Design of an Automated Sorting and Orienting Machine for Electronic Pins

by

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Abstract

At the power electronics manufacturer SynQor, the printed circuit board (PCB) assembly line is fully automated with the exception of the step which inserts electronic pins into the PCBs. Past attempts to automate this process have resulted in two unreliable machines that are not in use on the production line. Thus, electronic pin insertion is currently a manual process.

The design proposed in this thesis for an automated pin insertion system separates the sorting and orienting of the pin from the insertion of the pin into a PCB. This system decoupling allows for more reliable pin delivery, which can in turn increase the insertion speed and reliability. This thesis focuses on sorting and orienting of the pin.

The resulting design takes pins from a bulk state to an oriented state and inserts them in a pin holding magazine. Preliminary trials of the system show promise as an efficient way of preparing oriented pins for use by a pin insertion mechanism, but more experimentation is needed to test the robustness and speed of the sorting system.

Thesis Supervisor: David E. Hardt
Title: Ralph E. and Eloise F. Cross Professor of Mechanical Engineering

Acknowledgments

The production of this thesis arose from the contributions of multiple people, directly and indirectly, that I have interacted with during my time in the M.Eng Manufacturing program. Of course, the most constant source of feedback was from my teammates Daniel Cook and Rejin Isaac. You were both there every day of this project, and I thank you for inspiring me with your own work ethic.

The employees of SynQor, especially our mentor Lennart Pitzele, were instrumental in helping the team understand the project background and providing support for all aspects of our work. Thank you for your continual understanding despite my not always having a clear path. I wish the company the best in its future and hope that my work has helped in someway.

To my advisor Prof. Hardt, thank you for your patience and your guidance. Each meeting with you motivated me to continually evaluate what I have done and could go on to do.

I would also like to thank Jennifer Craig for her help and encouragement in the thesis process. Your support was doubly meaningful in this process for me in overcoming my writer's block.

Thanks to GQIE for your steady stream of e-mail updates; to Lihua Bai for her unfailing moral support and thoughts on life; to Steve Voinea and Dan Kolobrubetz for weekly caffeine breaks and helping with the heavy lifting; and finally to my parents and sister for their love and support in what has been a difficult year.

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Chapter 1

Introduction

1.1 Background & Motivation

The electronics manufacturer SynQor produces power conversion devices, which consist of one or more printed circuit boards with specially designed circuits of electronic components. Much of the manufacturing assembly for these devices is automated, but the insertion of electronic pins into the printed circuit boards (PCBs) is still done manually.

Automated processes are desirable as, in most cases, they lower manual labor requirements and increase through-put, while also maintaining a high level of accuracy. SynQor has used a number of customized pin insertion machines for the task of inserting electronic pins. As there are a number of pin types and PCB configurations to accommodate, the previous machines were all are too unreliable or too inflexible to complete the pin insertion fully automatically.

This project addressed that void with the goal of designing an automated pin insertion system, which would complete the automation of SynQor's PCB assembly process. This thesis in particular concerns itself with the sorting and orienting of electronic pins.

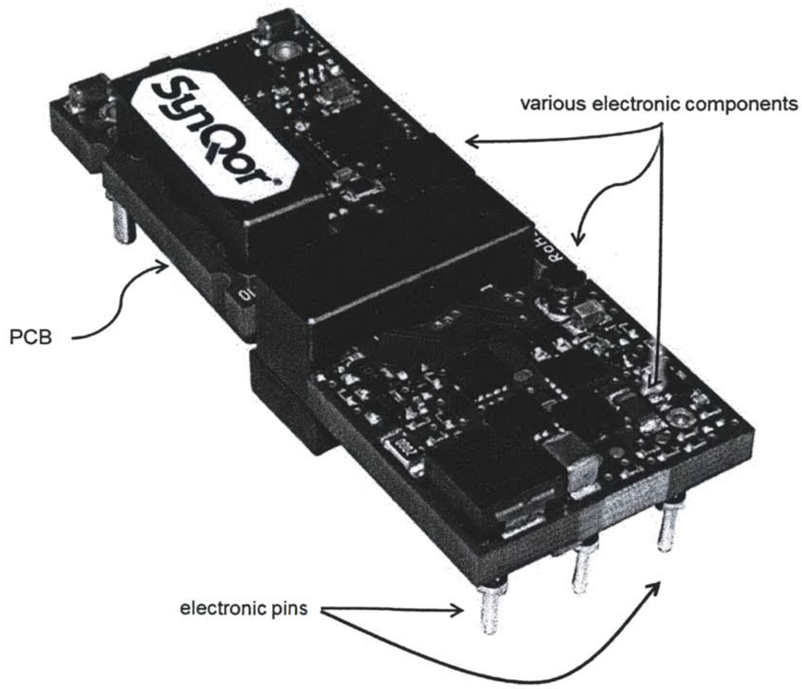


Figure 1-1: *A SynQor power conversion device, with electronic pins visible at bottom of board [1]*

1.2 Objectives

The project proposed to re-engineer a pre-existing pin insertion system into a production system that is robust, cost effective, and flexible enough to accommodate future pin variations. The key objectives were as follows:

- Develop a system which reliably sorts, orients, and inserts pins from a loose bulk state into the PCBs
- Reach a target machine rate of inserting 8 pins in 10 seconds
- Produce a system that is robust while remaining easy to repair and maintain
- Design flexibility into the machine for use with future product lines
- Integrate the machine with the company's centralized tracking system to enable parts traceability

1.3 Project Scope

Given the short project time frame, this project was limited to designing, building, and testing a prototype of an automated pin insertion system. Though there are many electronic pins in use at the company, the focus here was on designing a system that could effectively insert the company's most commonly used pin type (discussed in Section 2.1.2), while including the flexibility to adapt to other pin types. Though the system was not tested on the main automation line during the duration of this project, the lab bench implementation produced a design and recommendations for a robust future implementation.

1.4 Work Distribution

The system was divided into three tasks: (1) Sorting the pins from the bulk to an oriented state; (2) inserting the oriented pin into the PCB; and (3) developing the vision and control systems necessary for the two previous tasks. The initial development of each task was done as a group, but further work was split among the group members. This thesis focuses on the sorting of the pins from bulk to oriented state.

Daniel Cook worked on the insertion of the pin into the PCB, and Rejin Isaac was the lead for the vision and control system development. More detailed information about the pin insertion and control system can be found in Cook and Isaac's theses respectively. [2, 3]

1.5 Thesis Structure

This thesis consists of four parts, as listed below:

1. The problem and group project: Chapters 1,2
2. Background literature: Chapters 3,4

3. Machine design: Chapter 5
4. Critical review of work: Chapters 6,7

Part 1 — This part introduces the problem generally. The project objectives are discussed in Chapter 1, and the group's approach is outlined in Chapter 2.

Part 2 — Background literature is given in this part to position the thesis work here in relation to the greater field of automation. The background review also gives context to the proposed designs in Chapters 2 and 5.

Part 3 — This part describes the thesis author's design methodology and details the sorting system machine design.

Part 4 — The design detailed in Part 3 is reviewed in this part. Preliminary experimental results are presented, and further work and recommendations are suggested.

Chapter 2

System Overview

The current method of inserting electronic pins into printed circuit boards (PCBs) at SynQor is a mix of automated and manual processes. Though automated machinery exists to complete the task, it has proven to be unreliable, often requiring human monitoring and manual adjustments to complete their tasks. The work presented here is a system designed to overcome the previous systems' shortcomings and allow SynQor to completely automate their assembly line.

Section 2.2 discusses the current machinery present for inserting pins into PCBs, a process which is referred to as "pinning", at SynQor. Some of the requirements for an improved process are apparent in the discussion of the current systems' weaknesses. The group design overview is also described in this chapter. The overall design concept and a generalized group solution, along with requirements beyond functional considerations, are presented in Section 2.3.

2.1 The Pins

The main focus of this project is a specialized electronic pin used by the electronics manufacturer SynQor in the majority of its products. At its most basic, an electronic pin is a cylindrical rod of metal designed to carry current from one circuit board to another. Here, the basic function of electronic pins and the specifics of the pin involved in this project are discussed.

2.1.1 Electronic Leads

Pins are a type of terminal component — an electronic lead specific to PCB production. They are attached to the boards with through-hole technology. By making the connection through-hole rather than surface-mount, the pins can transfer an electronic signal through the thickness of the circuit board, useful for making interconnects on a multilayer board [4].

These pins are mostly used as interconnects between PCBs and other electronics external to the board they are mounted on. While one end of the pin is attached to the PCB, the other end may interface directly with the through holes of another circuit board or with receptacle terminals on another PCB or more flexible leads [4].

2.1.2 Project Pin Specifications

The pins involved in this project are two-sided, cylindrical rods with a collar near the center of the length. The insertion end of the pin is characterized by a square or hexagonal insertion head cross-section. The opposite end interfaces with the end users terminal connections. The length of the pin on either side of the collar is variable, and the total length of these pins ranges from about 0.3 inches to 0.5 inches.

The company uses three diameters of pins, which are 0.040 in., 0.062 in., and 0.080 in.. This project only looks at the most commonly used pin diameter of 0.040 inches. At this pin diameter, the insertion head is a square. The collar on these pins is 0.080 inches in diameter 0.040 inches in length. The only exception is a pin with a 0.060 inch collar length, intended to offset the symmetry of the insertion-end and interface-end lengths. Figure 2-1 is a drawing of the most common pin configuration used in SynQor assemblies.

The pin is attached to the board in a two-step process. First, the pin is inserted into a PCB with a small force fit from the non-circular insertion head. Secondly, the pin is soldered to the board. This project only concerns the first part of pin attachment – pin to board insertion — as soldering is a well automated process.

In addition to the mentioned features, the pins also have two chamfers on one side

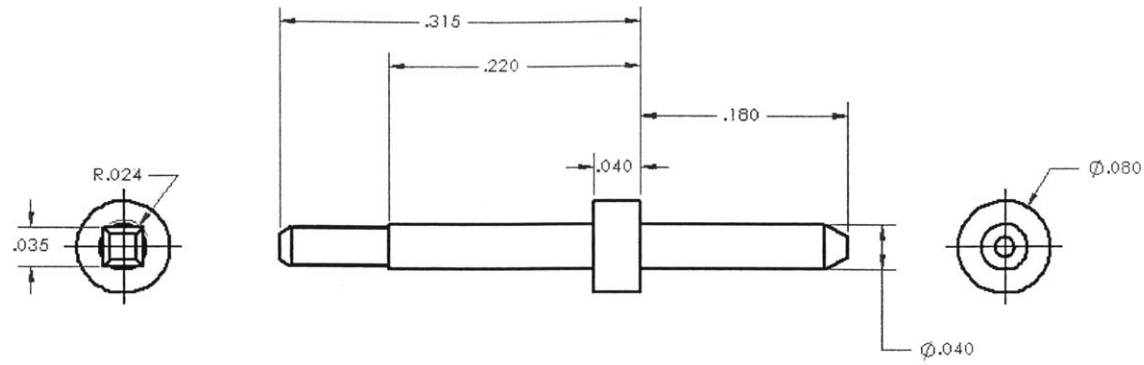


Figure 2-1: *The most common electronic pin used at SynQor*

of on the pin collars, which prevent solder cavities from forming during the soldering process. The pins are lead free and made of tin-plated copper. They are manufactured on screw machines and delivered in bulk.

2.2 Existing Pinning System

There are currently three methods for inserting pins into PCB boards, also know as "pinning", at SynQor. The most basic of the methods, manual pinning, relies on an operator to manipulate the pin and insert it into the board. The other two methods are different automated processes. The three processes and their inefficiencies are described in this section.

2.2.1 Manual Pinning

Manual pinning relies on operators to manipulate the pins. An arbor press with a special collet designed to hold a pin using vacuum pressure is used to press the pin into the PCB (Figure 2-2). To set up the process, the operator sets the pin insertion depth of the press by adjusting a hard stop and testing the resulting insertion depth. Once the desired depth is achieved, the operator locks the stop in place. This depth changes as the pin lengths vary, requiring numerous setup changes. The collets are specific to pin diameter, so a change in pin diameter also requires a setup change.

To insert pins in a circuit board, operators rely on drawings that show where and

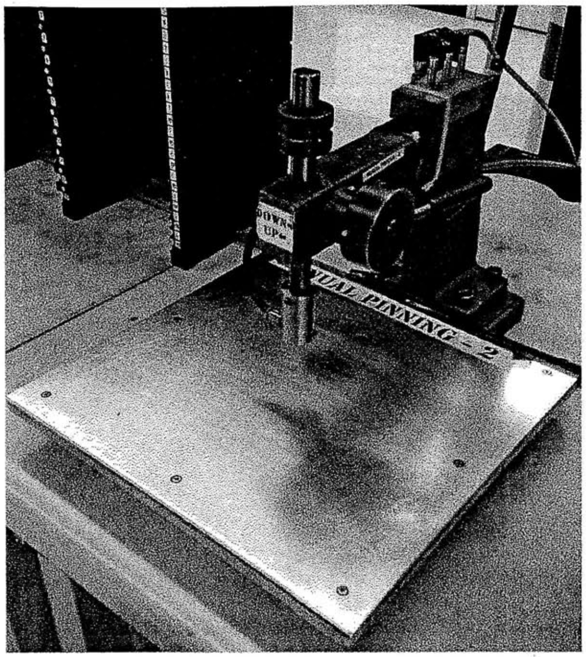


Figure 2-2: *Arbor press used in manual pin insertion process*

which pins are to be located on the PCBs. The operator takes a pin from a bulk box of pins and inserts the head of the pin into the collet, where the vacuum pressure holds the pin in place. The circuit board is positioned under the press, relying on the operator to visually align the pin end and the board through holes. The pin is then pressed into the board, and the process repeats. Once the board is completely populated with its required pins, it is moved into a queue for the next process.

The operators scan each board, and also the boxes of bulk pins being used, into the SynQor tracking system when pinning. This provides some level of part traceability, but is prone to errors as there are often multiple boxes of pins in use by the operators

Currently, the manual pinning process requires two to three full time operators, for two shifts per day, to match the work output of the SMT automation line.

2.2.2 Automated Pinning System I

SynQor worked with a custom automation solutions company in the early 2000s to design a pinning machine for integrated us on their assembly line. The idea was to develop a system that could handle multiple pin types automatically. The bulk pins would be loaded into the system by the operator; but the system would sort, orient, and insert the required pins automatically based on the PCB that is scanned in the machine.

The developed system consists of two units, the bowl table (Figure 2-3) and the insertion machine(Figure 2-4) , connected by a pneumatic air tube through which pins travel. The bowl table is a collection of multiple vibratory bowl feeders to allow the machine to accept a number of pins. The bowl feeders feed the pins onto a conveyor belt. The conveyor transports the pins, with their axis along the direction of motion, past a line-scan camera, and a full image of the pin is developed from the cross-sections that the camera takes. From this image, the pin is analyzed to determine its type and orientation. If the pin is an incorrect type, it is blown off the conveyor belt and sent back to the bowl. Downstream from the camera, an arm picks up the correct pin and orients it, then blows it through the tube to the second unit, the insertion machine.

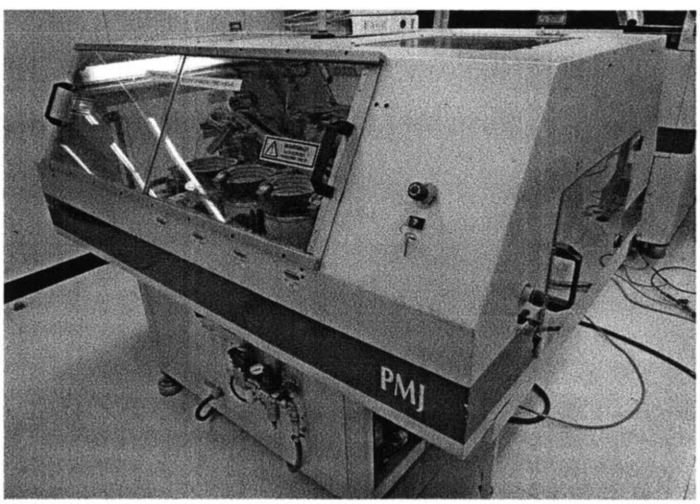


Figure 2-3: *The automated pinning system sorting unit*

In the insertion machine, the pin drops into a shuttle that is accessible to the insertion machine's robotic arm. This arm picks up the pin, using vacuum, and positions it at the correct point over the PCB. The machine then presses the pin to the correct depth. The positioning system (a dual-gantry Cartesian robot) on this machine is highly accurate, and part of the team's design relies on the use of this section of the machine.

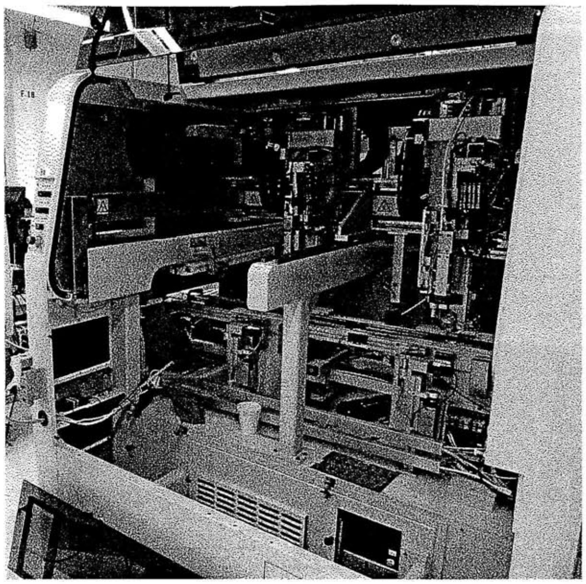


Figure 2-4: *The inside of the automate pinning system's insertion unit*

This machine was used in production briefly but was found to be very prone to failures. Mainly, the bowl table unit could not deliver pins reliably to the insertion machine. Pins would jam at multiple points in the system, such as in the tube that delivered pins from the sorting mechanism to the insertion robot. The sorting mechanism could not identify and orient pins fast enough to keep up with the pace of demand expected by the insertion robot. Often, the insertion machine sat idle while it waited for a pin to be sent from the bowl table.

2.2.3 Automated Pinning System II

The second automated pinning system present at SynQor was purchased from a company that specializes in odd-from parts placement. It is presented in Figure 2-5. This system employs specially designed vibratory bowl feeders to feed and orient the pins. The bowl feeders are highly customized to accept and sort only a single pin type per vibratory feeder. That is, each feeder is tuned to work with a single pin type. The vibratory feeder designs take advantage of the non-symmetric nature of the pins and employs traps which reject pins that are the wrong size and length, doing so with a fair amount of accuracy.

Once the feeders sort and orient the pins, they are queued in a slide which leads to an escapement. The escapement shuttle picks off one pin from the queue of pins and drops it down a short tube to the insertion head. The board is positioned under the insertion head and a pin is driven to the desired depth. Note that unlike in the first system (Section 2.2.2), here, the insertion head is fixed and the board is moved for positioning.

