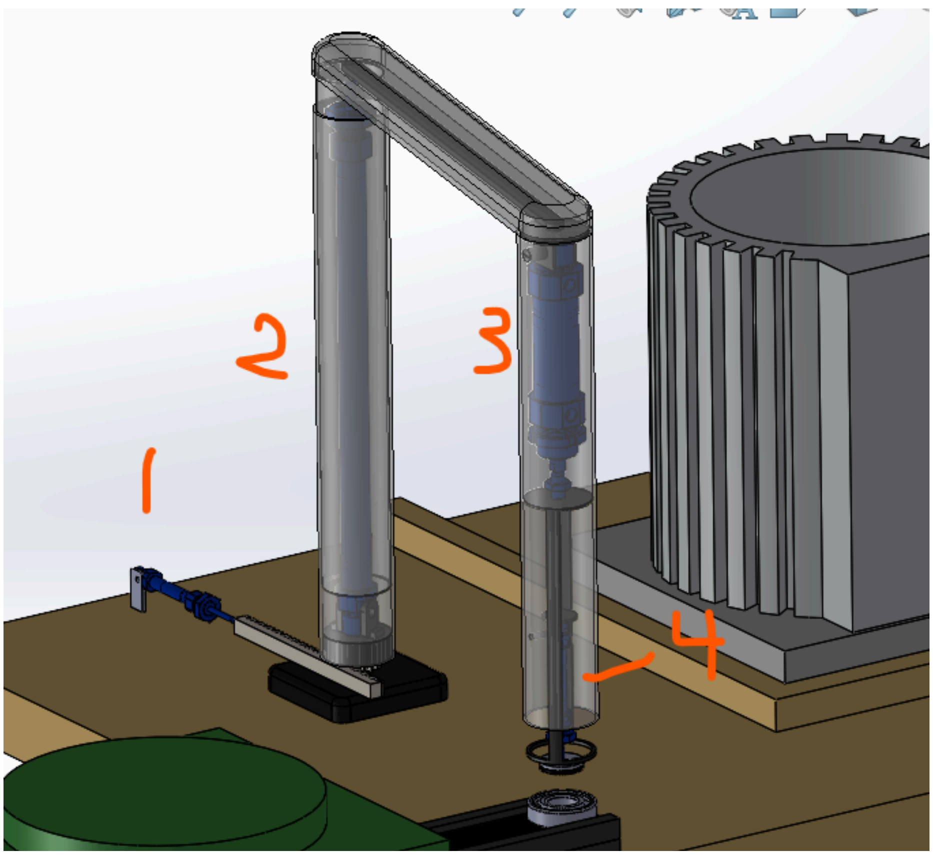

Figure 2. Functional Design
The created design is shown with 1, 2, 3, 4 all corresponding to pistons A, B,C and D respectively.

Safety Analysis

The safety of the designed bearing press-fitting machine has been ensured through the integration of multiple critical features. An emergency stop button has been incorporated to allow the operator to immediately halt the machine in case of any malfunction or hazardous situation, providing quick control and reducing the risk of injury. Additionally, custom-made clear guarding has been added around the working area to protect the operator from moving parts while allowing for full visibility of the operation. This guarding prevents accidental contact with the machine's components during use. To further enhance safety, the machine requires activation through a combination of two-hand push buttons and a foot pedal. The two-hand push buttons ensure that the operator's hands remain away from the hazardous area, while the foot pedal adds an additional activation point, minimizing the likelihood of accidental starts. Together, this three-point activation system ensures that the operator is in full control during operation. Furthermore, the design adheres to OSHA standards for safety interlocks and enclosures, ensuring compliance with regulatory requirements and providing a robust layer of protection against potential risks associated with pneumatic systems and moving parts. These features collectively prioritize worker safety while maintaining functionality and ease of operation.

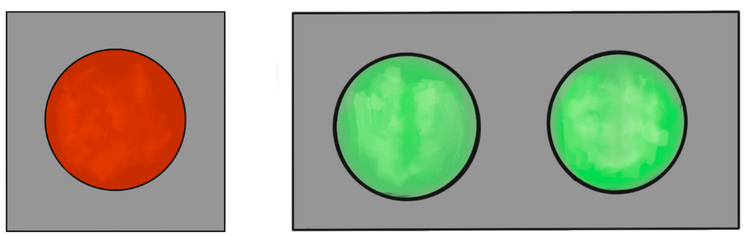

Figure 3. Emergency stop button & 2 push buttons

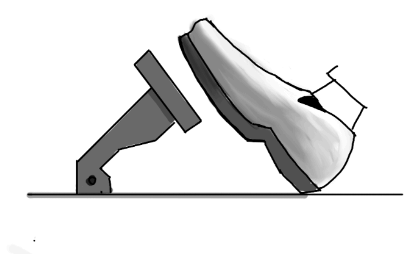

Figure 4: Foot pedal

Potential Risk Factors

Considering safety factors, there is likely a number of potential risks inherent in the designed bearing press-fitting machine, for which countermeasures would need to be taken. In general, one important potential risk involves human factors: For example, if one operator bypasses some necessary safeguard, or uses the machine otherwise than intended, unsafe operations will then follow. While the custom clear guarding works well to prevent accidental contact with moving parts, its effectiveness could be compromised through improper installation, wear, or damage over time, which creates a safety hazard.

Another possible issue could be the response time of the emergency stop button. In operations involving high speeds, there could be a slight delay between the time of activation and when the machine actually stops, posing a risk in critical situations. Besides, pneumatic system failures, such as leaks, pressure drops, or malfunctioning actuators, might lead to unintended motion or inadequate force application, thus damaging parts or injuring the operator.

Wear and tear on machine components, such as cylinders, push buttons, or the foot pedal, is another concern. Over time, these components may degrade, leading to operational failures or reduced safety. In the same way, electrical system issues, including faults in the PLC or sensor systems, could result in unintended activation or improper responses, compromising the system's reliability.

Lastly, poor maintenance and lack of training are continuing hazards. Poor routine maintenance may impair the effectiveness of key safety features, while failure to properly train operators may result in misuse of the machine or failure to follow safety practices. These risk factors are only mitigated by regular maintenance, detailed operator training, and continuous monitoring of the system's performance to ensure long-term safety and functionality. By proactively mitigating these risks, the machine's reliability and compliance with safety standards can be sustained.