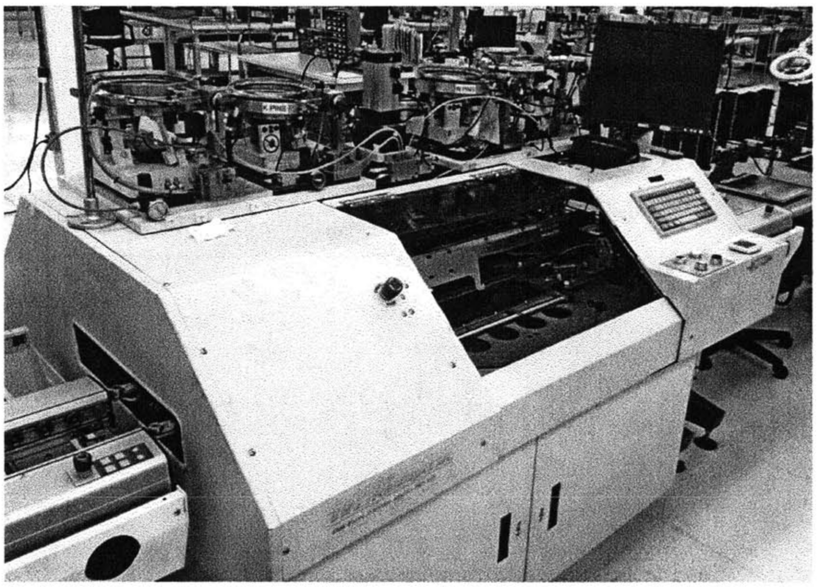


Figure 2-5: *The second automated pinning system. Notice the bowl feeders sitting on top of the machine.*

This system suffers from frequent jamming in the bowl feeder to escapement area of the process. Since the bowl feeder is vibrating, pins are constantly being driven forward, pushing against each other in the queue. This can cause the line of pins to jam as pins can ride up on each other, requiring operator intervention to clear the jam. Additionally, The positioning system in this machine has very little in terms of feedback to know if it has pressed a pin correctly.

2.3 Developed Solution

Based on the past systems and knowledge of machine design, the team designed its own system for inserting pins into printed circuit boards. An overview of the system is given in this section.

2.3.1 Pinning Design Overview

The pinning process consists of two sub-processes: sorting and insertion. In past attempts to automate pinning, the process was run as one series of tasks to be completed in sequence. A failure at one point meant a stop in the whole system. Therefore, the team decoupled the process into two parts to alleviate some of the bottlenecking issues.

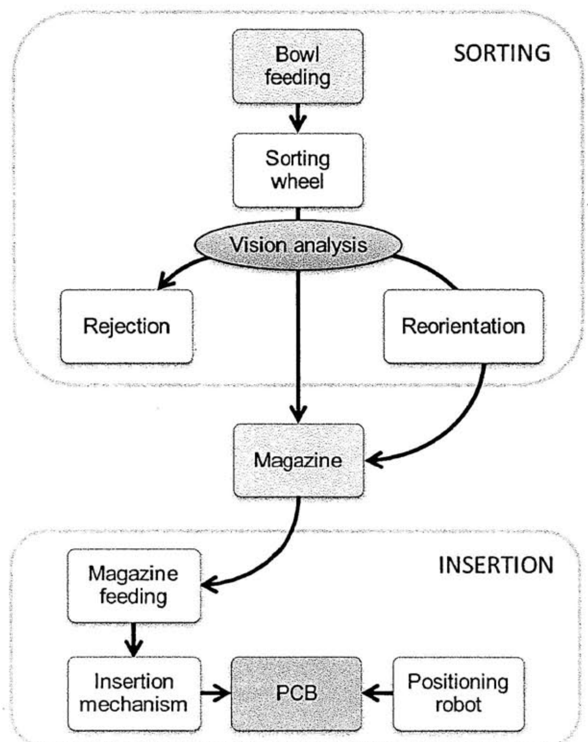


Figure 2-6: *The process of pinning a PCB is broken into two parts – sorting and insertion – that are interfaced with a magazine.*

The system was decoupled in between the sorting and insertion sub-processes by using a magazine as an interface. The magazine used here would hold a determined quantity of pins in an oriented state for quick dispensing in the insertion process.

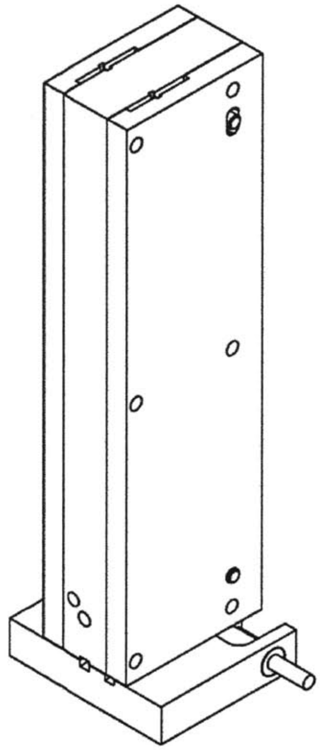


Figure 2-7: *The pin magazine used to decouple the sorting and inserting processes [2]*

2.3.2 Sorting

The process of sorting pins takes the pins from the bulk delivery state and aligns them in the pin magazine. The sorting process utilizes vibratory bowl feeders to initially feed and orient the pins. They are then transported onto a rotating wheel that has a few stages for process steps. The wheel presents the pins to a camera for vision analysis. This determines what orientation the pin is in and if it it is the desired pin. As the wheel indexes to each station, the pin passes a reorientation stage, which adjusts the orientation on those pins that need it, and the magazine delivery stage, where correctly oriented pins are inserted into the magazine. Pins that are determined to be of incorrect type are dropped into a separate holding spot.

This sorting process can be completed off of the production line, as it does not need to be run serially with the insertion process. When boxes of pins arrive at SynQor, operators can run the pins through the sorting machine to transfer them to a magazine so there are always magazines ready for the production floor.

2.3.3 Insertion

The insertion process re-purposes the insertion unit mentioned in Section 2.2.2. As previously mentioned, the insertion machine consists of two gantry-style Cartesian positioning robots. Attached to each carriage on the robots are two insertion mechanisms. One gantry has an insertion mechanism for 0.040 inch diameter and 0.062 inch diameter pins, and the other has a mechanism for 0.040 inch diameter and 0.080 inch diameter pins. As the 0.040 inch pins are used in the highest volume at SynQor, there are two insertion heads, one on each gantry, to handle and insert them, balancing the workload between the two gantries.

The insertion mechanism utilizes a feed shuttle integrated into the magazine body to dispense pins from the bottom of the magazine. The dispensed pin is sent into an insertion tube that rotates to orient the pin vertically for insertion. The positioning gantry locates the pin over the correct hole on the board and drives the pin down to the correct insertion depth. The process repeats until a magazine is depleted or a new pin type is required for the board. In either case, the positioning robot will automatically unload any empty or unneeded magazines, and load a new one from a magazine rack located within the robotic work envelope.

2.3.4 System Components

Although not completed as a part of this project, there are a number of features already developed at SynQor which the team believes may be reused as part of the current project. For example, the positioning unit's control system has the ability to scan the barcode located on each PCB to determine the correct pin insertion program for each particular board. This allows the machine to change product lines without operator intervention as multiple pin types can be loaded into the magazine rack for the machine to access. A product-programing interface has also been developed to allow engineers to easily program new PCBs into the system. The resulting pinning system is very flexible for introducing new products to the assembly line.

Chapter 3

Manufacturing Automation

This topic of this chapter is the field of automation, the engineering focus with which this project most closely aligns. It will discuss automation broadly and also as it related to this project.

3.1 Defining Automation

At its most basic, automation can be defined as the use of machines to make manufacturing processes more efficient. These machines combine operations or have skills that are not easily acquired by a human workforce. Modern automation is the *automatic handling and continuous processing* of a machine, made possible with computer control and robotic manipulation [5].

It is important to differentiate automation from mechanization. Mechanization is doing work with the help of machines. That is, operators use machinery to assist them in completing the bulk of their work. Automation reduces the human physical labor component by allowing the work to be controlled by computer technology. Automation operators are mainly responsible for ensuring the machines are in working order rather than making the parts [6].

Automation is characterized by the use of electromechanical devices, such as motors, servos, hydraulic and pneumatic systems; an increase in the productivity of a given process; improved precision and reproducibility; and a decreased workforce for physical labor.

3.2 A Brief History

The advent of automation came hand in hand with the development of the more complex control systems, chiefly through advances in digital computing. The term automation itself was first used at the Ford Motor Company in 1945 to describe the combination of automatic handling of product between machines and continuous processing of product in machines [5].

The roots of automation can be traced to the electrification of factories. As it became possible to provide machines with a constant power source, many already mechanized processes were combined in machines. Factories were able to implement continuous-flow mass production, but they used machines which were all tooled specifically for single tasks. The need for more flexible and sophisticated machine control became evident. Both numerical control (NC) and electronic controls grew from this need. [7,8].

3.2.1 Process Controls

An important aspect of automation history is the parallel development of the programmable logic controller (PLC) and the distributed control system (DCS). Both of these technologies are composed of many smaller innovations in control technology [8].

Programmable Logic Controllers

The PLC is a common digital control unit in automation systems. It is a basic computer that is designed for use on the shop floor to handle digital input and output (I/O). It has a robust design, is easy to operate, and is general enough for many applications. A PLC must support a number of discrete inputs and outputs, with the capacity to expand, while remaining fast enough for real time control of the process it is monitoring [9].

The programmable logic controller was first designed for the automotive industry as a replacement for hard-wired relays. Relay logic was a way of creating task sequences using hardware that was very difficult to modify. The first PLCs replaced these relay systems by implementing a microprocessor to control discrete inputs and outputs. Because these units were placed on the manufacturing floor, it was imperative that they be robust enough to survive the heat and vibrations of a normal facility. Today, PLCs are comparable to personal computers in terms of power and capabilities, but they are still preferred for industry use because of their more robust environmental tolerance [8].

Distributed Control Systems

The distributed control system is a broad term used to describe a control system having components (usually processes) which are distributed across a system rather than centralized as in a PLC. Each subcomponent may be a subsystem controlled by its own controller or controllers. DCS functions to bring these components together in a closed-loop system, where the output of one process may trigger an alarm on another [8].

DCS is more often used in process control rather than automation. This stems from its roots in processing plants, such as paper mills and power plants. Also a product of microprocessor development, a DCS is generally used to monitor and control a set of physical processes, possibly by direct connection to physical equipment such as mechanical or pneumatic switches. Distributed control systems are used where advanced information management is required for monitoring processes [8, 9]

3.2.2 Control and Positioning

Numerical control is what drives much of modern precision machining. This positioning control is the technology behind the computer numerical control (CNC) machines that are viewed as a trademark of automation.

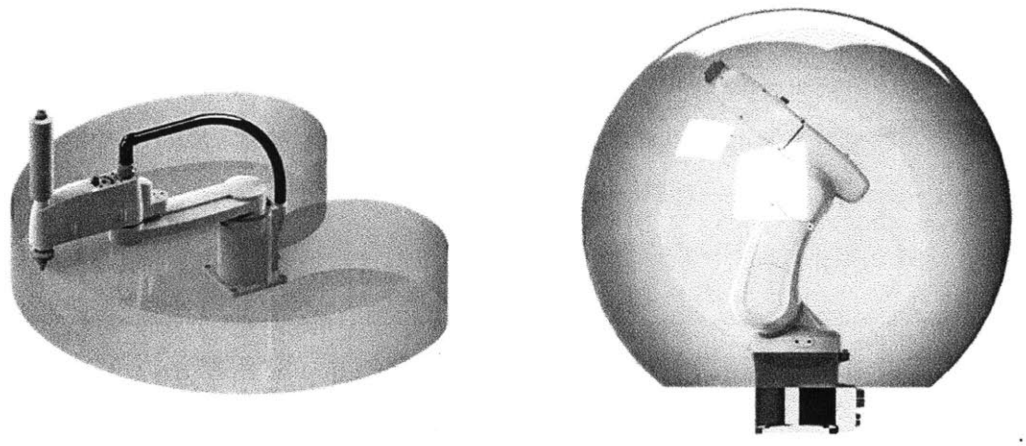
Early forms of machine control included cams and tracing machines, but these methods were not abstractly programmable. The development of the servomechanism and the subsequent selsyn (two servos working in tandem) meant it was possible to have highly accurate measurement information. The idea of combining this positioning system with a numerical calculator was first brought together by John T. Parsons in the 1949, with punch card readings as the calculator. [7].

The first working NC machine was developed at MIT in 1952 – a complex design involving a punch tape input, relay-based hardware registers, and many encoders and moving parts. The following decade showed many improvements to CNC systems, but it was not until the proliferation of minicomputers in the 1960s that the use of CNC machines became widespread. [7].

This positioning control technology has had usage beyond the field of machine tools. The precision positioning systems developed for machining have been extended to control of autonomous robots, many in the service of factory automation. The first such robot was the Unimate, used in a General Motors plant in 1961. The robot moved die castings and did automobile welding, jobs considered extremely dangerous for human laborers. The trend in automation has continued today, with many industrial robots doing the duties that humans cannot or would not want to perform. [7].

3.3 Industrial Robots

Robots used in industrial settings are generally specialized for their tasks, but all share common configuration types. Each robot is a combination of different types of linear or rotational joints that can be manipulated in order to reach a desired position. Common configurations include the SCARA (selective compliant assembly robot arm) robot, typically used for simple pick-and-place type operations (Figure 3-1a); an articulated robot, having the dexterity and joint structure of a human arm (Figure 3-1b); and the Cartesian coordinate robot (Figure 3-2), which is often seen in a gantry configuration [10].



(a) (b)

Figure 3-1: *SCARA and articulated arm robot configurations (a) the SCARA configuration, with its work envelope shaded [11] (b) an articulated arm robot, with its spherical work envelope shaded [12]*

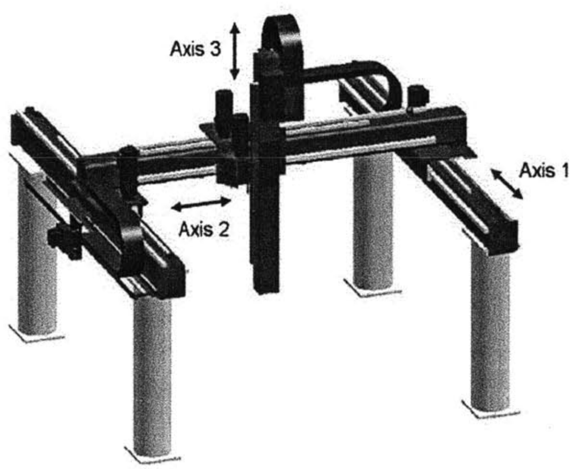


Figure 3-2: *Gantry robot configuration [13]*

3.3.1 Robotic Coordinate Systems

Each robot has a characteristic work envelope which represents the volume that the robot can reach with its end effector. A robot has three main coordinate systems which represent its work envelope. These coordinate systems are described in the following paragraphs [14]:

Joint Coordinates store the exact position of each joint in the robot. These coordinates are stored as joint positions relative to a local reference frame and are summed to reach the desired end effector position.

World Coordinates describe the position of an end effector relative to a fixed coordinate frame that is usually attached to the ground floor. There are multiple joint orientations that may satisfy the desired position in the world coordinate frame.

Tool Coordinates are a frame fixed to the center point of the tool on the robot. Using the tool coordinates, the robot can be programmed incrementally, without dealing with the kinematics of the robot itself since all motions are relative to the tool.

3.3.2 Programming Robots

Robots can be programmed through a few different methods. In the industrial setting, they can be generalized to on-line and off-line programming. On-line programming involves programming the robot directly, often requiring the robot be taken out of the production process in which it is currently used. Off-line programming, on the other hand, utilizes computer simulation or a separate physical model of the robot system to program the desired motions. Once the program has been generated off-line, it can be uploaded to the robot while on the production line, minimizing downtime compared to on-line programming methods.

Programming the motion of the robot can be accomplished in a number of ways. Text based programming methods rely on motion control languages such as Visual Basic or C and can program precise robotic motion. Physical programming methods teach the robot points by physically moving the end effector to the desired position and recording the sequence of points. Similarly, playback programming which involves teaching the robot the path it should follow between points rather than allowing the control system to interpolate between points.

3.3.3 End Effectors

The end effector on a robot is often used to hold a part or a tool for a production process. Robots that hold parts often have a gripping mechanism as an end effector.

The gripping mechanism can physically grip the part with pneumatic or electric actuation, or it can hold the part via vacuum or magnetism. Robots that hold a tool used in a production process have end effectors which accommodate that tool and any tool accessories. [10, 14].

3.3.4 Robotic Advances

The speed and accuracy of a robot result from many factors including the structural design of the between joint links, the power that the joint actuators can provide, and the resolution to which the joints can be controlled. Currently, one of the fastest robots on the market is the Adept Quattro robot, which has a parallel configuration of four arms. The Quattro has a payload capacity of 6kg, a maximum speed of 10m/s, and a repeatability of +/- 0.1mm, according to the manufacturer's specifications [15].

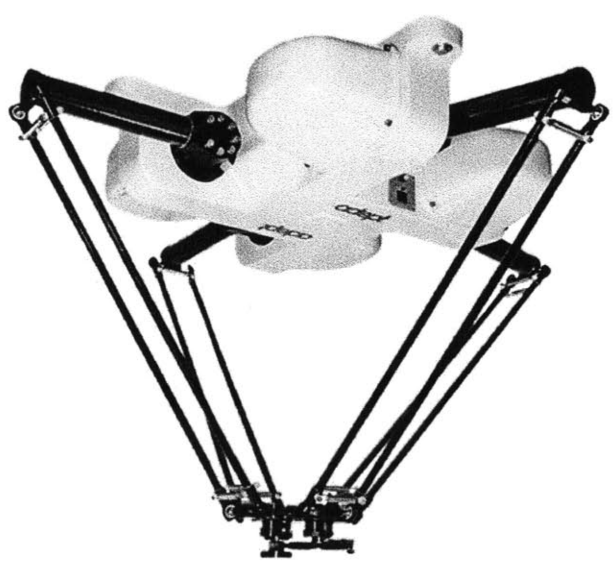


Figure 3-3: *Adept Quattro robot with four arm configuration [15]*

3.4 Machine Vision

Machine vision is the use and processing of imaging to gather information that supports the functioning of automation processes. The use of machine vision, rather than operator judgment, often decreases the time required for inspection processes, such as counting, gaging, or detecting defects, while also improving precision and reliability. Industrial machine vision systems are deployed in a wide range of industries from semiconductors to food packaging.

3.4.1 Vision Hardware

Imaging hardware used in the automation industry has a strong focus on speed, power, and form. Acquisition speed is an important parameter that defines how fast the system can capture and process images. Many cameras used in modern vision systems are based on the Gigabit Ethernet (GigE) interface standard that allows data transfer rates up to 1000 Mbit/s [16]. The fastest systems in the world can process up to 500 frames per second with the use of multi-core processors [17]. Some imaging processors are powerful enough to function as stand-alone PLCs. These camera processors can handle the I/O from related sensors and lighting rigs, simplifying the set-up for a system [18].

While the speed of imaging hardware continually grows faster, the size of the cameras continues to grow smaller. The smallest cameras available are often just a few centimeters in length and width [17]. Many cameras forgo fans for a heat sink design to reduce volume [19]. In addition, many small cameras have an embedded processor within their frames. These miniature form factors are ideal for use within automation machinery, where space is a constraint.

3.4.2 Vision Software

Machine vision software is built for feature recognition, with pattern matching and edge detection being the most commonly used. In recent years, developments in computer algorithms and processing speeds have facilitated the introduction of new features for image processing, such as the joint use of image and sensor information or comparisons of multiple images.

Traditional vision systems are controlled through network protocols like RS-232, RS-485, Ethernet, allowing them to be easily added to a network. Some software allows real-time, web-based monitoring of the production process through the vision system [20]. Thus, an automation network may be remotely managed easily via its machine vision capabilities.

The Future of Machine Vision

The machine vision industry is slowly moving towards the use of 3D imaging. Three dimensional imaging involves the use of multiple cameras to gain information about object dimensions in the depth direction [17]. Depth and thickness analysis is especially useful in industries, such as the semiconductor industry, where object thickness is a critical element of the product.

3.5 PCB Automation Technology

Automation that directly relates to PCB assembly is an advanced field that often incorporates the latest technologies in its continual advancement. Machine vision, for example, is often used alongside human visual inspection to assess the quality of printed circuit boards at hundreds of points per board. And modern part placement machines, called "pick and place" machines, are common on surface mount technology assembly lines. There are two methods for securing components to a printed circuit board: surface mount technology is one and through-hole technology is the other. These methods are illustrated in Figure 3-4 and further discussed in Sections 3.5.1 and 3.5.2.

3.5.1 Surface Mount Technology

Surface mount technology (SMT) is the placement of small and lightweight components, having small or short leads, directly on the surface of the printed circuit board

Figure 3-4: *The two main methods of securing electronic components to PCBs differ in regards to the location of their leads (a) through-hole technology solders leads through the PCB (b) surface mount technology solders leads on top of the PCB. [21]*

(PCB). Usually too small to be handled by human operators, SMT components are packaged in tape reels to ensure proper part orientation and easy dispensing. They are then moved using vacuum heads and placed on the board, with solder paste acting as a temporary adhesive.

3.5.2 Through-Hole Technology

Through-hole technology (THT) is a component mounting method in which parts have leads which go through a hole in the PCB. These leads are then soldered to the board. Through-hole components are bulkier than those used in SMT, making tape or reel packaging more difficult but human handling easier. The fact that through-hole components also tend to be irregularly shaped, as opposed to the rectangular SMT components, gives THT components the name "odd form". These parts must be inserted into the board with some force and are held in place with a press fit. Here, solder is used an additional attachment method rather than as the primary.

The project discussed in this thesis deals exclusively with the THT component called an electronic pin, as was discussed in Section 2-1. But while the machine deals with through-hole technology, the machine design is also influenced by the efficiencies of surface mount technology.

Chapter 4

Assembly Systems & Part Handling

The problem presented in this thesis centers around the design of an assembly system. And while the design of assembly systems usually begins with an examination of part design, the design of the electronic pins to be used here are not within the scope of this project. Assembly systems can be described as a combination of handling and transfer mechanisms. This chapter discusses a number of these mechanisms, with a focus on those incorporated into the project's system design (Chapter 2).

4.1 Designing Assembly Systems

An assembly is a grouping of components that, together, make up a working unit. An assembly system is the group of mechanisms by which this assembly is put together. When planning automatic assembly systems, there are many factors to consider, such as equipment cost, allowed cycle time, system waste. Some, but not all, more mechanism-related questions include the following:

- How should parts be presented to the system?
- How should parts be moved within the system?
- How should parts be manipulated or inserted?

Designing an assembly system is about choosing the right resources to do the work required on time.

Additionally, assembly systems should aim to be easy to operate and repair. An extremely complex mechanism may complete a task precisely and quickly, but its repair may be difficult and lengthy. In many cases, a slower but more simply designed mechanism that has little down time may be the better option for overall efficiency. A well designed system will complete the required tasks in the necessary cycle time while minimizing the time needed for maintenance or repairs.

4.2 Carrier Mechanisms

Within an assembly system, there must be a mechanism in place to move parts from one location to the next. This mechanism maintains the positions between a part assembly and the robot or workhead, while transferring parts and assemblies through the system. These assembly machines are called work carriers, and they are usually categorized as in-line or rotary, according to their method of transferring parts. In-line carriers move parts along a straight path; rotary carriers move parts in a circular path. Besides their physical path, carriers also operate either continuously or intermittently, an important distinction that will be further discussed in this section. [22]

4.2.1 Continuous Transfer

Continuous transfer is the movement of parts at a constant speed, without interruptions or pauses to the part flow. Carrying parts in this manner means that the assembly operations must be carried out with the same movement as the part. That is, the operation mechanism must move with the part while it passes through the workstation and then return to a starting position to work on the next work piece. For rotary transfer, there may be an array of workheads arranged on a circular pattern that is tangential to the part flow. The difficulty in continuous transfer is maintaining alignment between both the moving parts and workheads. An example of this transfer type is the filling of bottles in the food industry. [22]

4.2.2 Intermittent Transfer

The more common transfer type in automation systems, intermittent transfer moves parts intermittently. Each part or assembly pauses at the workstation, which remains stationary. Often, the parts all move together such that each step will move a part into position at a workstation. This is indexing. In a rotary system, multiple workstations can be set around the indexing table such that a part will be finished after a complete revolution. The sorting system to be discussed in Chapter 5 is an example of a rotary indexing transfer system. In in-line systems, multiple stations can be set up along the line of movement, with the part being complete at the end of the line. Here, some method of removing and returning the assembly pallet to the beginning of the line must be made. Figure 4-1 illustrates these indexing systems. [22]

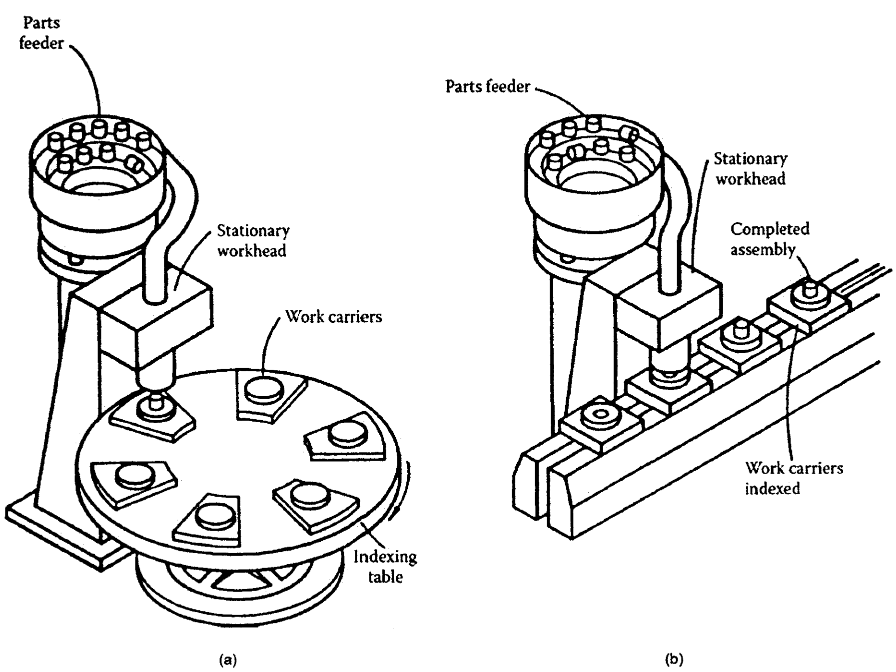


Figure 4-1: *Examples of indexing carrier mechanisms shown with an arbitrary parts feeder (a) an intermittent, rotary transfer system, where the assemblies are removed manually when completed (b) an intermittent, in-line transfer system where the assemblies are removed and the pallets reset manually [22]*

4.3 Parts Handling

"If a part can be handled automatically, then it can usually be assembled automatically." [23]

When developing an assembly system, how parts are conveyed and how parts are presented are important design considerations. Part handling is a main area of difficulty in automation; if a part cannot be handled with ease, then it obviously cannot be inserted into an assembly. Part handling mechanisms concerned with orienting and feeding are discussed in this section.

4.3.1 Feeding and Orienting Mechanisms

The first step in assembly is part presentation – that is "to bring parts to the point where they can be assembled" [24]. This is accomplished through some mechanism that feeds and orients the part. The following sections describe a number of feeding and orienting mechanisms commonly used in assembly systems for small parts. The problem of feeding of large parts is out of the scope of this project.

Hopper, Rotary, and Conveyor Feeders

The most basic method of automated feeding is to use a bulk feeder such as a hopper, a conveyor (or belt), or a rotary feeder. These feeders are best suited to feeding parts with basic geometries, with some being able to handle a more limited range of part shapes than others.

Hopper feeders consist of a storage container with an attached delivery mechanism that relies on slight agitation and gravity to deliver parts. An example of a hopper feeder is a a hopper with a reciprocating delivery tube. The tube moves up and down relative to the hopper, catching and delivering a few parts in the tube each time. This mechanism is illustrated in Figure 4-2. Other hopper designs may employ a reciprocating blade that catches parts at the track along the blade's top edge or a reciprocating fork that catches parts between its two prongs. [22]

Rotary feeders work similarly to hopper feeders, but employ a rotary motion

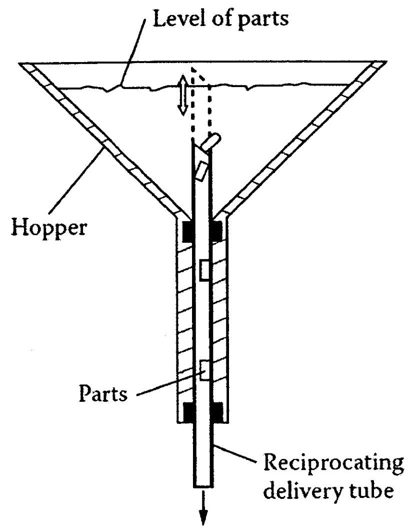


Figure 4-2: *A reciprocating tube hopper feeder. The feeding tube moves vertically to allow parts to into the tube for delivery. [22]*

of the part storage container rather than movement of the delivery chute. Rotary feeders are usually rotating disks set at an angle. The disk has a series of slots and ledges that catch parts as it rotates. At the highest rotation point, a slot will align with a delivery chute; the parts which were carried by the ledge will slide down the chute. Alternately, a rotary feeder may work much the same as the reciprocating blade hopper mentioned previously, but replaced the single blade with a continuously rotating bladed wheel. [22]

Conveyor or belt feeders also work through a similar concept to the hopper and rotary feeders. A conveyor belt moves upward at an angle through a storage container filled with parts, and the belt has slots designed to accept parts in a certain orientation. These parts are then delivered off the top of the belt via a chute. Wipers are employed to push back any parts that did not fall into a slot. [22]

The hopper, rotary, and conveyor feeders do not actively sort and orient parts. Rather, parts are agitated until they fall into a desired orientation, which may be the only state allowed through the delivery chutes. These feeding mechanisms also depend on having a certain amount of parts in the storage container to maintain a steady feed rate. [22]

Trays and Pallets

Trays and pallets are platforms on which parts have been arranged for individual feeding. The pallet is filled then presented to the assembly system for insertion or placement. The system may use a robotic arm to pick parts from the pallet. This is essentially a two part feeding system, isolating the bulk feeding from the individual part presentation (similar to the project's use of a magazine).

A well known pallet filling method is the Sony APOS (Automatic Positioning and Orienting System). In this system, a pallet has a number of pockets that accept a specific part in a specific orientation. The pallet loaders hold the pallets at a slight angle while vibrating them. Parts are simply dumped into the pallet, and the vibration and angle fill the pockets with parts. The filled pallets are then loaded into a robotic assembly system. This feeding method is less specialized than other bulk feeders but has a large cost associated with the manufacture of multiple pallets and a time cost associated with the changing over of pallets during assembly. [24]

Carrier Strips

A type of feeding system that usually requires manufacturer participation, carrier strip feeding systems rely on parts that are linked together like a "paper doll chain". The parts are carried via these strips until the moment they are cut from the strip to be inserted into the assembly. Carrier strips can be metal parts stamped onto a metal strip or parts that are plastically molded or inserted into a strip. The creation of the strips are usually integrated into the part manufacturing process such that the part may be part of a carrier strip through its finishing process. An example of carrier strips is the packaging of axial-lead resistors on a tape. Much like the tape reel packaging of surface mount parts, parts on carrier strips are already sorted and oriented, allowing for very high feed rates with low rates of failures per part. [24]

Vibratory Bowl Feeders

Vibratory bowl feeding is the most common small parts feeding mechanism. A vibratory bowl feeder is a feeding mechanism that works by using specially designed vibratory bowls in conjunction with part geometry and friction. The bowl has a spiraling path along side which leads to its rim from the bottom center of the bowl. Parts are vibrated rotationally and vertically, such that they climb this track, moving upwards and eventually out of the bowl. Bowl feeders are simple to refill for continuous work, but they also wear under long-term use, causing small changes that affect their ability to feed the part the bowl was designed to feed. [22]

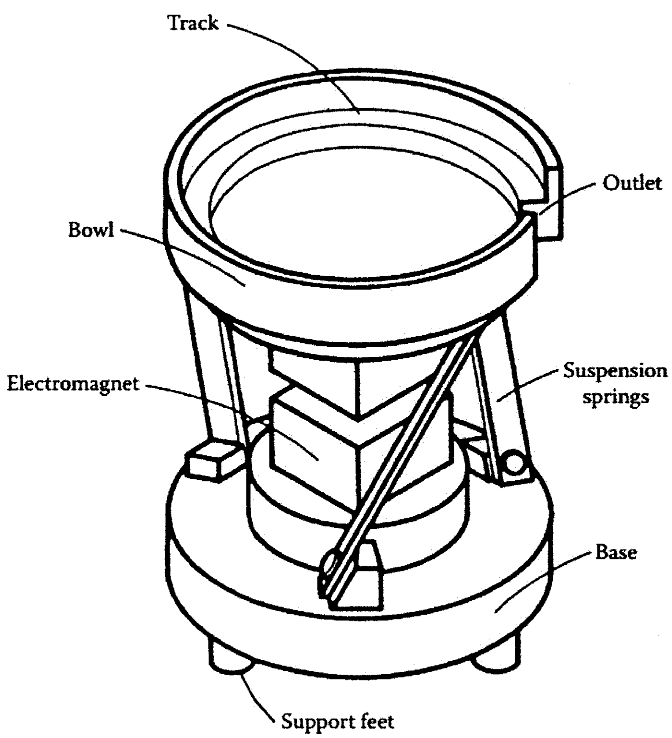


Figure 4-3: *A generalized representation of a vibratory bowl feeder. The bowl track itself is specialized to accommodate the part being fed. [22]*

Vibratory bowls are able to do some sorting and orienting of parts as they move along the circular track. This is done by limiting the number of stable states in which a part can travel up the bowl by adding "traps" along the part path. Mechanical traps take advantage of the geometric properties of the part being fed. The most simple trap is a width adjustment. Parts arrive at a narrowed ledge along the track, and only parts oriented such that their center of mass is still on the track will be able to pass. Other traps include wipers which control the height of passing parts, pressure breaks which only allow parts to move past one at a time, cutouts that certain part orientations cannot pass, height tracks and slots that the parts must fit onto, and many more. Many of the mentioned traps are both sorting and orienting mechanisms, as they only allow the certain part geometries at certain orientations to pass. [22, 24]

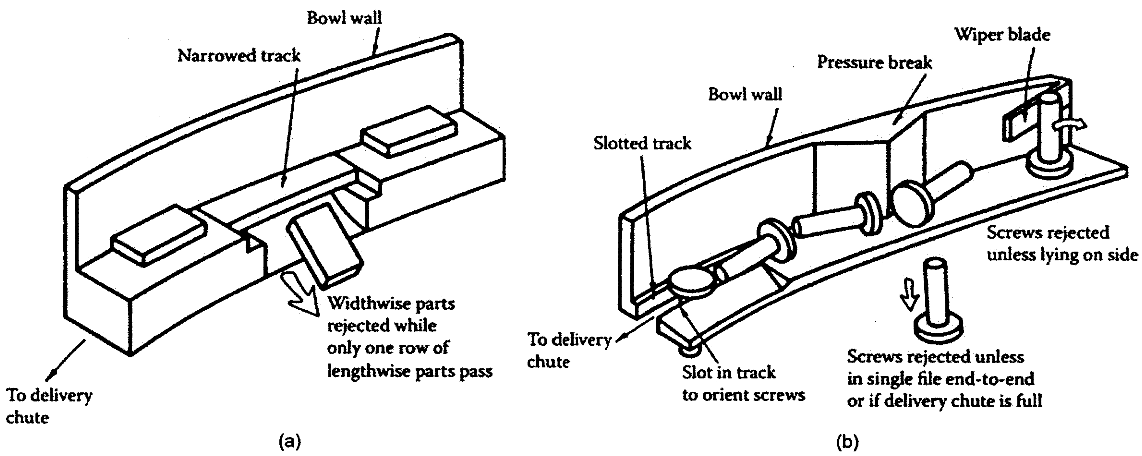


Figure 4-4: *A few types of mechanical traps used commonly in vibratory bowl feeders. (a) a change in trap width only allows parts with a center of gravity in a certain range to pass. (b) the traps from right to left: a wiper controls for part height; pressure breaks prevent part buildup by only allowing one parts through single file; the slotted trap orients parts of certain geometries, a screw here, and is applicable to the electronic pin of this project. [22]*

Recent research in bowl feeding has focused on adding flexibility to these system through the design of non-mechanical traps. These traps rely on air-jets and sensors instead of passive mechanical tooling. For example, a wiper can be replaced with a pneumatic air-jet at the desired height. Having an array of jets can allow a single bowl feeder to sort and orient multiple part types by changing the active air-jets. Additionally, machine vision can be used with air-jets to replace fixed mechanical traps. In these cases, the vision system can activate air-jets to reject certain parts or to orient parts as necessary. While these systems may be more flexible than mechanical traps, they are usually more expensive because of the sensors and vision system required and are therefore not yet widely used. [25]

4.3.2 Feeding Tracks

After a part is fed via one of the above mentioned mechanisms, the part must still be moved within the assembly system. If it is not possible or efficient to actively move the part with a robotic arm, feeding tracks are used instead to move the part while maintaining its orientation. Feed tracks can move parts through gravity or through a powered mechanism.