Logic Analysis

The design consists of four pistons which have a sequential extension and retraction order as follows:

B+, A+, B-, D+, B+, A-, B-, C+, D-, C-

Table 3. Status Table

	B+	A+	B-	D+	B+	A-	B-	C+	D-	C-
Ai	1	1	0	0	0	0	1	1	1	1
Ao	0	0	1	1	1	1	0	0	0	0
Bi	1	0	0	1	1	0	0	1	1	1

Bo	0	1	1	0	0	1	1	0	0	0
Ci	1	1	1	1	1	1	1	1	0	0
Co	0	0	0	0	0	0	0	0	1	1
Di	1	1	1	1	0	0	0	0	0	1
Do	0	0	0	0	1	1	1	1	1	0

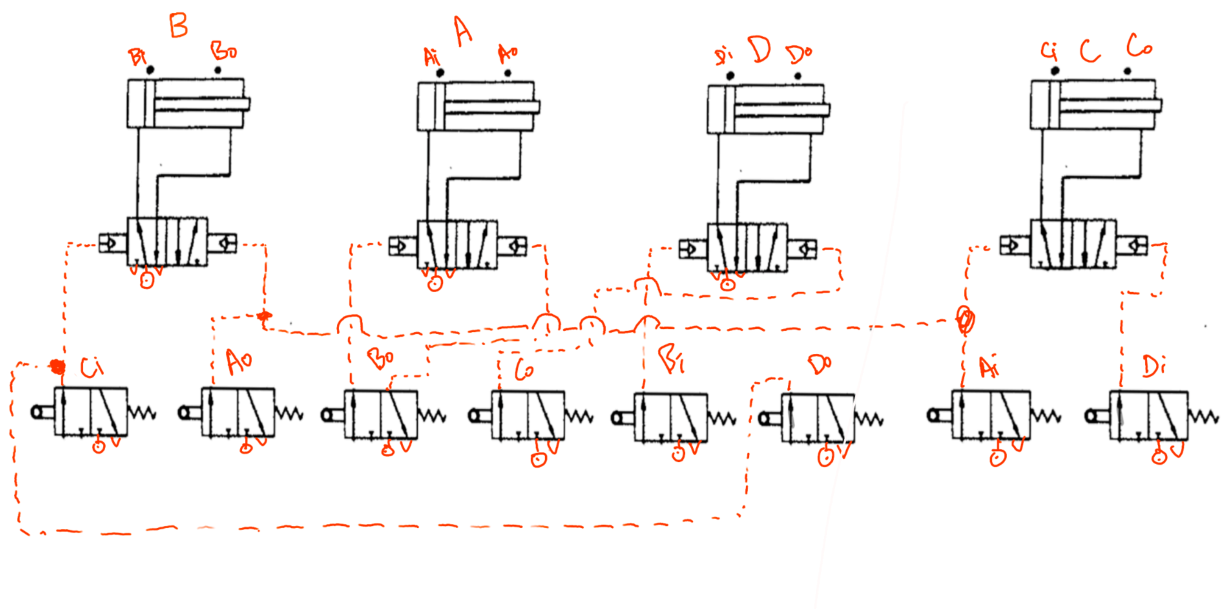

Figure 5. Pneumatic Diagram

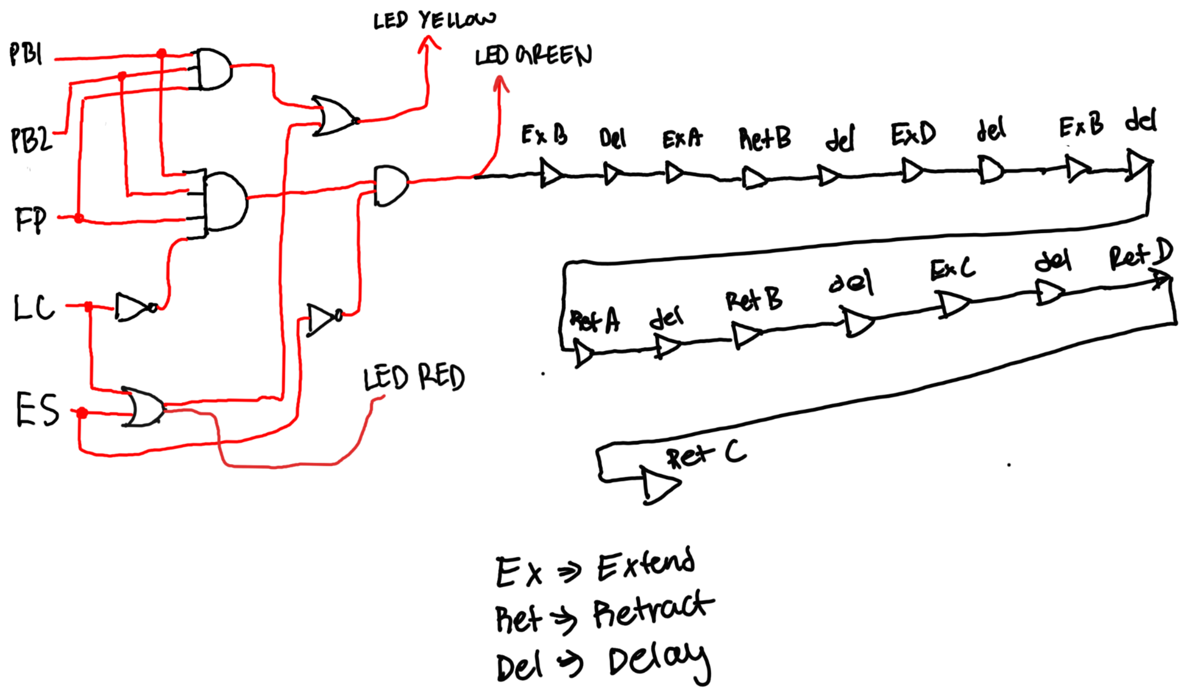

Figure 6. Boolean Logic Diagram

PLC model & Algorithm

The PLC was programmed to control the control system of the pneumatic motor-housing bearing installer. The link below leads to the completed algorithm:

https://www.plcfiddle.com:/fiddles/a2869fe9-04f3-437a-9473-c110a8c8412a

The Figure below provides a preview of the findings on the link above.