Gravity Tracks

Gravity driven feed tracks are the most common type of feed track. The designs of these tracks rely on gravity to move parts from one point to the next. They are of two types depending on the necessary delivery end condition: horizontal delivery or vertical delivery. These are illustrated in Figure 4-5

These tracks feed differently based on different track loading conditions. The vertical track will give a more reliable feed rate in a situation with no pushing occuring .The vertical feed track will always load to the assembly system by relying on gravity, but the horizontal feed track needs a certain amount of parts in the track to feed. This is because the parts resting on the horizontal section of the track will not move forward without pressure from behind to overcome the friction of the part against the track. Depending on the design of the track, the necessary push can be from just one or two parts or many parts. While vertical tracks seem to be the best option here, horizontal delivery tracks are often the result of a mandatory end condition for interfacing with the rest of the system. [22]

Powered Tracks

To overcome the friction on horizontal delivery feed tracks, a feed track can be powered by vibration or air. A vibratory feed track works in much the same way as vibratory bowl feeders, with vibrations normal and parallel to the track driving the parts forward. These tracks also have the same limitations as the bowl feeders, with special tuning necessary between the parts and the feeding track to get parts moving

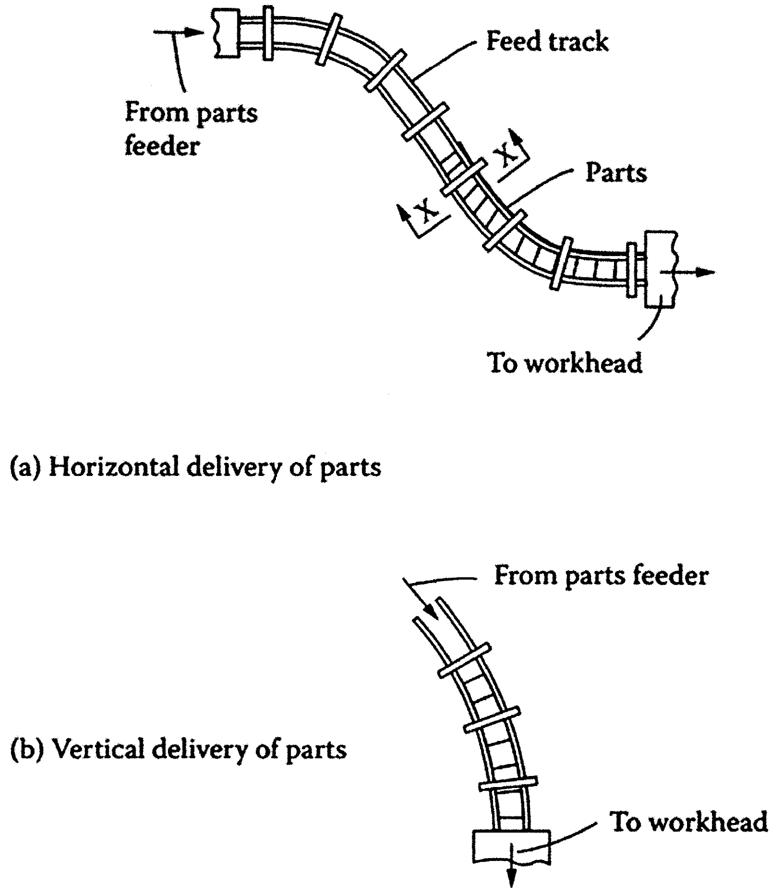


Figure 4-5: *The two types of gravity tracks (a) horizontal delivery end (b) vertical delivery end [22]*

forward. Air-powered tracks are simply feed tracks with air-jets placed to assist in the movement of parts. Added to a horizontal delivery track, an air-jet can help to push the parts in the delivery section such that a single part can still be fed.

Chapter 5

Sorting System Design

The sorting system was designed to be a standalone machine. As previously mentioned in Chapter 2, two automated methods of inserting pins in boards, and thus sorting and orienting pins, exist at SynQor, but they have not proven reliable in use. The system devised by the team differs from these methods in the decoupling of the sorting from the actual pin insertion. This idea takes its cue from the surface mount technology "pick and place" machines, which depend on quick part dispensing for their high part placement speeds. These parts are easily dispensed using tape reels, and this project mimics the reel with a specially designed pin magazine (Section 5-13).

This chapter describes the design of the sorting system (photograph of complete system in Figure 5-1), which sorts the pins from a bulk state to an oriented state and places the pins in a pin magazine. The basic requirements and practical thought process behind the system are discussed here, while the preliminary testing observations are presented in Chapter 6.

5.1 Design Methodology

The sorting system was designed through a combination of observation and necessary considerations. Though several different designs were proposed, the chosen system – an indexing rotary wheel – met the design goals listed as follows:

- Constrain the pin as it travels through the system

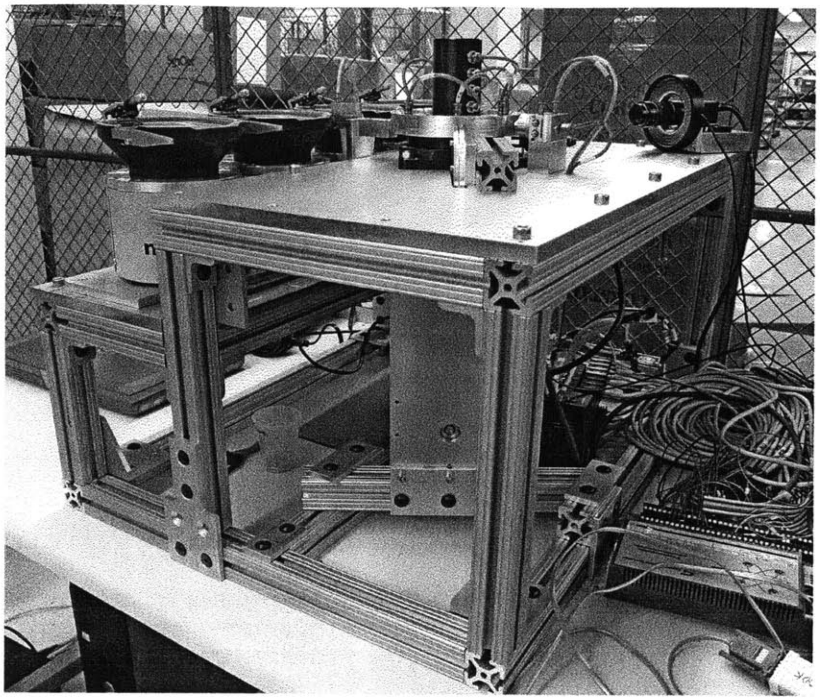


Figure 5-1: *Photograph of the completed sorting system*

- Minimize mechanical movement/degrees of freedom
- Reuse parts from existing pinning systems
- Minimize necessary system floorspace
- Simplify manufacture and repair

Observations of Previous Systems

In previous observations of the existing sorting mechanisms, two key observations were made. The first is that an unconstrained pin is often the root of a system error. Much of the reliability of existing systems stems from pins behaving in ways the systems are not designed to handle. For example, in the sorting system discussed in Section 2.2.2, pins are blown through a pneumatic tube as a means of conveyance. This often results in pins becoming jammed in the tube if the initial pin orientation is at an angle. In that same system, the line scan camera used to determine the pin orientation gives unreliable analysis in part because the pins carried through its path are lying freely on a conveyor belt and vibrate from the belt movement. These problems could be alleviated by constraining the pin as it is carried through the sorting process, which is further discussed in Section 5.2.3.

Secondly, it was observed that the overall system speed is dictated by the amount of movement the pin must undergo. Because the pins are relatively small in relation to the mechanisms handling them, system speed is determined by the mechanism speed rather than a handling speed safety factor. In the system mentioned in Section 2.2.2, the pin travels more than half a meter along a long conveyor belt and undergoes at least three orientation processes before being sent to the insertion system through a long tube. Much of the distance, and thus much of the sorting cycle time, no processes are being performed on the pin. There is a time cost associated with moving pins and mechanisms in general. The rotary wheel idea arose to address these issues, and is further discussed in Section 5.2.1.

Other Design Considerations

Other considerations were related to the cost effectiveness and usability of the system at SynQor. This includes the use of existing systems or parts where possible. Many parts were sourced from the existing sorting system discussed in Section 2.2.2, and are indicated as such. The system footprint has been minimized since the system may be placed in either a storage area or next to the pin insertion machine on the production floor, both areas that would benefit from a smaller system size. In terms of creating a simple system to build and repair, the processes were designed to have both a minimum number of parts and simple mechanisms.

5.2 System Overview

The completed sorting and orienting system can be characterized as a series of processes surrounding a central rotary wheel. This section will explain the overall system, its processes, and the method for constraining the pin used throughout. The parts, excepting off the shelf and re-purposed parts, were designed using the SolidWorks 3D CAD software and made using CNC mills.

5.2.1 Rotary System

The main mechanism of the sorting system, a rotary setup, is a result of the design goals to minimize travel distance and limit mechanical movement. In this rotary design, the pin is constrained on a main wheel which rotates to different stations at which different processes can be completed. This minimizes the overall area the pin must travel over. The wheel itself has only one degree of freedom for motion (rotation) and only allows pins one degree of freedom as well. And by placing processes around a central wheel with mostly fixed pin positions, the pin will be oriented by only two mechanisms, one passive and one active, as will be described further in this chapter.

System Processes

The sorting process was broken down into five steps to be completed at the wheel, resulting in five processes or mechanisms to accomplish them. The processes and their functions are listed and detailed in Table 5.1, and a top view of their assembled layout can be seen in Figure 5-2.

Table 5.1: *The five processes of the sorting system and the sorting steps they complete. They are listed in the order of occurrence on the sorting wheel.*

Step	Sorting Step	Process Name	Description of Mechanism
1	Feed pins onto wheel	Bowl Feeding	A vibratory bowl feeder is used to initially orient and present pins to the main wheel.
2	Analyze pin type and orientation	Vision	A machine vision system images each pin, analyzes the pin's type and orientation, and sends the information to the controller.
3	Correct pin orientation	Reorientation	A rotating head pulls the pin off the wheel, flips it 180 degrees, and replaces it on the wheel.
4	Deliver pin to magazine	Delivery	Pins are sent down a stationary, curved slide to the pin magazine.
5	Clear rejected pins	Rejection	Pins remaining on the system are dropped in a receptacle.

The design of these processes will be discussed in this chapter within their own

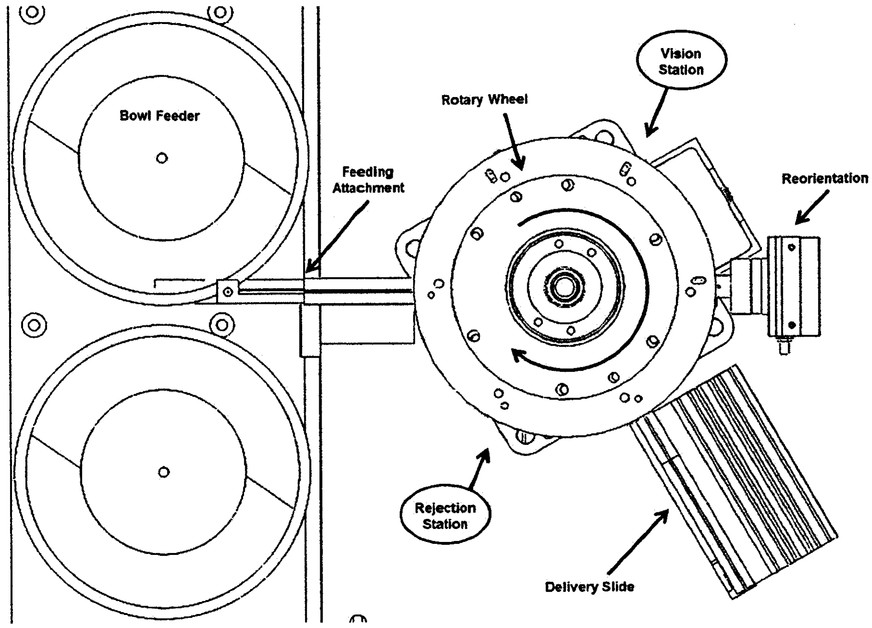


Figure 5-2: *A CAD drawing of the sorting system station layout, with the vision system and rejection stations marked with ovals.*

sections with the exception of step 5, for which no special system was designed. The rejection of undesired pins is discussed briefly in Section 5.6.2.

5.2.2 Main Frame

The frame upon which the whole system is attached is a simple square frame composed of extruded aluminum bars and aluminum flat sheets. Figure 5-3 shows a CAD drawing of the system assembly, though without the vision system. The dimensions of the frame are 28 in. in length by 23 in. in width by 15.5 in. in height. There are two levels: the top level secures the main wheel, camera, reorientation mechanism, and delivery slide and a lower level holds the bowl feeders. The magazine is positioned underneath the the top level.

The second level is positioned such that the top of the bowl feeders is roughly in line with the wheel's pin cavities. Because of the area of the bowl feeder units, the end of the feeding attachment cannot be directly aligned to the main wheel. A connecting bridge is placed between them; its effects will be discussed in Section 6.2.1.

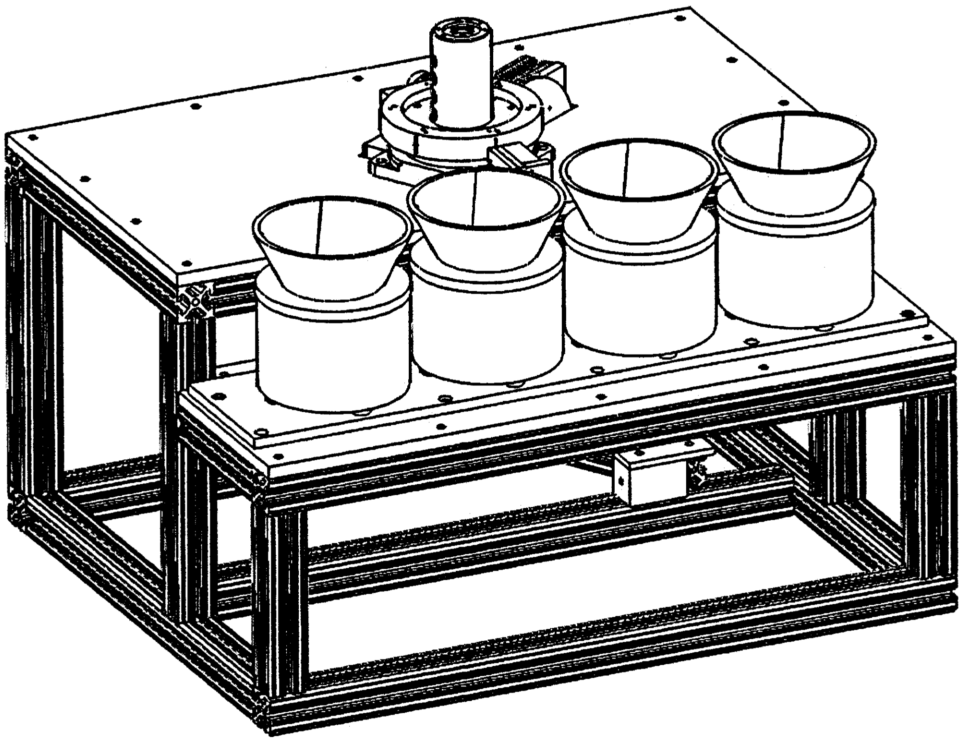


Figure 5-3: *CAD drawing a the sorting system (minus the vision system) mounted on its frame*

5.2.3 Constraining the Pin

As a number of previous problems in SynQor's existing sorting mechanisms can be related to the fact that the pins are not constrained in their movement, the system was designed to hold the pin in a known axial orientation throughout.

In analyzing the pin geometry, it was determined that the best way to constrain the pin is to hold it by its collar feature. The pin can most generally be modeled as an elongated cylinder as it is mostly symmetric about its length axis. However, this assumption would ignore the kinematic effects of the collar.

The collar placement affects the pin movement more than any other pin geometry. Because the pins are quite small, their mass does not vary greatly despite varying lengths. Also, the square insertion head can cause a pin to be heavier at the insertion end, but it is the placement of the collar along the overall length that determines the "center" about which the pin will rotate. Thus, by directing the motion of the collar, the system can direct the motion of the pin in a controlled manner.

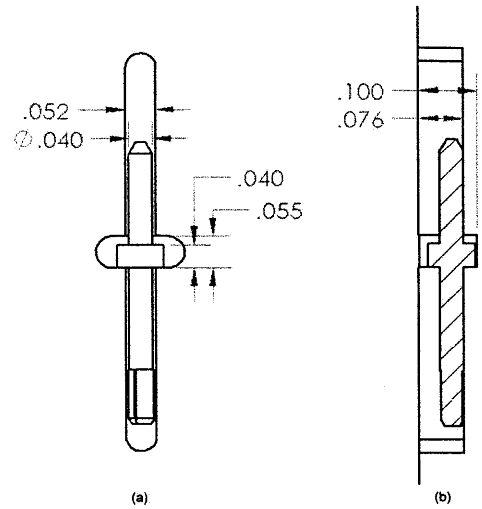


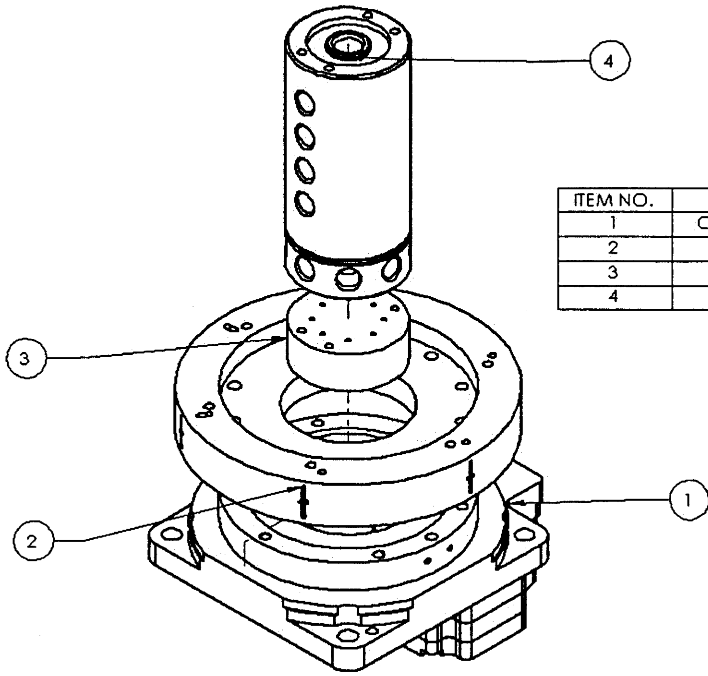
Figure 5-4: *The common profile used to constrain the pin (a) the front view, with expected pin motion to be out of the page (b) the side profile for use on the rotary wheel*

To constrain the pin, a common profile is used throughout the system (Figure 5-4). This profile supports the pin on two sides underneath the collar, preventing horizontal movement except in the desired direction. Vertical movement is constrained with a mirror image of the support constraints. Clearance between the pin and the top-side and bottom-side collar constraints mean only two places on the pin are constrained at any one time, preventing the problems that come with over-constraint.

5.3 Main Rotary Wheel

The rotary wheel is the center of the sorting system. Fabricated out of aluminum, the wheel is only six inches in diameter, in keeping with the goal of minimizing the system footprint. The section of the wheel which directly interacts with the pins employs cavities with the common constraint profile as the pin interface, leaving only one degree of freedom – radially along the wheel – for pin loading and unloading. Figure 5-5 shows the four parts that make up the wheel assembly.

The wheel is designed with six evenly spaced pin holding locations, allowing six simultaneous processes to occur around the wheel. Though there are only five steps



ITEM NO.	DESCRIPTION	QTY.
1	Oriental Motor Rotary Actuator	1
2	rotary wheel	1
3	rotary union facemount	1
4	rotary union	1

Figure 5-5: *Assembly drawing of the parts of the rotary wheel*

in the sorting process, the sixth station gives added flexibility in positioning the mechanisms required for each step, as some require more area than others. This extra station also allows for the possibility of future steps to be easily added.

This section describes in more detail the main points of the wheel: the pneumatic handling of the pins and the choice of rotary mechanism. Besides the aluminum wheel, all other parts are off the shelf components and will be briefly described.

5.3.1 Pneumatic Handling

As this system is expected to reach fairly fast rotation speeds, it is necessary to hold the pins at their wheel stations by an active mechanism. Here, and in the rest of the system, pneumatics are used extensively to move the pins from point to point or to hold them firmly in place. This is done by adding three small air ports at and near the collar constraint in the wheel pin cavities.

These ports can alternately eject air or pull a vacuum at the pin cavity. These two actions are the main way in which the pins are actively handled in this system.

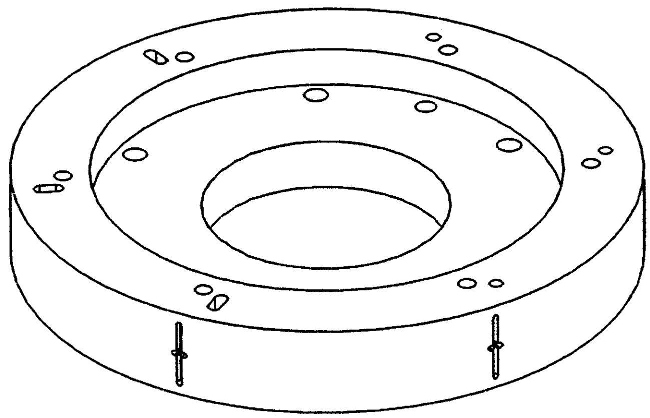


Figure 5-6: *The main rotary wheel*

By keeping the vacuum on during the wheel's rotation, a pin will be firmly held in the wheel cavity. Alternately, when the pin needs to be removed from the wheel, a burst of air can eject it from the wheel.

The pneumatic valves used to control the pin movement on the wheel are the *Festo VAD-ME-I* solenoid valves. This unique valve is a combination of a vacuum generator and an air ejector, minimizing the need for separate solenoids and vacuum generators. The vacuum and air pressure are run through the same port on this solenoid, simplifying the pneumatic tubing for the system.

5.3.2 Rotary Mechanism

The rotary motion required for this system is single direction indexing of a rotary table. The rotary table would preferably be fabricated with a large opening in the middle to allow easy mounting of the rotary union, and the rotary motor would preferably be easily integrate with the table.

Many options were considered, including fixed-station pneumatic indexers and servo motors. A stepper motor was chosen in the end, as much for its fast and precise positioning as its easily applicable form factor. The *Oriental Motor DG130* hollow rotary actuator is a rotary table with an integrated stepper motor. It is unique it that its size is small, but still has the hollow center to accommodate this projects pneumatic needs.

In addition, a rotary union, the *DSTI LT-2181*, is used to carry the air lines from the valves (stationary) to the wheel (rotating). The union allows the wheel to turn freely without any interruption to the air connections, which are interfaced with a face mount connection (more detailed drawing in ??). The union has enough ports for eight air connections, which may allow for future adjustments to the number of wheel cavities.

5.4 Feeding

The first station in the pin sorting process is the feeding of the pins onto the main wheel. The feeding mechanism used in this system is vibratory bowl feeding.

ITEM NO.	DESCRIPTION	QTY.
1	Bowl feeder vibrator	1
2	bowl	1
3	bowl feeder attachment	1
4	bowl to wheel bridge	1

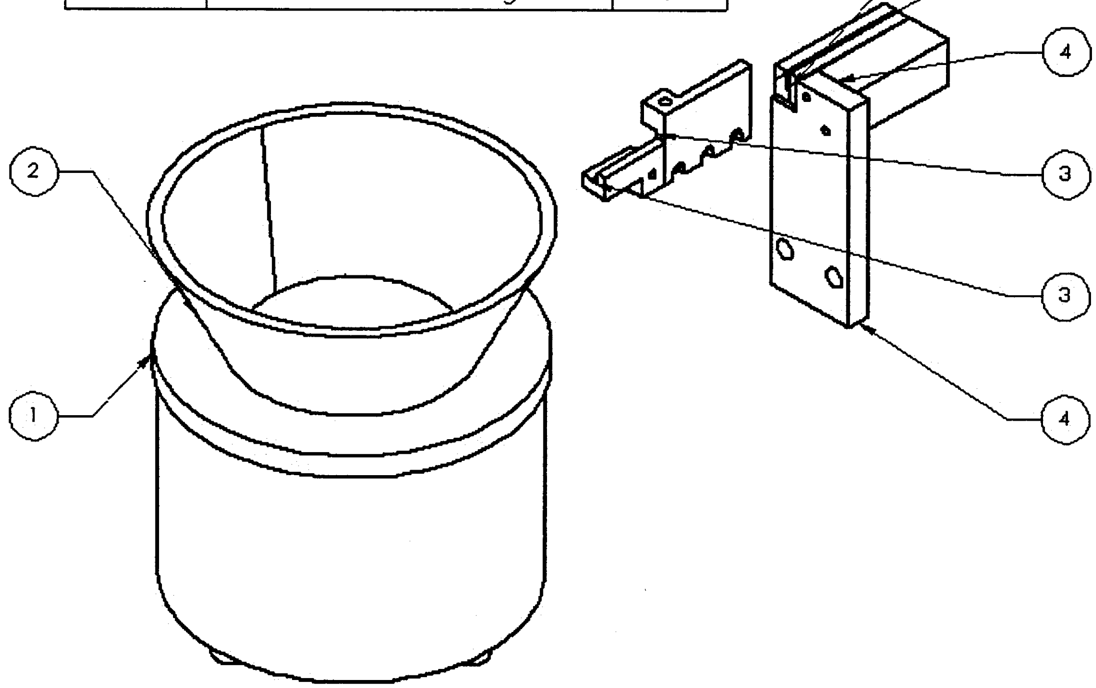


Figure 5-7: *The bowl feeder assembly. The bowl and vibrating units here are simple models.*

5.4.1 Bowl Feeders

Vibratory bowl feeding was chosen as the feeding method for its proven effectiveness. Both previous pinning systems at SynQor use bowl feeders to feed pins, and it is a mechanism that works well for moving parts of a pin's size. The pin geometry was also a consideration for choosing to use bowl feeders, as the odd geometry could likely cause jams in a hopper or feeding wheel type systems.

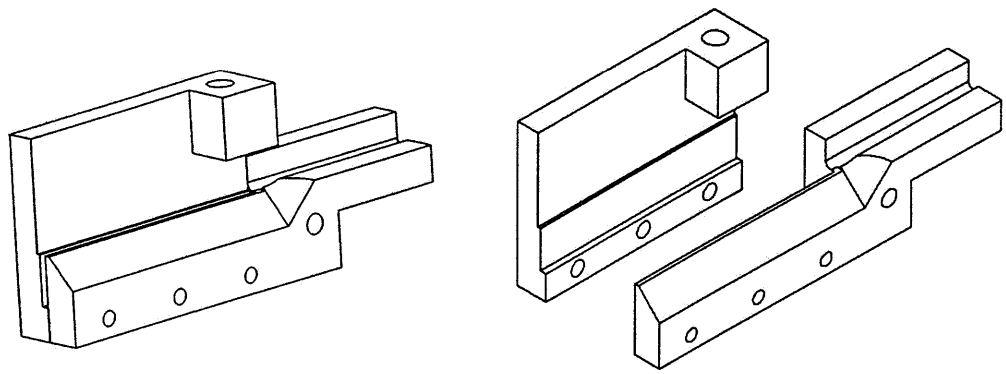
The bowl feeders used in this project are re-purposed from the pinning system described in Section 2.2.2. From that system, a unit of four bowl feeders has been taken for this sorting system. Though only one bowl feeder is necessary, all are firmly attached and properly tuned on a single plate of aluminum. For the purposes of this project, this was not disassembled to preserve the tuning. The bowls are made of a hard plastic material and coated with a rubberized film to allow the pins to easily climb their bowls.

5.4.2 Feeding Attachment Design

The main adjustment necessary to the pre-existing bowl feeder is to its end feeding attachment. This is a part that attaches to the top lip of the bowl and directs pins out of the bowl. The existing attachment was designed to feed pins out in a horizontal position; the designed sorting system calls for pins in a vertical position.

A new bowl feeding attachment was designed to orient pins vertically. It consists of two pieces of aluminum with a unique geometry to passively orient the pins. After an initial grove to continue the bowl feeder's track, there is a gap space a little more than a pin width, about the same width as the bottom half of the previously discussed common constraint profile. Above the beginning of the gap is an outlet for air pressure. To one side of the gap is a inclined trap. The total length of the attachment was limited by the bowl feeder specification that any attachment not exceed the length of the bowl radius (about 3 inches) in order to prevent any instability from occurring when the bowl vibrates.

The attachment works through a combination of geometry and gravity. As the



(a) (b)

Figure 5-8: *The bowl feeder orienting attachment assembly. The The pins are fed from the far right to the front left. The hole near the top accepts a pneumatic fitting.(a) completed assembly (b) the exploded view*

pin is fed horizontally onto the gap, the air pressure from the outlet will force the pin downward. Because the collar is resting on the sides of the gap, the pin will rotate about the collar, usually ending up upright, with gravity holding the pin in a stable position.

The angled trap on the side of this orienting section is an attempt to prevent pins from jamming when the section is full of pins. In some cases, the bowl feeder may feed pins faster than the wheel is accepting them. Incoming pins will naturally start to push against the upright pins. By placing the trap directly at the point where pins may start building up, the pins have no wall to push against and will simply fall off the attachment.

5.4.3 Bridge to Wheel

6.2.1 Because of the length requirement on the bowl feeding attachment, a bridge piece (as seen in Figure 5-7) has been designed to carry pins from the bowl feeder to the wheel. The bridge sits horizontally between the two mechanisms. This piece consists of two pieces of aluminum that form the same gap space as in the bowl feeding attachment and several brace pieces for frame attachment. The piece is designed to allow the upright pins to slide over to the main wheel pickup point, driven only by the pressure of the pins being fed behind.

5.5 Reorientation

The determination and reorientation of a pin is a two step process, and accordingly has two stations in this system. This section discusses how pins are analyzed and how they are reoriented.

5.5.1 Orientation Determination

At the first station after being fed onto the main wheel, the pin is positioned in front of a machine vision system which takes its image. The system runs a pattern matching analysis and returns one of there signals: correct pin type, correct orientation; correct pin type, wrong orientation; and incorrect pin type. This information will determine if the pin will next take action at the delivery slide, at the reorientation mechanism, or at the rejection station, respectively. More details about how the vision system completes its analysis can be found in Rejin Isaac's thesis [3].

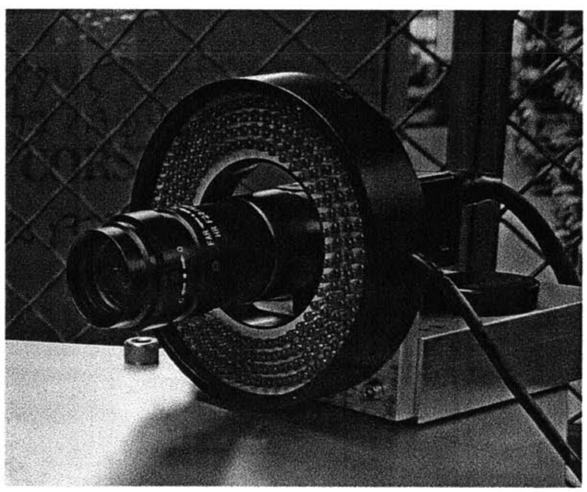
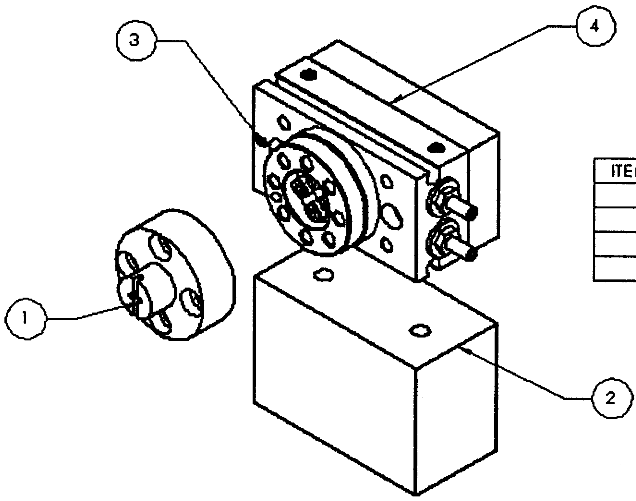


Figure 5-9: *A photograph of the vision system camera and light ring. More details can be found in Isaac's thesis [3]*

5.5.2 Reorientation Mechanism

If the machine vision system sends the signal that the pin being held is correct but in the wrong orientation, action is taken at the next station to flip the pin vertically. This is done using pneumatic air flow and a pneumatic rotary actuator. The pneumatic port on used in the reorientation mechanism is identical to that used for the main wheel. The pneumatic rotary actuator was re-purposed from the pinning system in Section 2.2.2 and runs on a single solenoid.

At this station, the wheel cavity faces a mirrored cavity on a specially designed reorientation head. This head has the common profile to support the pin by the collar and also a pneumatic port to support pulling vacuum and ejecting air. The reorientation head and the wheel surface are positioned no more than one millimeter apart.



ITEM NO.	DESCRIPTION	QTY.
1	reorientation head	1
2	rotary actuator mount	1
3	pneumatic rotary actuator	1
4	rotary actuator base block	1

Figure 5-10: *Exploded view of the reorientation assembly*

When the pin arrives at the reorientation station, the vacuum holding it in the wheel cavity is turned off to be replaced with a flow of air pressure. The pin is blow directly into the mirrored cavity on the reorientation head, which has turned on its own vacuum to hold the pin. When the pin is secure, the rotary actuator is activated and turns 180 degrees. The process of moving the pin is then reversed, and the wheel can turn to the next station with the reoriented pin secured back in its cavity. This process is depicted in flow chart from in Figure 5-11.

The reorientation head is made of aluminum like the much of the parts in this system. It is attached directly to the rotary actuator, and the rotary actuator is attached to an aluminum mounting block as the frame to mechanism interface. Though this may be the most complicated process in the system in terms of part movement,

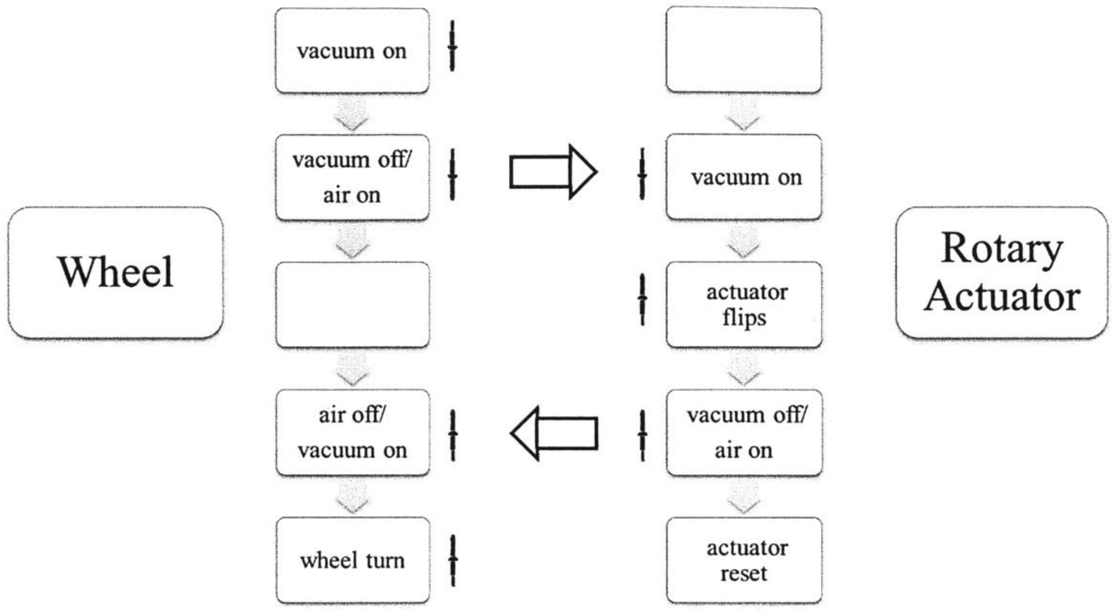


Figure 5-11: *Flow chart of reorientation mechanism. The wheel activity is on the left; the reorientation head on the right. The movement of the pin can be followed in the center.*

the actual construction of the mechanism is very simple.

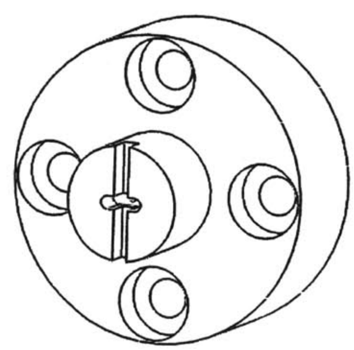


Figure 5-12: *Detail of the reorientation head. It closely mirrors the common profile and air vents found on the main wheel.*

5.6 Delivery

The fourth station in this process is the magazine delivery process. Here, pins that have been deemed of the correct type and in the correct orientation will be inserted into the pin magazine via a delivery slide.

5.6.1 Pin Magazine

The pin magazine is a receptacle which holds the pins such that their orientation is not lost. It can be described basically a rectangular form that stores the pins horizontally, collar to collar, in vertical stacks. These stacks are formed by inserting pins along tracks having the common constraint profile. As the pins are only held by their collars within the magazine, the pins are free to slide along these tracks. Thus, the pins are inserted from the top by the sorting mechanism and dispensed at the bottom by the insertion machine. The details of the magazine design and dispensing mechanism can be found in Daniel Cook's thesis [2].

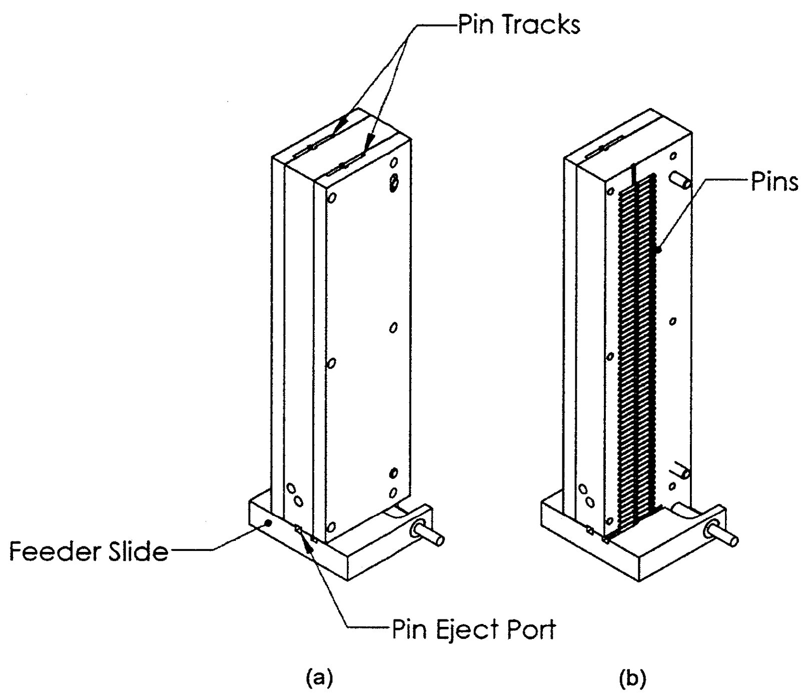
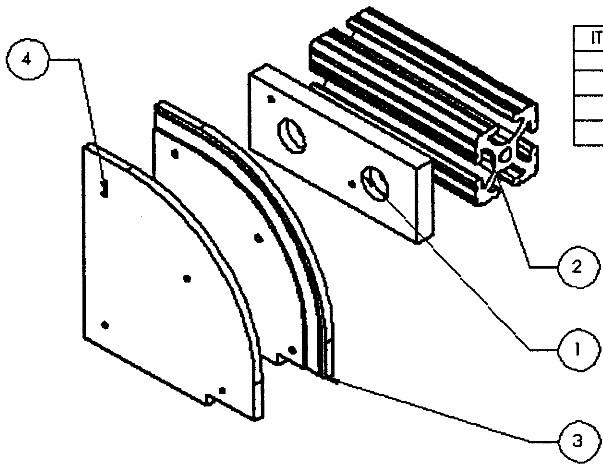


Figure 5-13: *Pin magazine (a) complete assembly (b) internal view of pins stacked collar to collar [2]*

5.6.2 Delivery Slide

The mechanism for inserting pins into the magazine is a passive mechanism. The delivery slide uses the common constraint profile to direct the pin down a 90 degree curve and into the magazine. There are no moving parts. The pin is set in motion with a burst of air at the wheel cavity, which pushes the pin down the slide. While the collar remains constrained as in the rest of the sorting system, the top of the pin is visible as it travels down the slide because the top of common profile is cut. This allows some ease in releasing pins if they become wedged in the slide before entering the magazine.