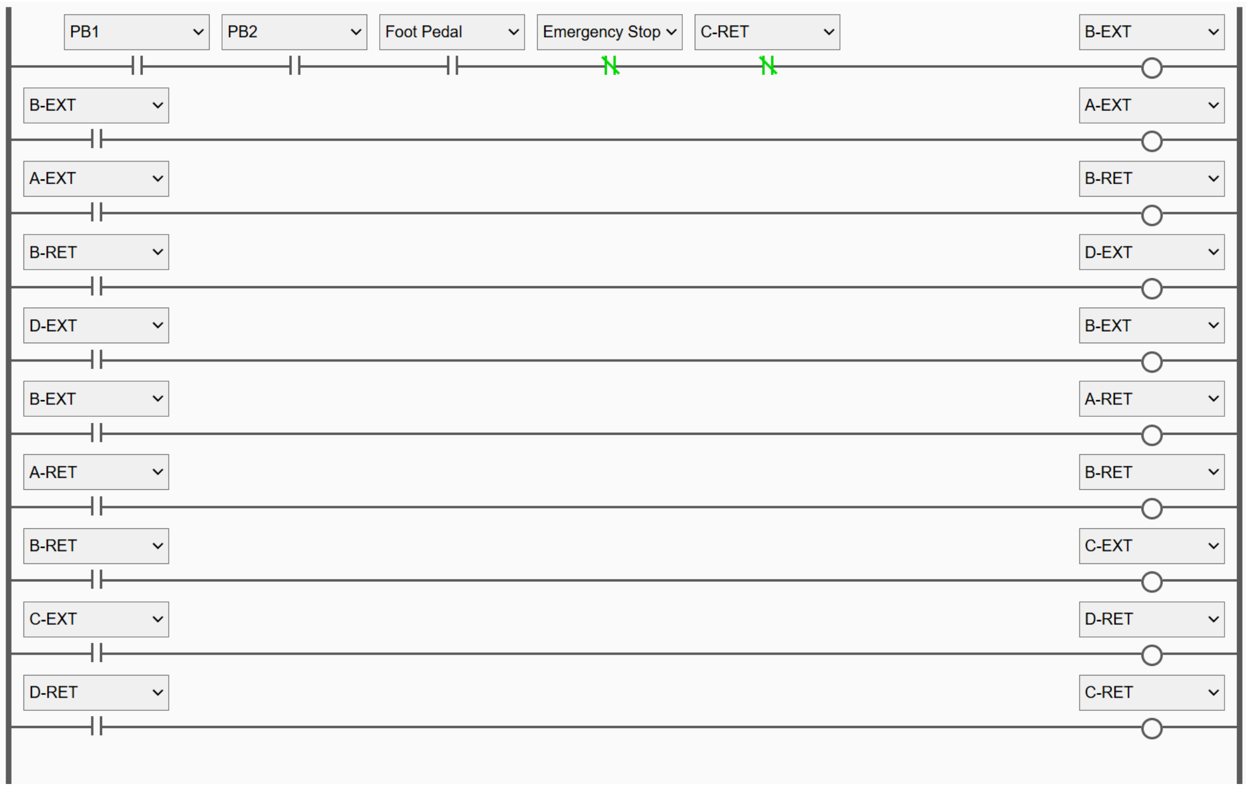

Figure 7. PLC Modelled Program (PLCFiddle)

Conclusions & Recommendations

The design and implementation of the electro-pneumatic bearing press-fitting machine have met the client's needs in terms of precision, efficiency, and safety. The reliable pneumatic components used, including the Festo DSNU cylinders, are combined with a robust control system using the Allen-Bradley Micrologix 1400 PLC for consistent and precise operation within the specified cycle time of 30 seconds. Through a Soldiworks motion simulation the ETC was determined at 16.2 seconds but may be subject to change in a real life application scenario and characteristics of the setup. Equipped with safety features like emergency stop, two-hand push-button controls, and a foot pedal, this will protect the workers and also meet the OSHA standards. The project has its challenges, like mismatched dimensions and the need for precise alignment, but it does serve to illustrate a very practical solution for automated manufacturing systems. The combination of technical rigor, safety prioritization, and operational efficiency makes this design a reliable foundation in similar industrial applications and also provides a framework for further development. In addition, the following recommendations are given for further effectiveness and reliability in the electro-pneumatic bearing press-fitting machine. First, the extended use of advanced simulation tools at the design phase should help anticipate potential dimensional mismatches and alignment issues in advance, thus reducing iterative corrections. In addition, a more robust maintenance plan for critical components such as pneumatic cylinders, sensors, and safety mechanisms will ensure long-term reliability and reduce downtime.

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[8] Bolt Depot, "Hex bolts, Stainless steel 18-8, 1/4"-20," [Online]. Available: https://boltdepot.com/Product-Details?product=6209.