ITEM NO.	DESCRIPTION	QTY.
1	delivery slide mount	1
2	4" Al extrusion	1
3	delivery slide (pt1)	1
4	delivery slide (pt2)	1

Figure 5-14: *Exploded view of the delivery slide and the frame mount.*

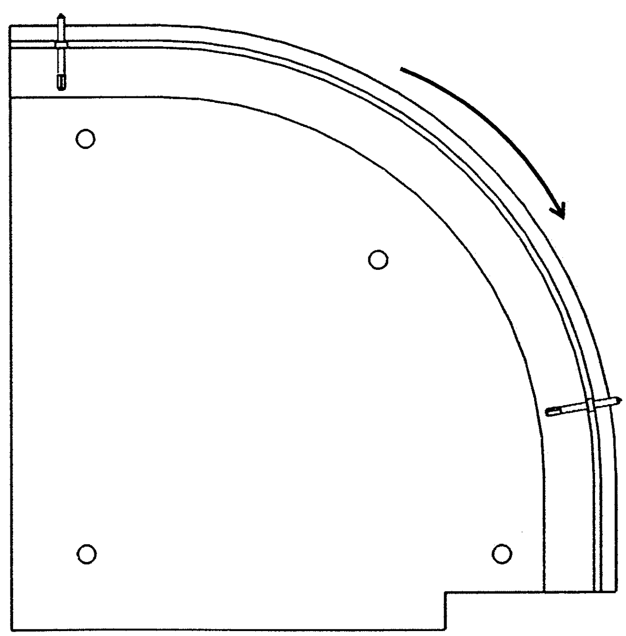


Figure 5-15: *A cross-sectional view of the delivery slide, with the direction of pin movement indicated by the curved arrow.*

The delivery slide is made of two pieces of aluminum that compose the slide and other aluminum pieces to anchor the slide to the frame. The slide sits in a slot within the frame's top sheet, which gives the slide outlet access to the magazine positioned below. The pins are passively delivered to the magazine by aligning the constraint profiles.

The air ejection mechanism is the basic mechanism for the last step in the sorting process – the clearing of pins analyzed as not acceptable. When the pin reaches the designated clearing station, an air blast will drop it into a simple receptacle. Since this mechanism is very basic and the project time line limited, no specific work was done to further define this station.

Chapter 6

Sorting Machine Performance

Because of the limited time scope of the project, the sorting system has not been fully tested and optimized up to production ready speeds and robustness. However, each process has been run individually in the lab bench model. This chapter discusses the results of this qualitative preliminary experimentation.

6.1 Evaluation Methods

As the system was not ready to be fully integrated and tested as a whole, each sorting system process, that is, each system component, was tested as a stand-alone process. These individual tests consisted of running the station task for some number of cycles. The cycles were timed with a stopwatch, and problems or errors that occurred during the cycle were recorded.

Note that egregious problems resulted in immediate action. The system was adjusted several times during its testing period, which may have affected the resulting testing.

6.2 Component Performance

The setup and results for each station experiment are explained in this section.

6.2.1 Bowl Feeding

The bowl feeding station had two parts to consider for testing. The first is the design and effectiveness of the bowl feeding attachment in orienting the pins upright and delivering them to the wheel. The second is the effectiveness of the wheel pneumatic system at picking up the pins from the delivery point.

Vibratory Bowl Feeding

Testing the bowl feeder and the feeding attachment showed that while the attachment worked well to rotate the pins upright, the possibility of jamming was still present. This was mostly a function of the vibration rate. A very high rate would drive the pins fast enough to accommodate the "one pin a second" goal, but would also be prone to jams when the pins were entering the feeding attachment faster than they were being removed. This is because a faster vibration rate means the pins are being propelled forward faster, in larger steps, and with more force. All three contribute to the higher rate of pin jamming as the pins are behaving more erratically.

Slower rates tended to avoid this jamming problem, with the extraneous pins falling off the trap as designed in a smoother flow, but there is not enough forward momentum to push the pins to the wheel pickup point at the desired rate. This is also related to the design of the bridge between the bowl feeding attachment and the main wheel. The bridge is horizontal, meaning the pins must be pushed across to the wheel. And since the bridge is not connected to the bowl feeder attachment, the push from the pins coming off the feeder onto the bridge is the only force to move the pins toward the main wheel. This force is very small, even with multiple pins waiting to move onto the bridge.

Main Wheel Feeding

Once pins were in the end position on the bridge, they were easily fed onto the main wheel. The vacuum from the main wheel pin cavities is surprisingly strong. If the pins were positioned on the bowl feeding bridge at a distance of one millimeter from the wheel cavities, the vacuum was usually able to pull the pin into the wheel cavity. Placement a little farther was, however, more unpredictable in regards to loading the wheel. This is related to the unpredictability of the pneumatic valves used, as will be discussed in Section 6.3.2

Tests were run with both no delay in the motor rotation and a 100 ms delay. In the first case, when the controller detected that the motor had decelerated to zero, it immediately started accelerating again, resulting in a millisecond or so of time when the cavity was stopped directly in front of the feeding bridge. The second case forced a delay between the indexing cycles of 100 ms. The tests with pauses showed an almost 100% rate of successful pin feeding. Adding a delay would not affect the overall cycle time as it is not the bottleneck process.

There were some interesting jamming problems to occur when there was no time delay given to feeding. At times, the pins were not pulled into the wheel cavity completely before the wheel started turning again, resulting in a damaged pin, wheel cavity, feeding bridge, or all three. This occurred most frequently if one was attempting to feed the pin in an insertion head up position. This is due to the fact that, in this position, the pin collar is balancing on the side with chamfered edges, sometimes resulting in the pin resting at an angle. The wheel cavity vacuum pulls on what ever is presented to it uniformly, so the pin may be pulled forward at an angle. When the wheel turns, some part of the pin may still be within the bridge, leading to damage as the pin is forced through.

Bridge Redesign

A slight redesign of the system is needed to allow the pins to reach the main wheel more easily. There are two options to do so. The first involves redesigning the bowl feeder attachment piece such that it is much longer and the bridge such that it is shorter. This would provide a driving force for the pins' forward movement to a point much closer to the wheel than previous. The only drawback is that having the extra long attachment on the bowl feeders is discouraged by the manufacturer and its effects on the vibratory action are unknown.

The second option is to redesign the bridge piece by giving it a slight downward incline and to raise the bowl feeders such that the part outlets still align properly. The incline would allow gravity to pull the pins towards the wheel pickup point. However, the incline must be fairly small; a dramatic slope would lead to pins accelerating downward too quickly and causing jamming or simply falling out of the bridge.

6.2.2 Reorientation

Because of the relative complexity of the reorientation sequence in comparison to the other stations, it is the system bottleneck. All of the processes being run in parallel on the rotary wheel will run no faster than the speed of the reorientation mechanism.

Bottleneck Station

The reorientation process was found to have a cycle time of about 900 ms. The tests were done by cycling through a set of six reorientations. The recorded time on this was compared to the time it took the wheel to index those same six time without any process occurring. The difference due to adding the reorientation step was about 900 ms.

The cycle time of the reorientation mechanism is a combination of time delays set to (1) allow the pneumatic valves fully actuate and (2) allow the pins to fully transfer from the wheel to the reorientation head and back. The first point is discussed more fully in Section 6.3.2 but is related to the necessary delay when switching between vacuum and air pressure on the *VAD-ME-I* valves. This delay is currently set at 100 ms.

The second point is related to the settling time necessary after transferring a pin between the reorientation head and the wheel cavity. The pins have a tendency to bounce back slightly after being blown between heads. In testing, it often happened that the pin was not yet secured on one side when the rotary actuator attempted to flip or the wheel attempted to turn. This lead to jamming between the wheel and the reorientation head as the pin was free to slide between them. This problem was alleviated by adding a delay in the initial transfer time such that the side pulling vacuum could securely grasp the pin. However, this also leads to a longer cycle time in a process that already requires the most mechanical movement. The delay is currently set at 300 ms, but there is the possibility of decreasing this delay length if the vacuum strength can be raised.

6.2.3 Delivery

The delivery of the pin to the magazine via the delivery slide was mostly tested at the wheel-slide interface. Overall, the delivery was not consistently successful, with much of the problem coming from the fact that misalignment was difficult to avoid. When the delivery slide was misaligned to the main wheel, the burst of air pressure to blow the pin down the slide would merely bounce the pin back into the wheel cavity.

Though the interface between the delivery slide and the wheel is similar to that of the reorientation head and the wheel, the delivery slide lacks the reorientation head's ability to use vacuum to pull the pin out of the wheel. This means the slide opening must be modified more to accommodate any misalignment between it and the wheel. This can be accomplished by opening up the collar slot vertically as well as adding a horizontal chamfer that will funnel a pin into the slide.

6.2.4 Wheel Indexing

The performance of the motor has not yet been optimized for speed and repeatability. So while specifications indicate that the motor can run up to 200 revolutions per minute, the testing has only used speeds up to 10 revolutions per minute out of caution and for ease of manual observations. Using this as the maximum speed and 400 revolutions per minute squared as the acceleration, an time of approximately 2.6 seconds per index was recorded. This speed setting was used throughout the system testing.

Though the current testing speeds are well below an acceptable indexing time, the wheel can be programmed to index much faster, just based on the specifications. In this system, as each index is only 60 degrees, the speed of acceleration and deceleration contribute most to the indexing time. Future testing should increase both the acceleration and max speeds such that the total indexing time is one second minus the time of the bottleneck process of reorientation (discussed in Section 6.2.2). Thus, the target indexing time would be approximately 100 milliseconds.

6.3 Process Independent Problems

In addition to the process specific issues noted above, there were a few problems that seemed to occur during testing for every process. These process independent problems are discussed here.

6.3.1 Fabrication Imperfections

As with any manufactured part, the final parts contained deviations from the original CAD model. In this case, the most noticeable fabrication problem was the depth of the wheel cavities. Originally designed such that a pin would sit completely within the cavity, the resulting part still has a section of the pin collar protruding. This protrusion means the feeding, reorientation, and delivery mechanisms could not be placed as closely to the wheel as intended without causing pin to be damaged or jam the system.

6.3.2 Pneumatic Pressure and Sensitivity

There were unexpected problems with the pneumatic valves that included uneven air and vacuum pressures and valve response delays. Though sensors are needed to verify, it was observed that the air pressure is not evenly distributed to each of the wheel cavities. This is most noticeable at the pin rejection station, where a test was run that simply rejected pins into a cup. Occasionally, a wheel cavity would fail to reject the pin despite the air pressure being triggered. This did not occur regularly to certain cavities, but seemed randomly distributed.

These pressure problems only occur when a majority of the pneumatic valves are actuated, as they will be on a completed system. This does suggest that the uneven pressure problems are occurring in the air supply rather than at the valves themselves. A possible solution is to replace the current pneumatic tubing (all 4 mm in diameter) with larger tubing. This will carry more air to each valve and thus more air or vacuum to each wheel cavity.

The valves also have occasional delayed response times. While running the system, there would occasionally be a noticeable lag in a single valve's response to the controller signals. This could be a technical glitch as does happen. Another valve delay problem is the switching on the *VAD-ME-I* valves between vacuum and air pressure. A delay is required between the two so the valve is not attempting to simultaneously draw vacuum and eject air, but the length of this delay is not specified by the manufacturer. Testing has shown that the delay of about 100 ms seems to be its limit, as the change of electronic signals is waiting for the settling of the air flow. It is possible this problem may be alleviated by replacing the valves with larger versions, but more research needs to be done to confirm this.

6.3.3 Burrs & Dents

A noticeable problem that occurred with use of the system is the denting of the edges of the pin cavities and to the other pin constraint profiles. It seems that the material of choice for these prototype parts, aluminum, is easily damaged by the imperfect insertion and removal of the pins, as when parts are misaligned or a pin is pressed into the cavities by hand. The edges of the common profile on the wheel especially showed wear.

Besides being visual imperfections, these dents or burrs often cause problems in pin transfer or even damaged the next pins to be carried in the damaged pin cavities. For example, the burred edge of the wheel cavity may prevent a pin from properly exiting the cavity at the delivery point. This pin may then become jammed between the delivery slide and the wheel.

By using a harder material in the next iteration of parts, some of the denting problem may be reduced, but better chamfering of the edges that will be in contact with pins is recommended as well.

6.3.4 Difficult Positioning

One observation that could be made without even running the system is that positioning the mechanisms around the wheel is a difficult and poorly designed task. All the frame to mechanism interfaces are not easily adjustable, and are not easily lined up with the wheel either. If a jam occurs, the whole mechanism has to be removed to properly remove the jammed pin without causing more damage. A more flexible system for attaching mechanisms to the frame is necessary to decrease the amount of set up and repair time needed for this system.

Chapter 7

Conclusions, Recommendations, & Future Work

7.1 Conclusions

A sorting system for electronic pins was designed, and its first prototype was built during this project. Preliminary testing showed that, though there is much work to be done, the idea of the system is feasible. The following conclusions about the sorting system can be drawn from this work:

- Bowl feeding works very well for these electronic pins, though the extension geometry of the feeding attachments needs further work.

- The reorientation mechanism needs to be optimized for speed, but may be limited by the ability of pneumatics.

- The delivery slide can be made more reliable by adding more slop to its pin receiving end.

- Though it was the limiting factor in the preliminary work, the wheel indexing speed can and should be greatly increased without harm to the wheel or surrounding mechanisms.

7.2 Recommendations

Based on the results of the work presented, a few recommendations can be made in regards to the continual improvement of the system. In addition to the process specific suggestions made in Chapter 6, a few more general suggestions are given here.

Of course, more experimentation on the current system is needed. While knowing how each individual component works is a step in the right direction, complete integration will give a better sense of the sorting system's overall cycle time, failure rates, and problem areas. In particular, the integration of the machine vision system is especially important to the function of the overall system.

Sensors should be installed to monitor the function of the system. While visual inspection is passable for individual mechanism observations, a fully functioning system will need several monitoring points that the controller can use to evaluate the process for error. An example would be several vacuum sensors on the wheel to detect if a pin is absent, which can mean it was lost to a mechanism error.

Almost all parts which were designed for this system should be fabricated in a harder, more durable material. Substituting hardened steel for aluminum will likely alleviate the problems with dented edges that caused many system failures.

New mount designs should also be considered for all mechanisms surrounding the main wheel. In order to make the system easier to repair in case of a failure, quick-release type mounts should be implemented. Also, the bowl feeder unit comprised of four bowl feeders should be separated into individual units. The girth of the four bowl unit is a hindrance to proper positioning and mounting of the bowl feeder to the system frame.

7.3 Future Work

Beyond this sorting system, there are a few ideas which may be of interest in future system designs. The first concerns the use of the common constraint profile. Though the profile worked fairly well in this sorting system, there is still room for an improved way of constraining the pin that is more flexible to pin tolerances and less susceptible to damage by the pins. Interesting ideas encountered include changing the outline from a cross to a diamond such that the collar will still sit in a consistent position but have fever alignment issues or eliminating the wheel cavities in favor of more open indentations with large vacuum holes.

Another idea of interest is the idea of stacking the sorting process such that one wheel has many levels of pins being sorted at once. The idea is that one system can run a few different pin types together on the same wheel, taking up less floorspace than having multiple wheels and frames. Setting up this system would be a large undertaking, but would also be able to double (or more) the rate at which pins are sorting using this sorting system.

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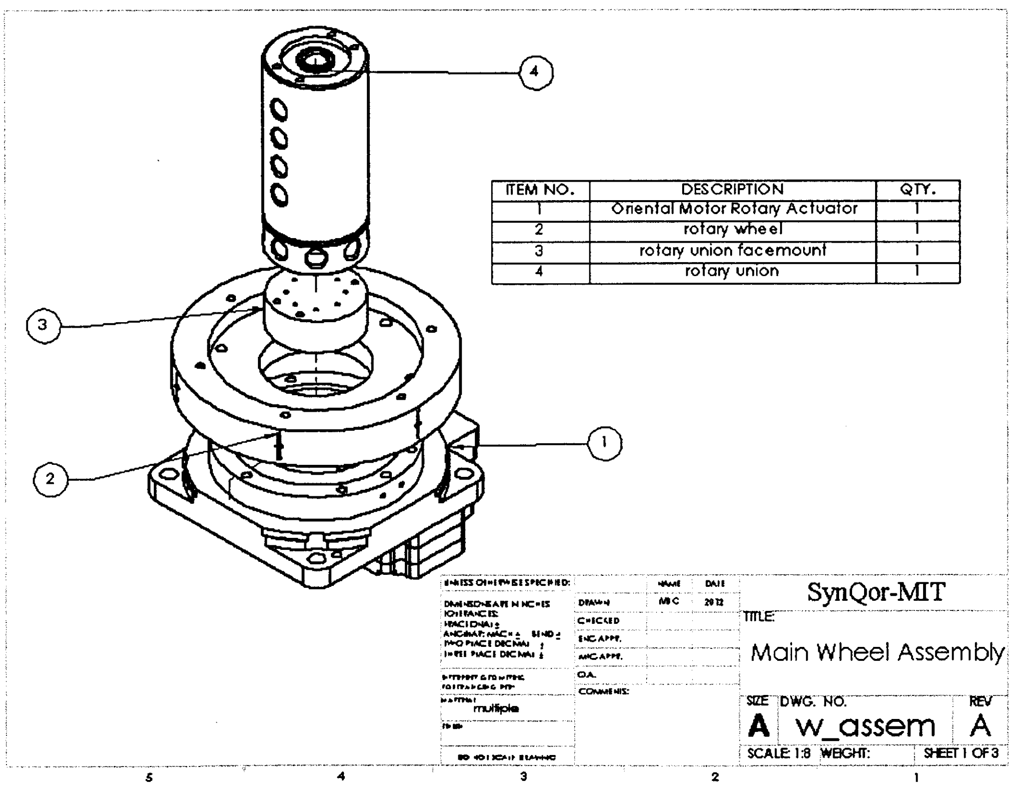
Appendix A