Appendix A - Diagrams

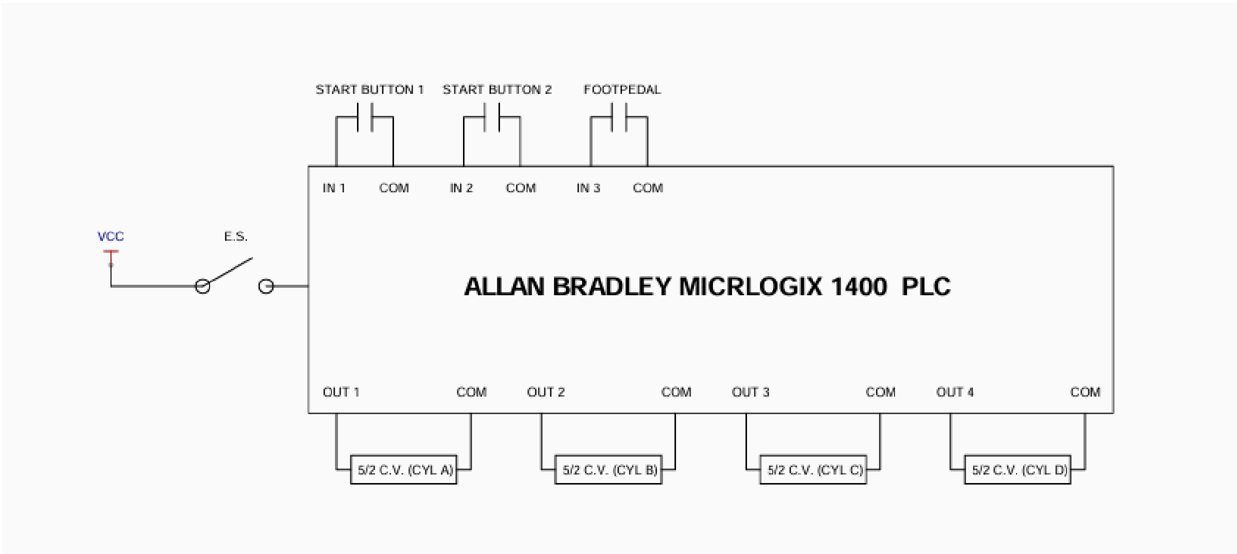

Figure 8. Logic Diagram

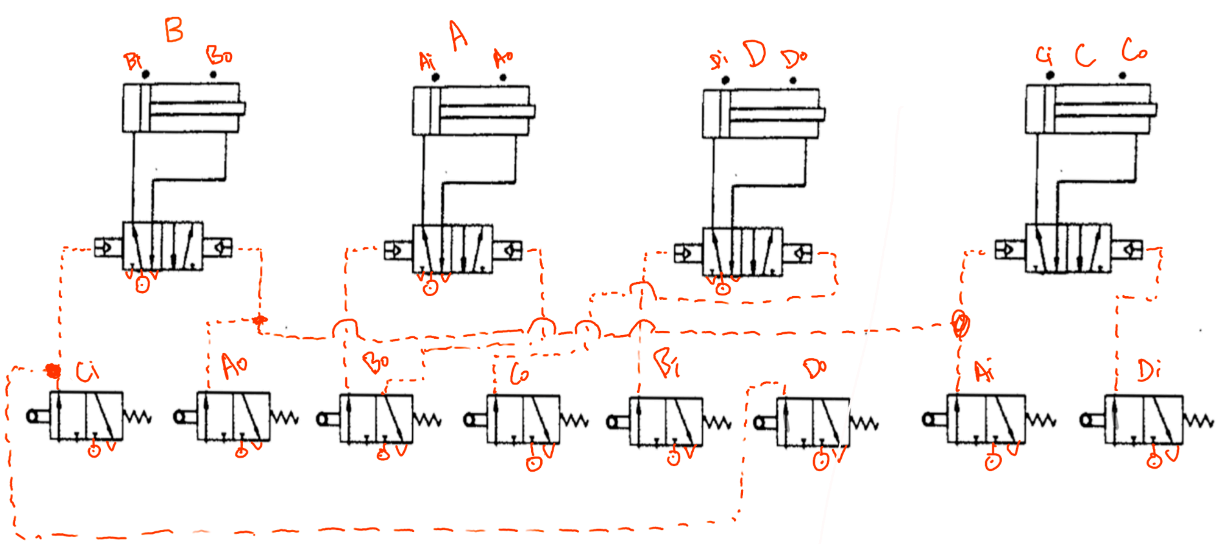

Figure 9. Pneumatic Connection Diagram

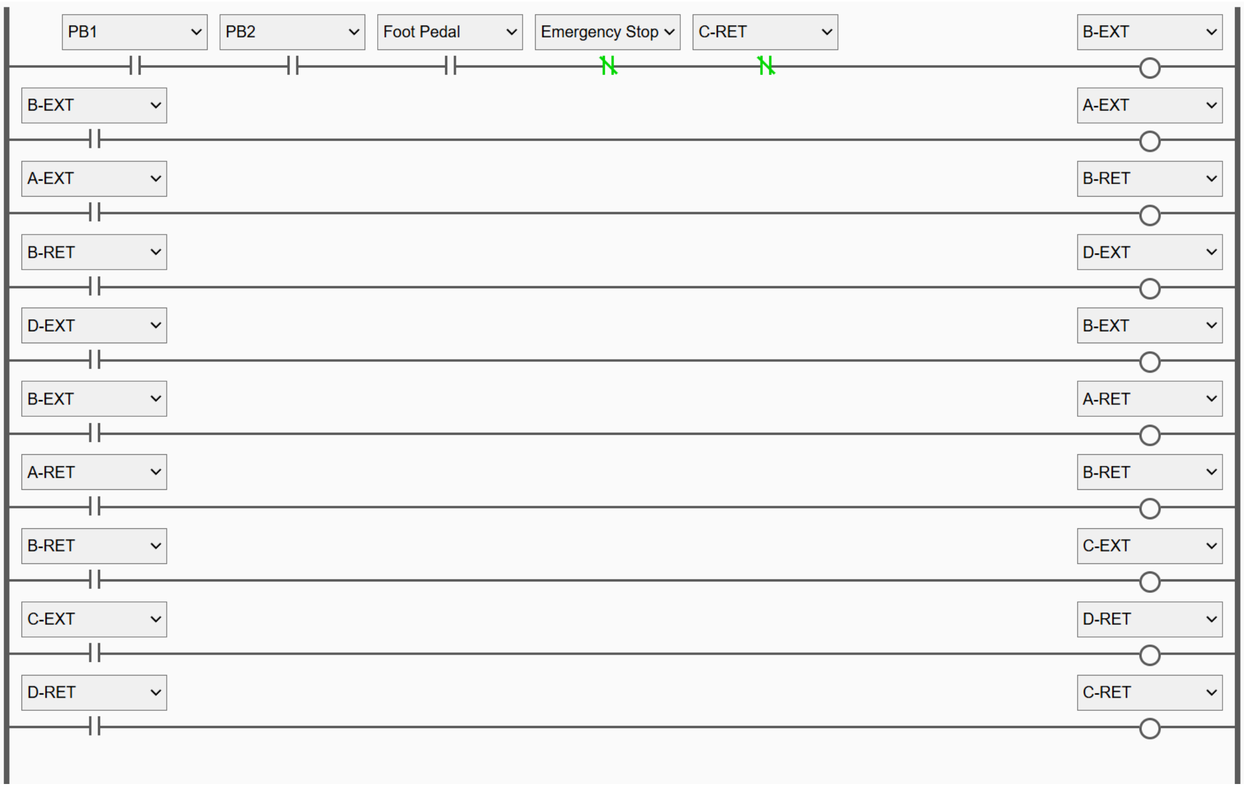

Figure 10. Ladder Logic Program Diagram

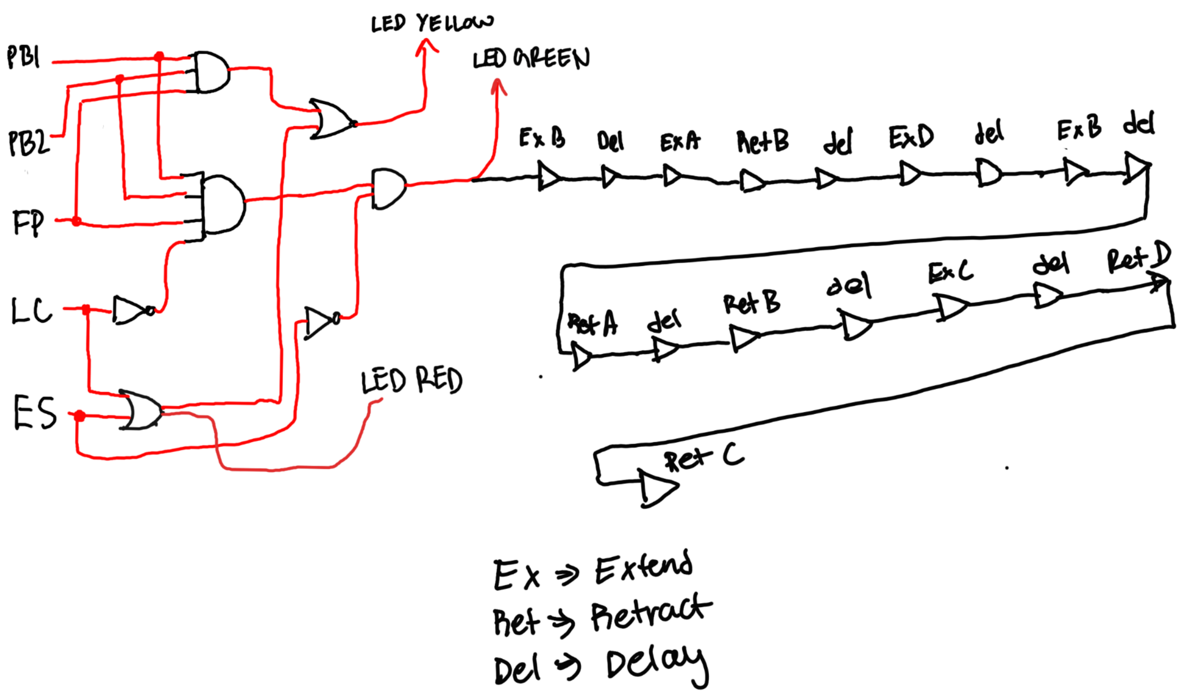

Figure 11. Boolean Logic Diagram

Appendix B - CAD

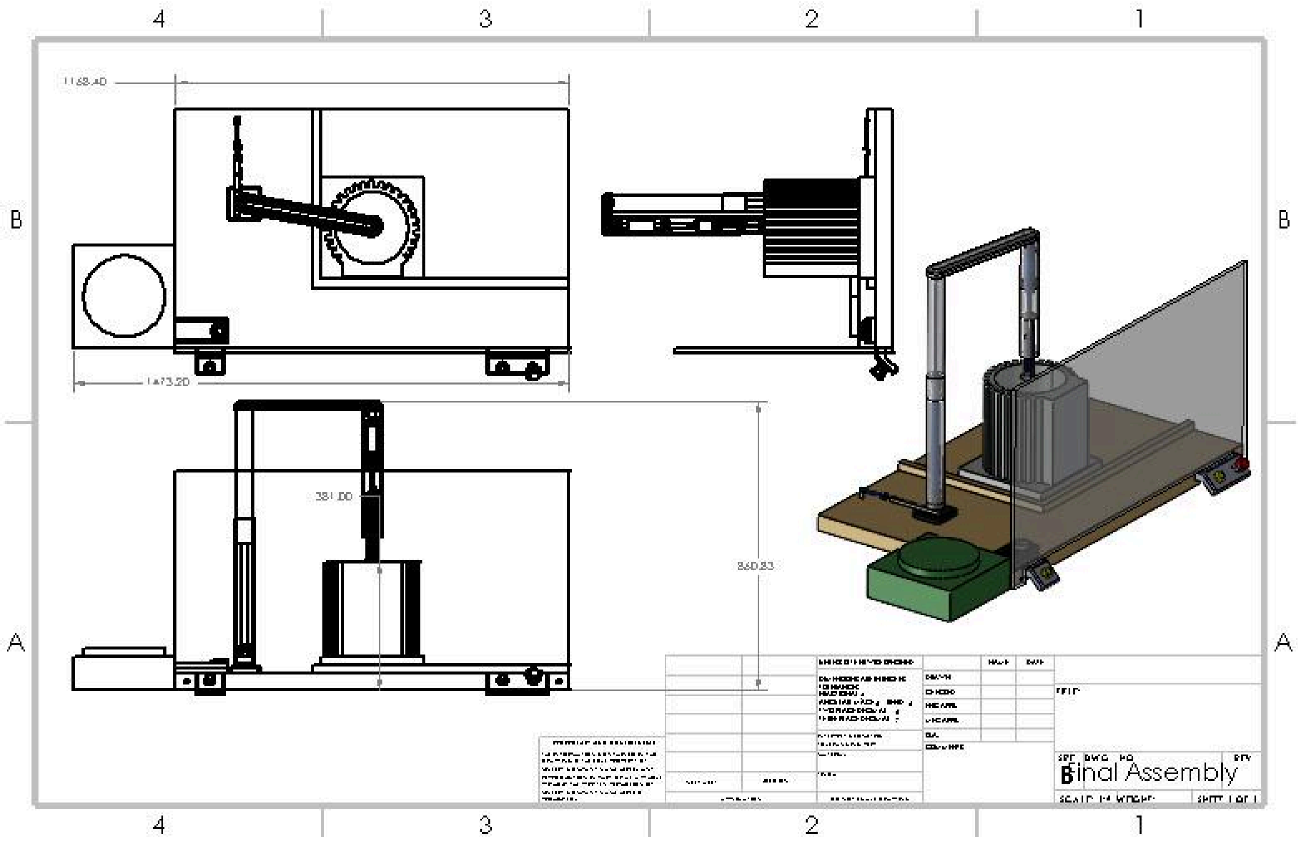

Figure 12. Final Assembly Drawing

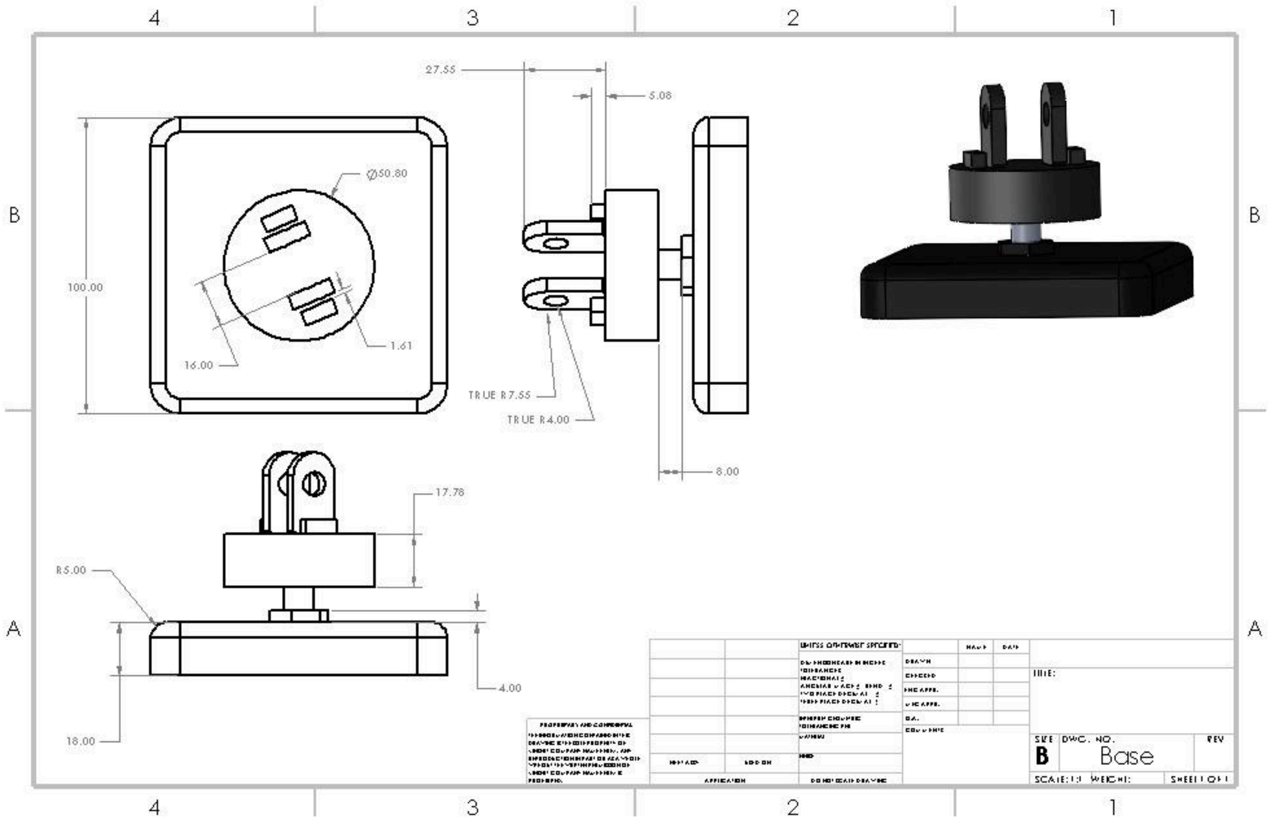

Figure 13. Base Part Drawing

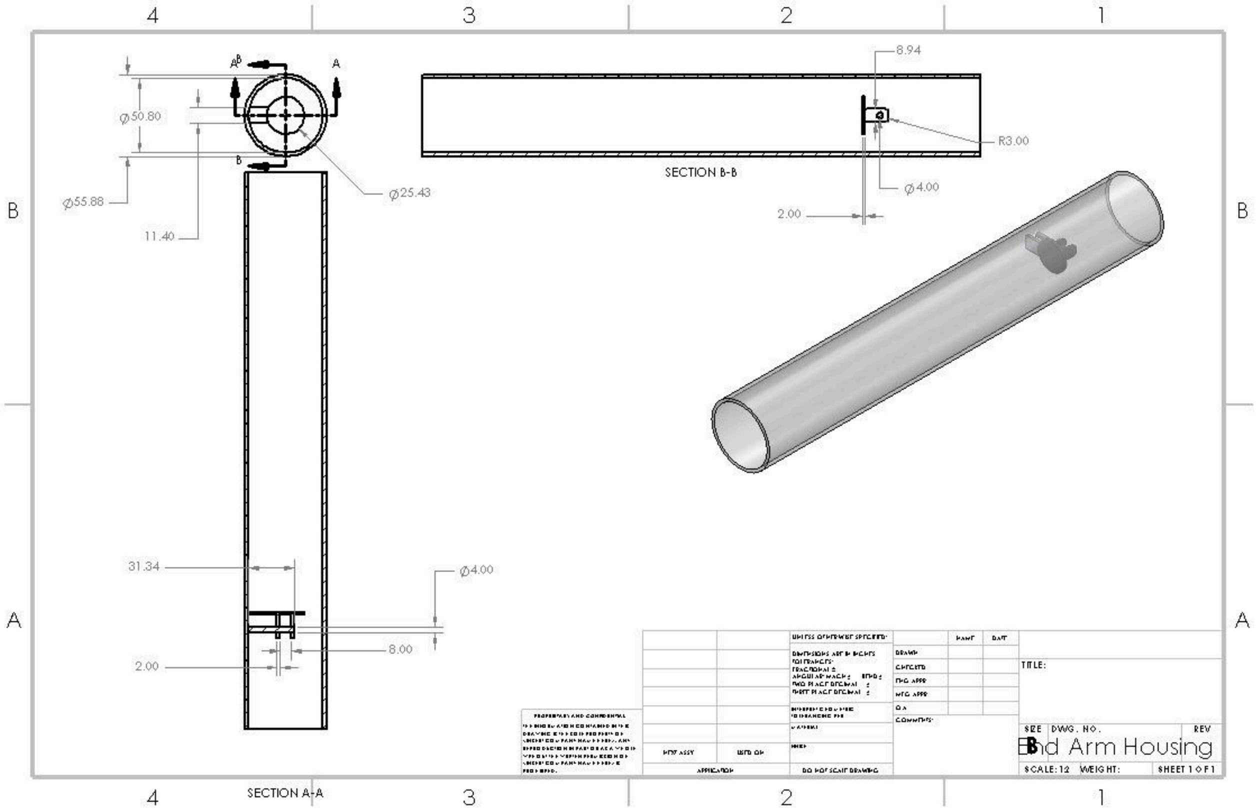

Figure 14. End Arm Housing Drawing

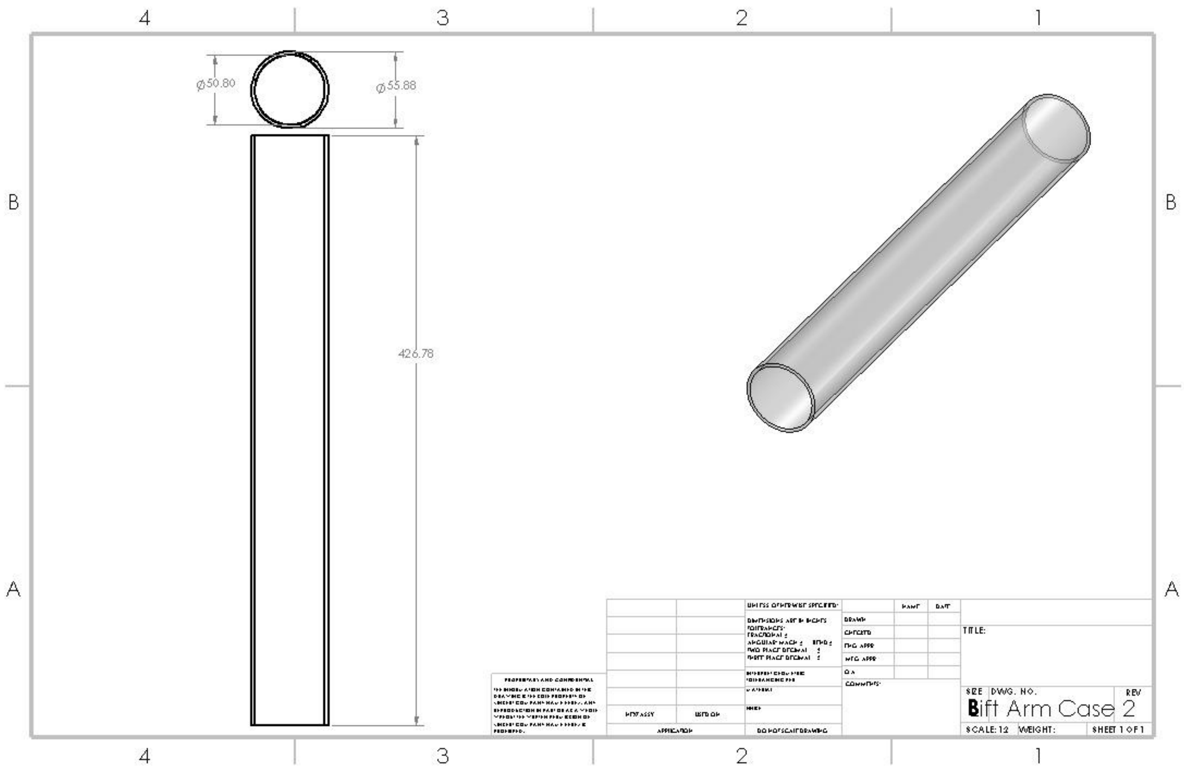

Figure 15. Lift Arm Case 2 Drawing

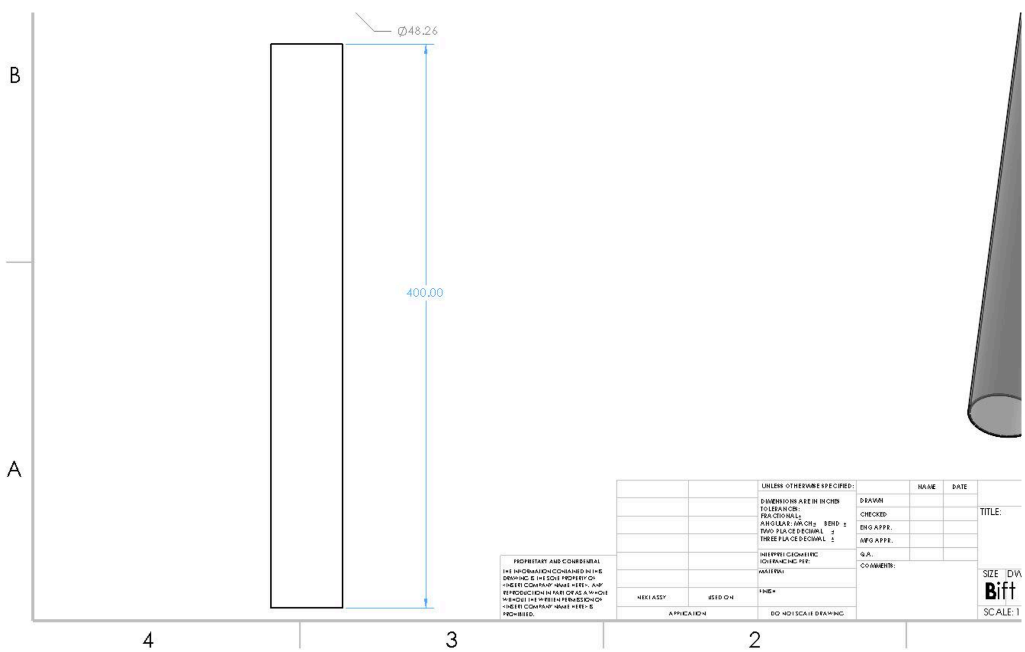

Figure 16. Lift Arm Case 1 Drawing

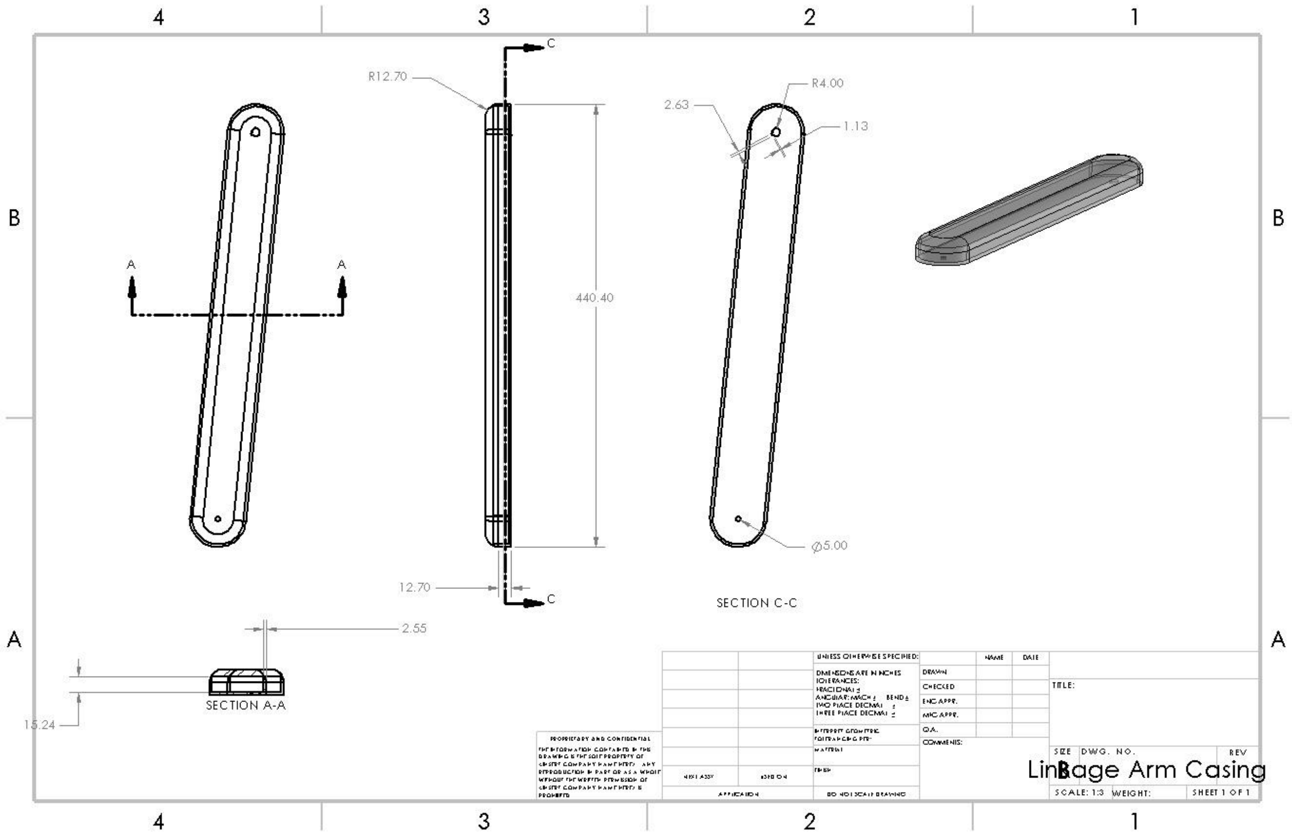