Engineering Drawings

A.1 Wheel Assembly



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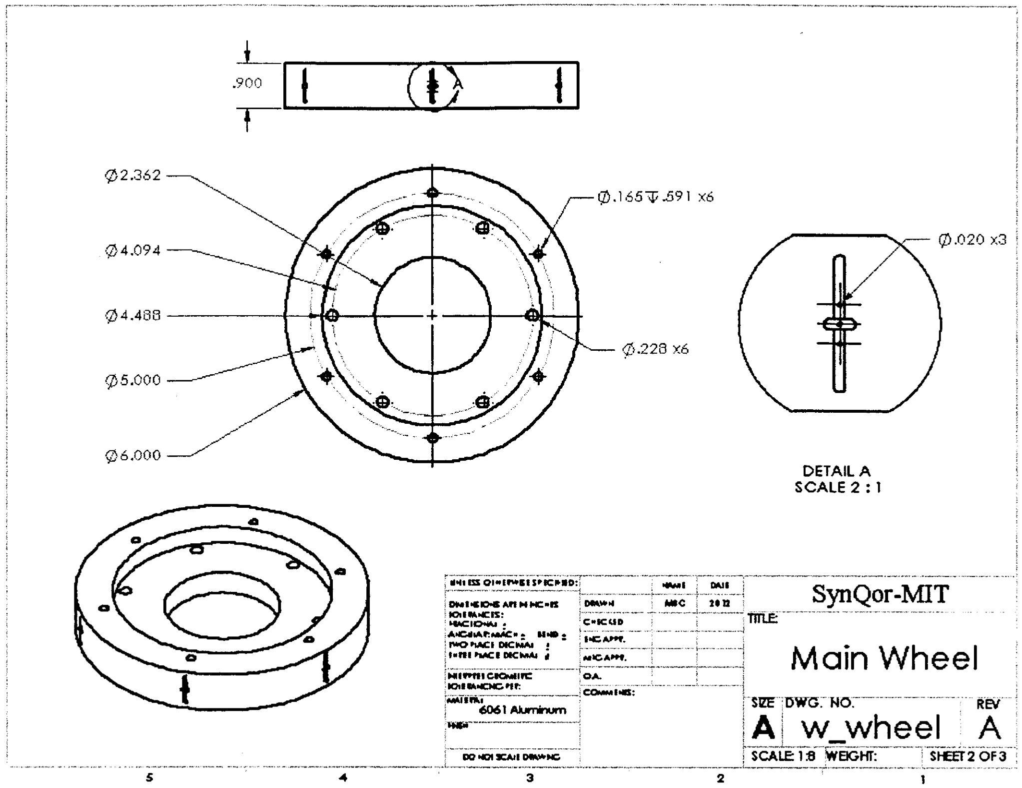
3	rotary union facemount	1
4	rotary union	1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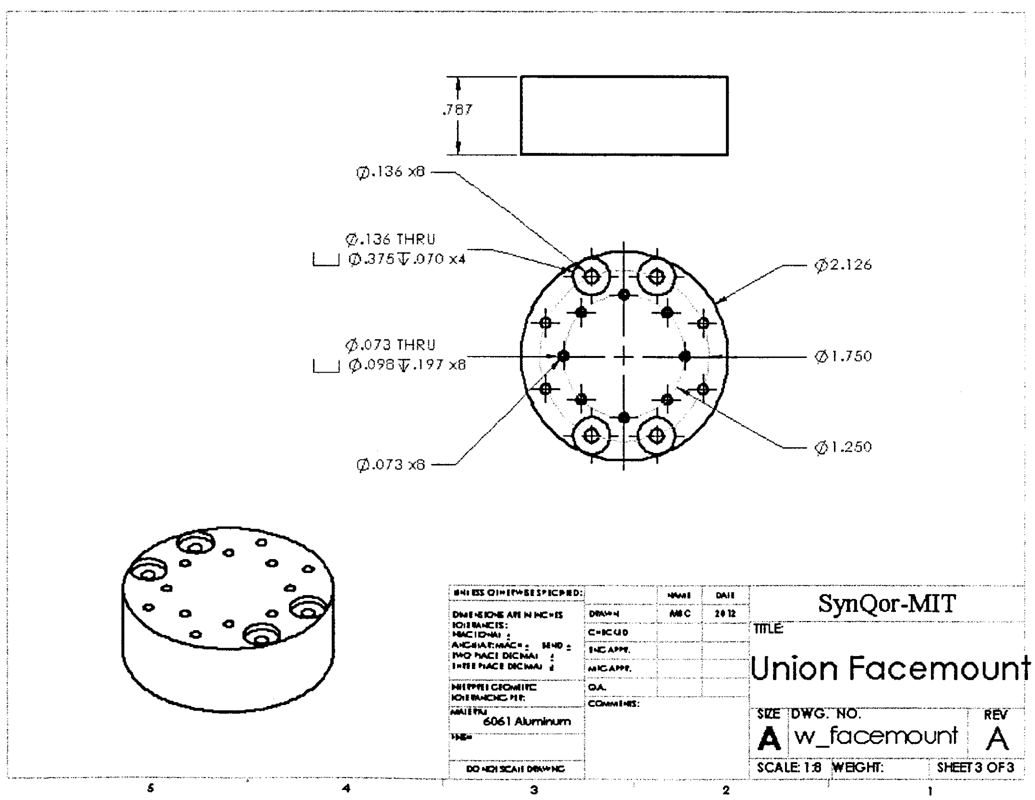
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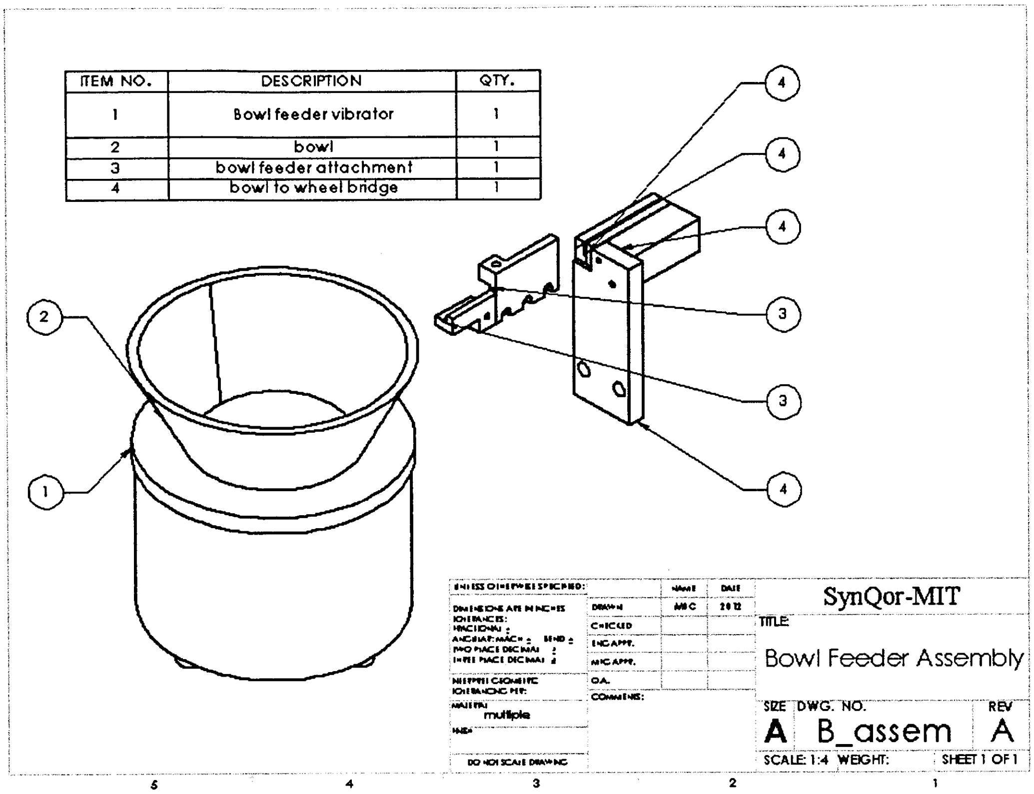
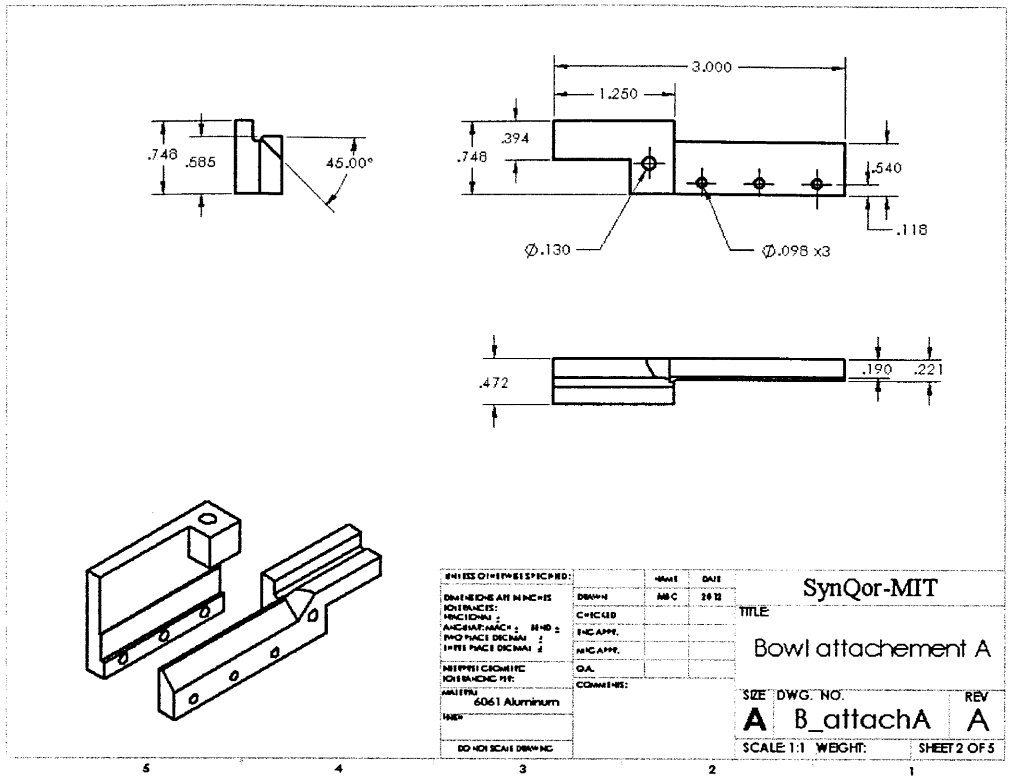
A.2 Feeding Assembly

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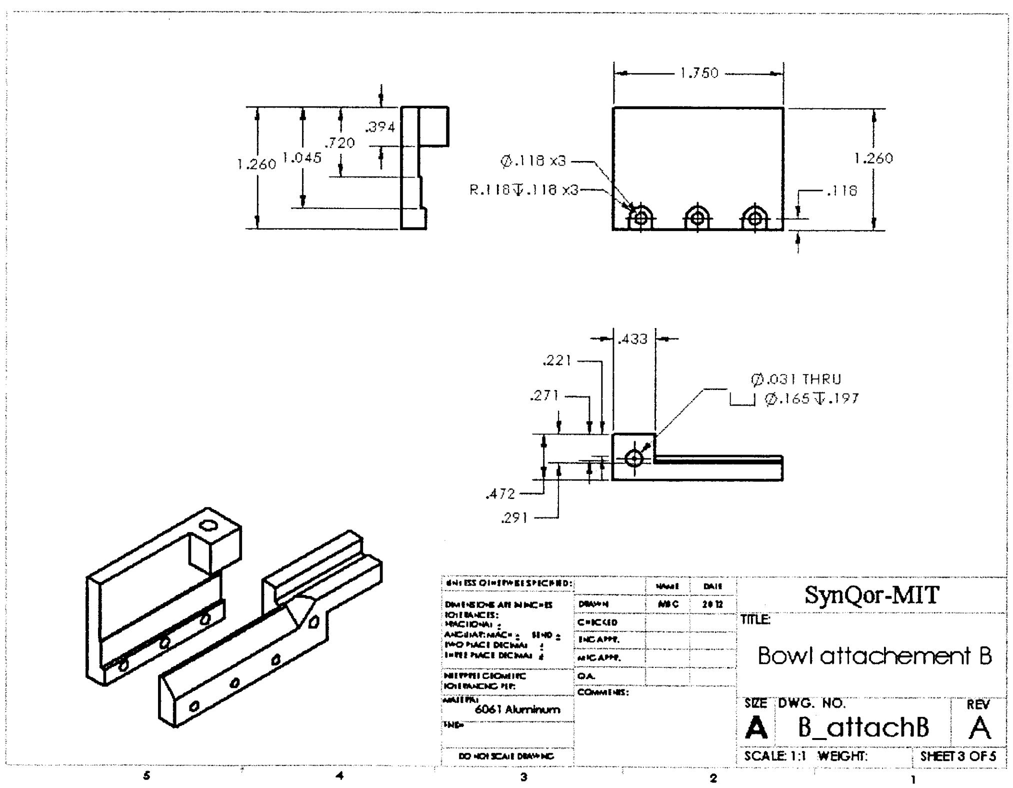
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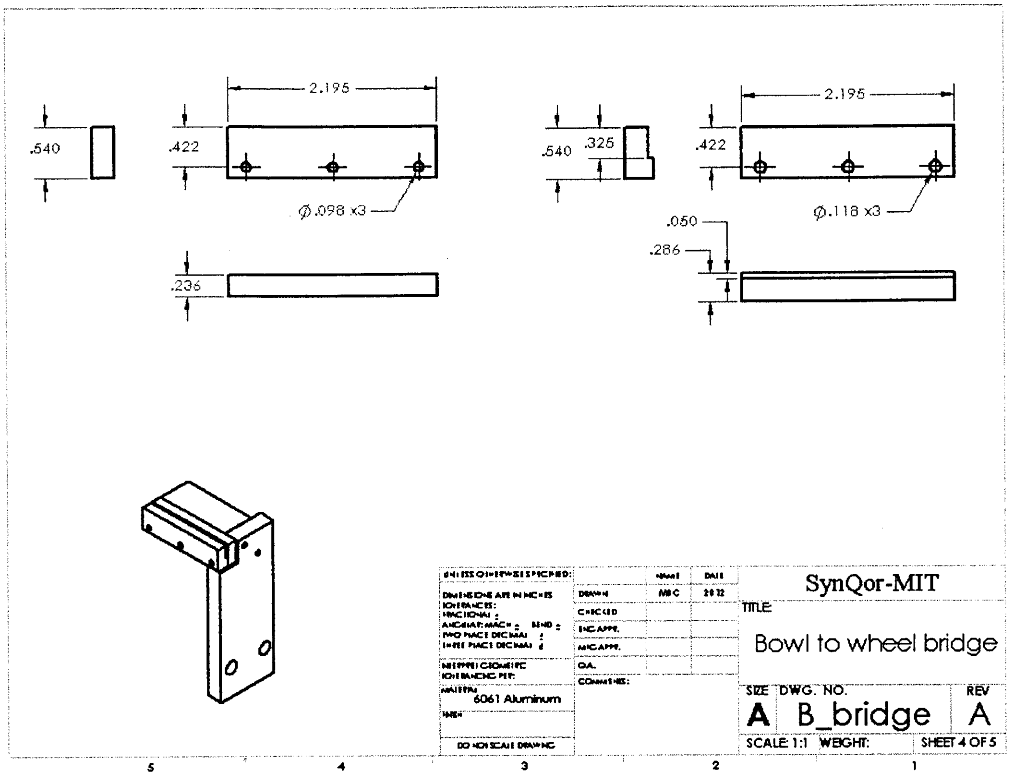
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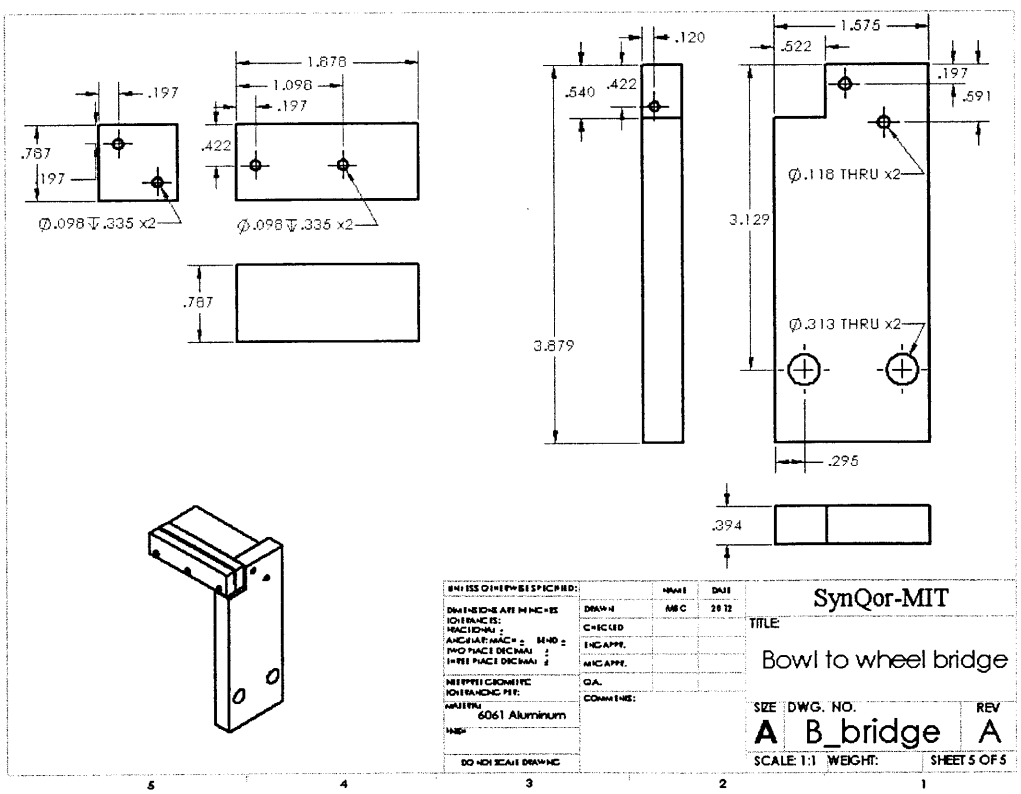
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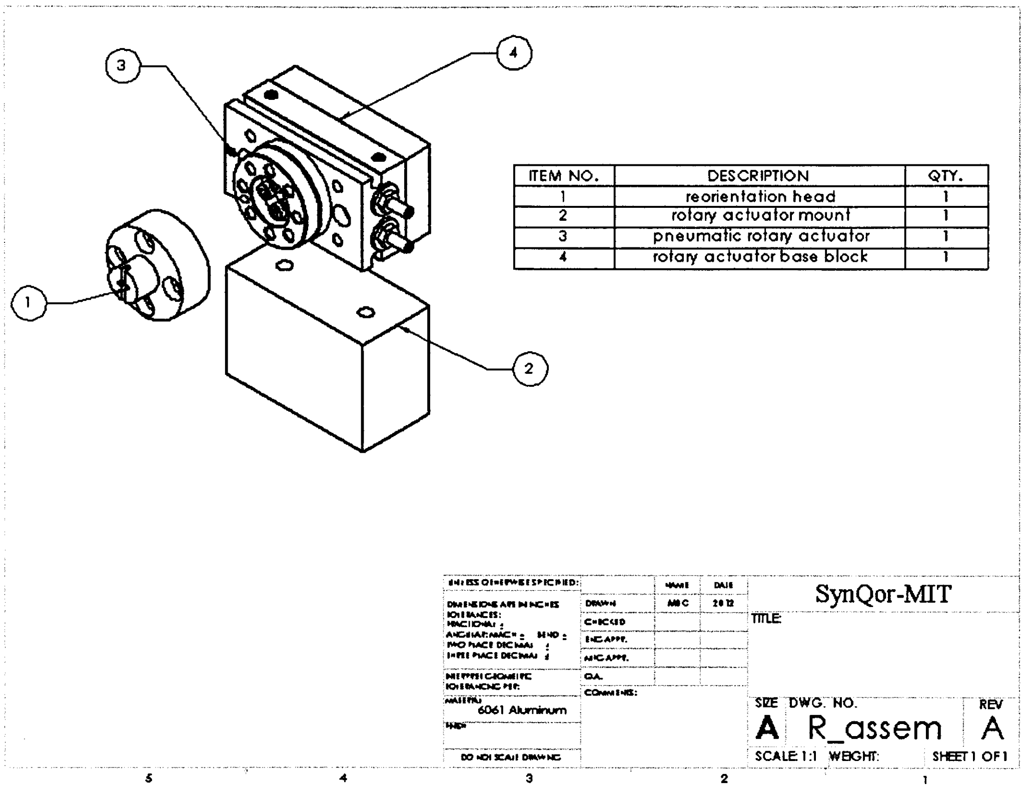
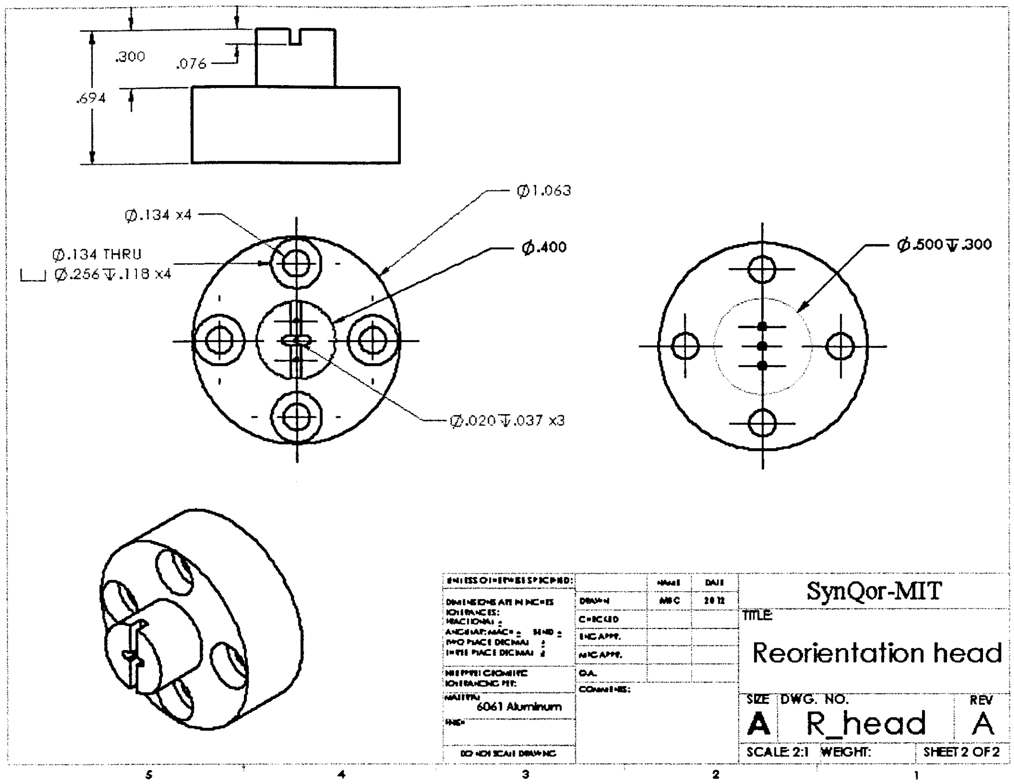
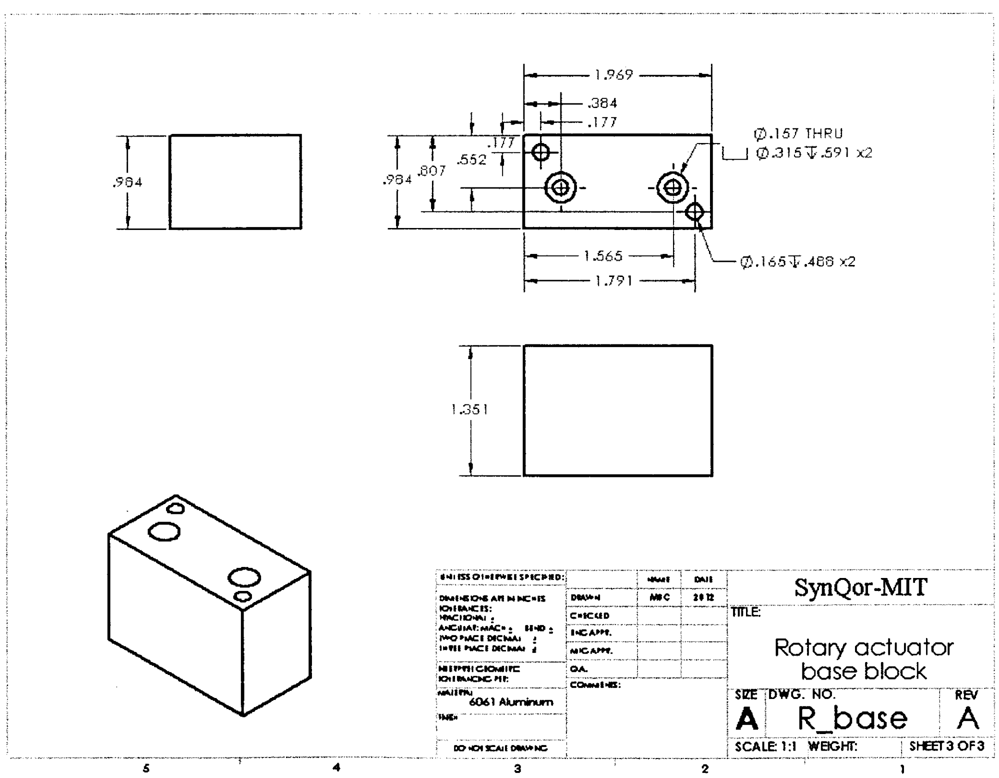
1.098
.197
.787
.422
⌀.098 ↧ .335 x2
.120
.540
3.879
1.575
.522
.591
⌀.118 THRU x2
3.129
⌀.313 THRU x2
.295
.394
6061 Aluminum
SynQor-MIT
TITLE:
Bowl to wheel bridge
SIZE DWG. NO. REV
A B_bridge A
SCALE 1:1 WEIGHT: SHEET 5 OF 5