Figure 17. Linkage Arm Casing Drawing

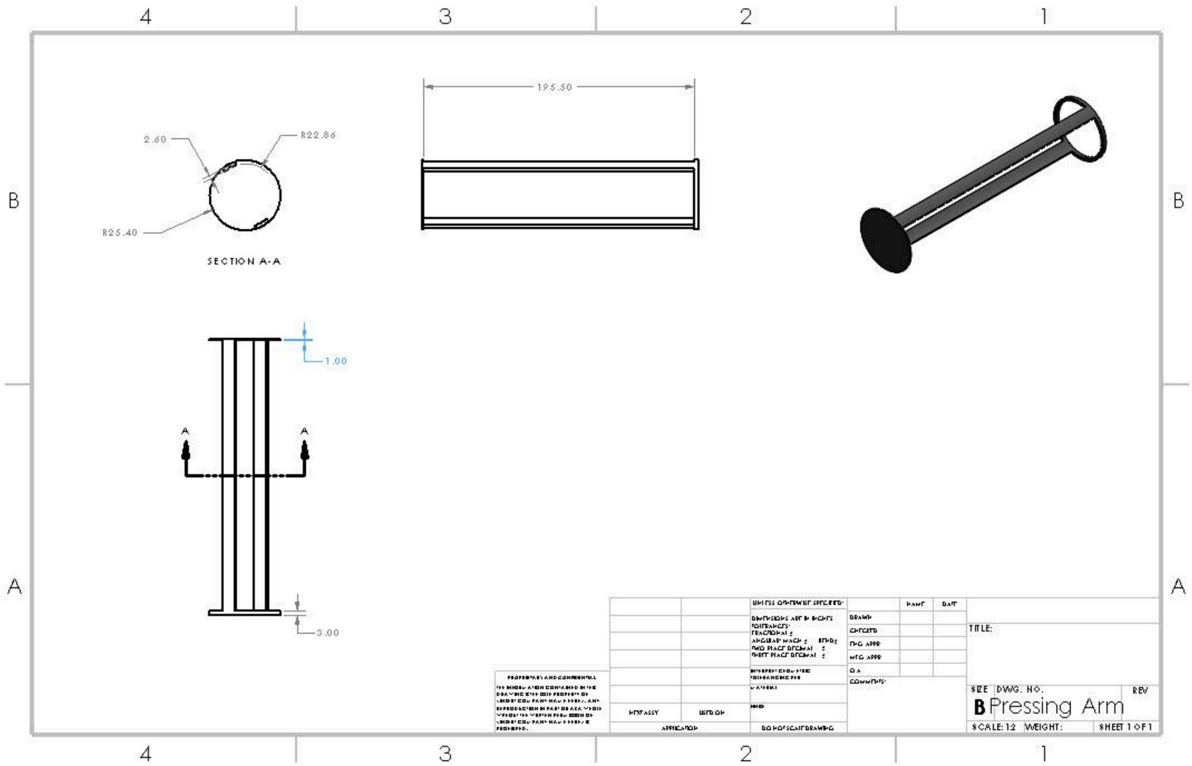

Figure 18. Pressing Arm Drawing

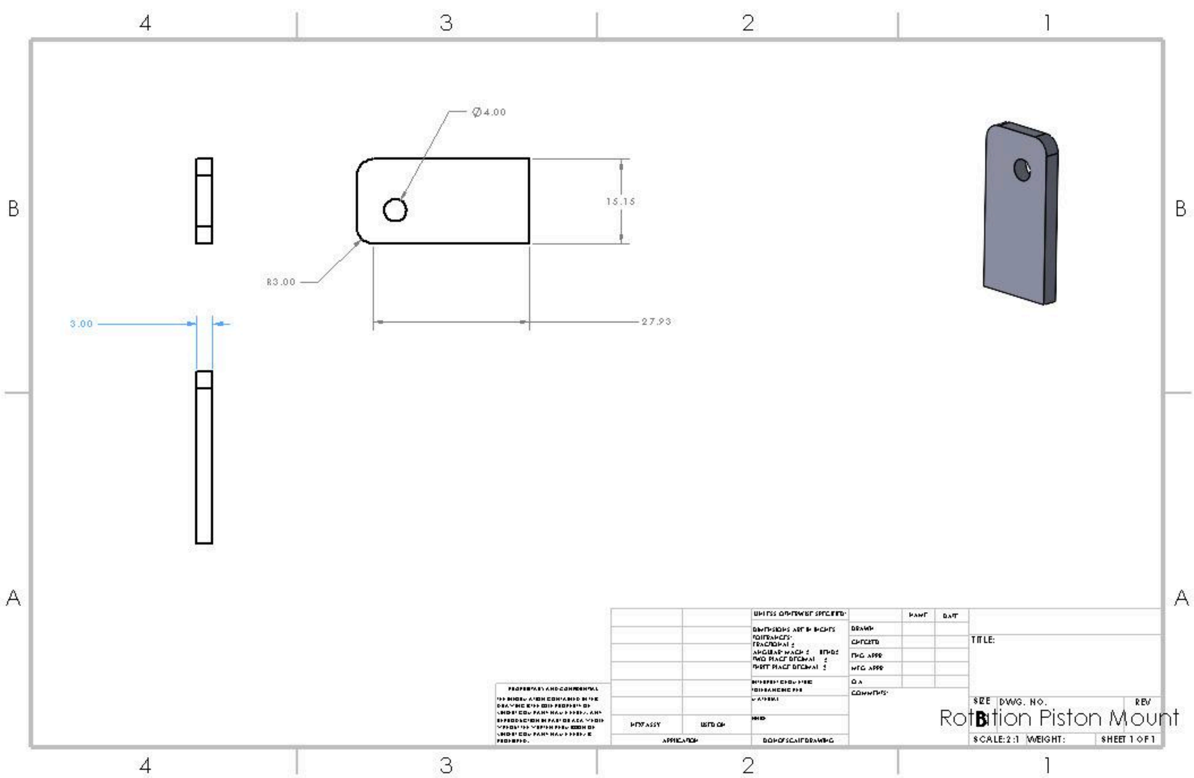

Figure 19. Rotation Piston Mount Drawing

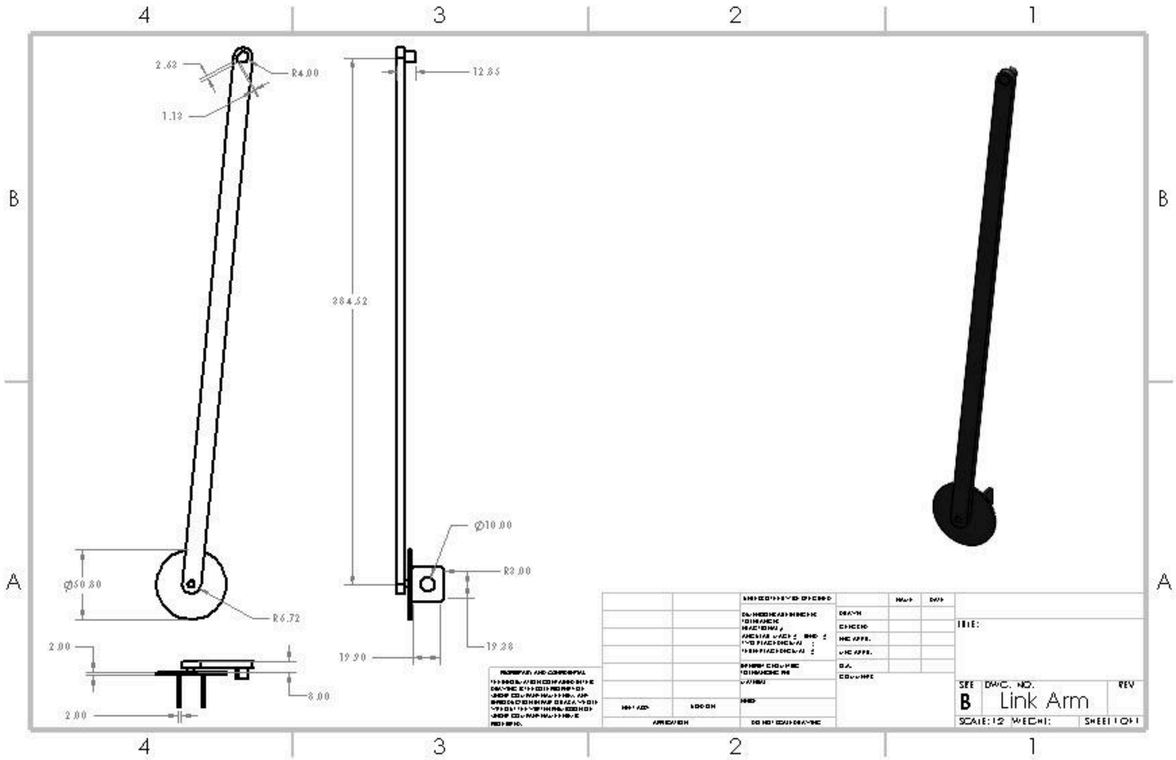

Figure 20. Link Arm Drawing

Appendix C - Work Distribution Form

MEC617 Manufacturing Systems Control
Electro-pneumatic Project

Workload Distribution Form

Please print and hand in this form with your final project Report

Ladder Logic
(3 marks)

	Student #1	Student #2	Student #3				Total
Percent Work	33.33%	33.33%	33.33%				Must add up to 100%

Drawing Package
(7 marks)

	Student #1	Student #2	Student #3				Total
Percent Work	33.33%	33.33%	33.33%				Must add up to 100%

Final Report
(10 marks)

	Student #1	Student #2	Student #3				Total
Percent Work	33.33%	33.33%	33.33%				Must add up to 100%

	Print Name	Signature
Student #1	Hamayoon Ashraf	H.A
Student #2	Muhammad Waseem	M.W
Student #3	Shayan Kaker	SK

*Marks will only be adjusted per student on a ½ mark basis. ie. For final report (out of 10), there has to be a greater than 5% difference between student's work distribution before individual marks are adjusted up or down.