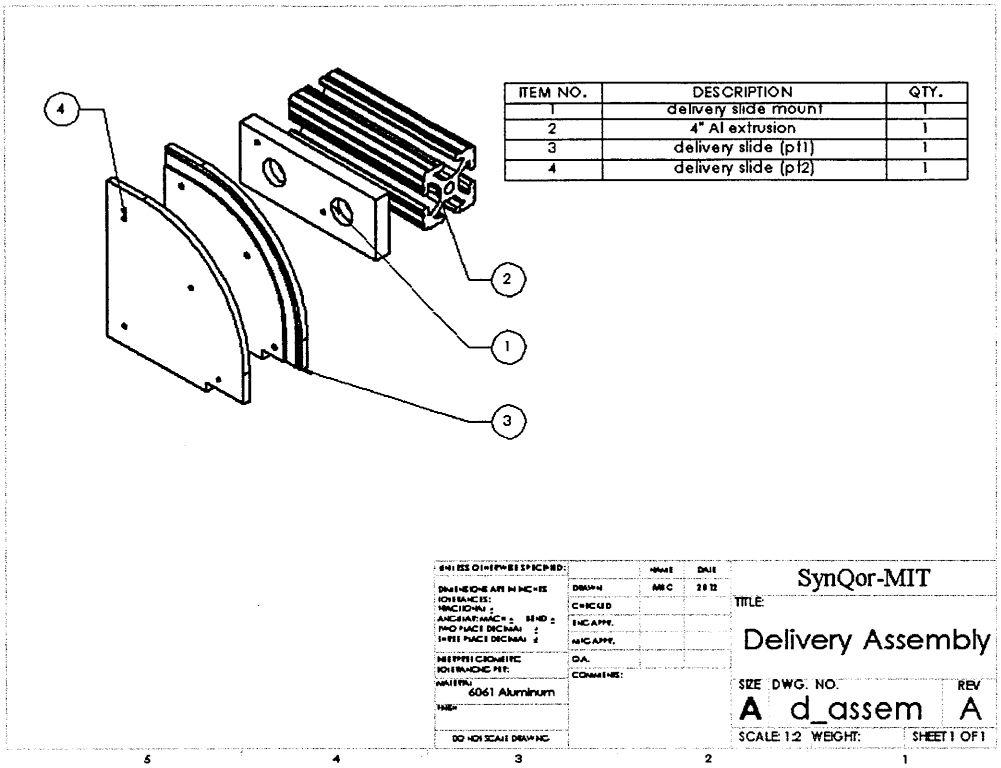
A.3 Reorientation Assembly

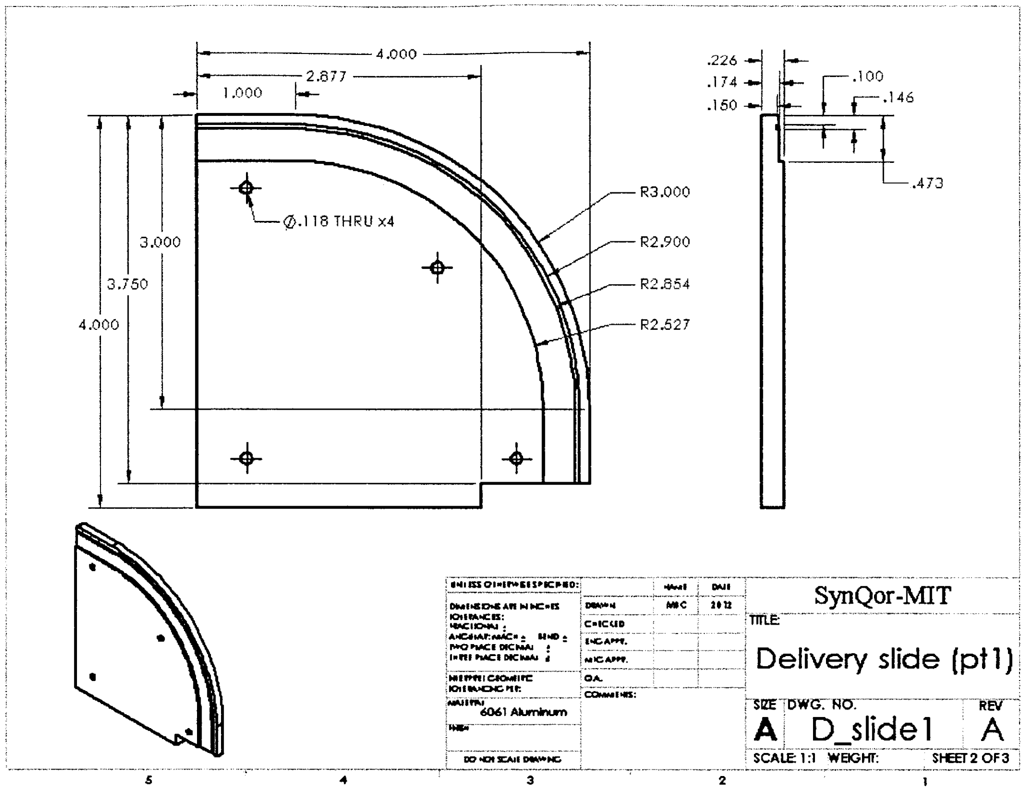


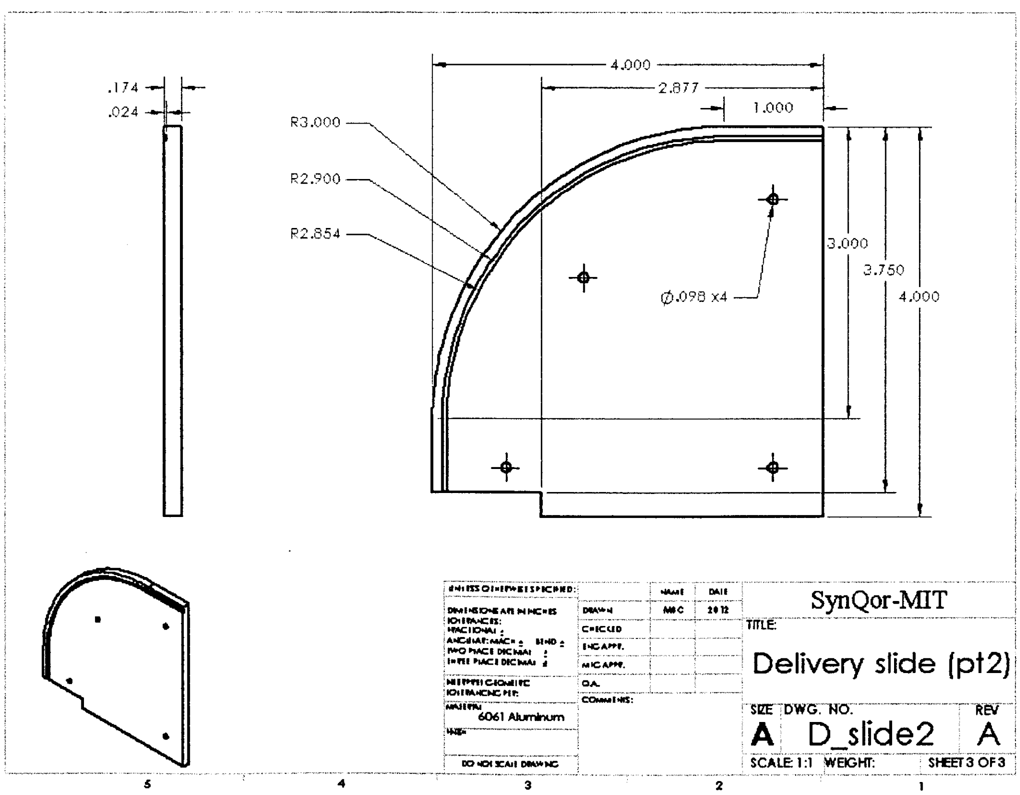

.300
.076
.694
Ø.134 x4
Ø1.063
Ø.134 THRU
⌴ Ø.256 ↧.118 x4
Ø.400
Ø.500 ↧.300
Ø.020 ↧.037 x3
SynQor-MIT
TITLE:
Reorientation head
6061 Aluminum
SIZE DWG. NO. REV
A R_head A
SCALE 2:1 WEIGHT: SHEET 2 OF 2

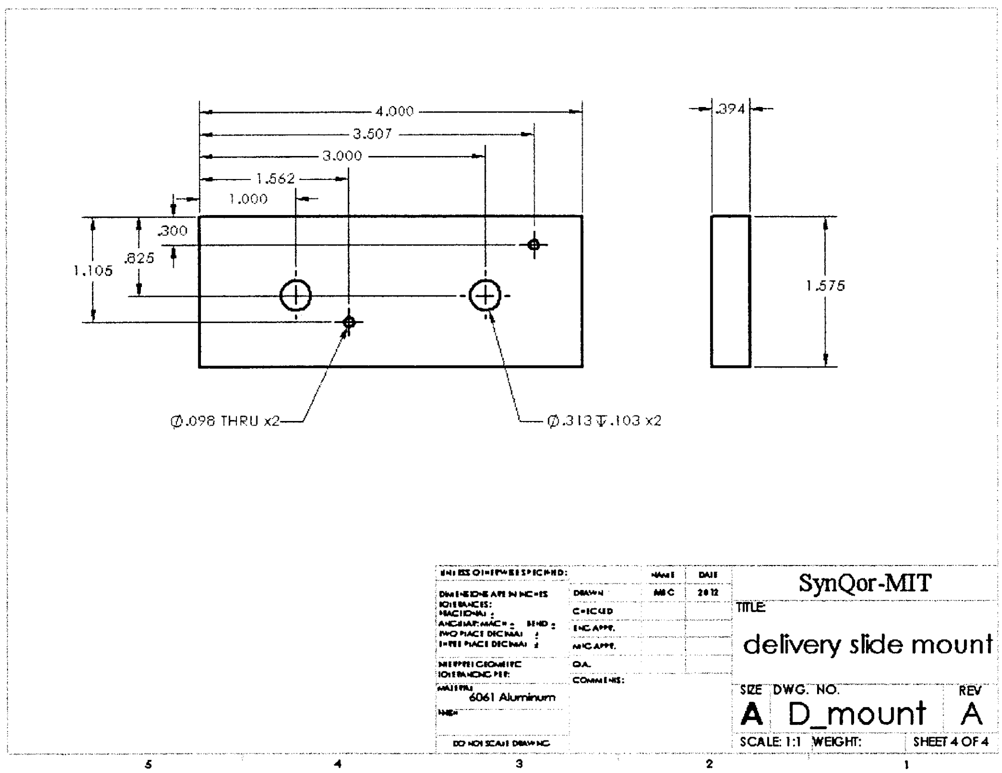

1.969
.384
.177
.177
.552
.807
.984
.984
Ø.157 THRU
⌴ Ø.315 ↧.591 x2
1.565
1.791
Ø.165 ↧.488 x2
1.351
SynQor-MIT
TITLE:
Rotary actuator
base block
6061 Aluminum
SIZE DWG. NO. REV
A R_base A
SCALE 1:1 WEIGHT: SHEET 3 OF 3

A.4 Delivery Assembly




4.000
2.877
1.000
.226
.174
.150
.100
.146
.473
R3.000
R2.900
R2.854
R2.527
Ø.118 THRU x4
3.000
3.750
4.000
6061 Aluminum
SynQor-MIT
TITLE:
Delivery slide (pt1)
SIZE DWG. NO. REV
A D_slide1 A
SCALE 1:1 WEIGHT: SHEET 2 OF 3


.174
.024
4.000
2.877
1.000
R3.000
R2.900
R2.854
Ø.098 x4
3.000
3.750
4.000
6061 Aluminum
SynQor-MIT
TITLE:
Delivery slide (pt2)
SIZE DWG. NO. REV
A D_slide2 A
SCALE 1:1 WEIGHT: SHEET 3 OF 3


4.000
3.507
3.000
1.562
1.000
.300
.825
1.105
.394
1.575
Ø.098 THRU x2
Ø.313 ⊽ .103 x2
SynQor-MIT
TITLE:
delivery slide mount
6061 Aluminum
SIZE
A
DWG. NO.
D_mount
REV
A
SCALE: 1:1
WEIGHT:
SHEET 4 OF 4

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Appendix B

Bill of Materials

ITEM NO.	DESCRIPTION	QTY.	MFG
1	28" Al extrusion	4	80/20 Inc.
2	20" Al extrusion	2	80/20 Inc.
3	12" Al extrusion	4	80/20 Inc.
4	7.32" Al extrusion	2	80/20 Inc.
5	13.5" Al extrusion	3	80/20 Inc.
6	6.5" Al extrusion	2	80/20 Inc.
7	25" Al extrusion	3	80/20 Inc.
8	bowl level Al top sheet	1	SynQor-MIT
9	wheel level Al top sheet	1	SynQor-MIT
10	bowl feeder driver units	4	MHK-Afag
11	bowl feeder bowls	4	PMJ
12	bowl feeder attachement (ptA)	2	SynQor-MIT
13	bowl feeder attachement (ptB)	2	SynQor-MIT
14	bowl to wheel bridge (pt1)	1	SynQor-MIT
15	bowl to wheel bridge (pt2)	1	SynQor-MIT
16	bowl to wheel bridge mount 1	1	SynQor-MIT
17	bowl to wheel bridge mount 2	1	SynQor-MIT
18	hollow rotary actuator motor	1	Oriental Motor
19	8 channel rotary union	1	DSTI
20	rotary union face mount	1	SynQor-MIT
21	main wheel	1	SynQor-MIT
22	pneumatic rotary actuator	1	SMC
23	rotary actuator base block	1	SynQor-MIT
24	rotary actuator mount	1	SynQor-MIT
25	reorientation head	1	SynQor-MIT
26	delivery slide (pt1)	1	SynQor-MIT
27	delivery slide (pt2)	1	SynQor-MIT
28	delivery slide mount	1	SynQor-MIT
29	4" Al extrusion	1	80/20 Inc.

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