Desktop Pick and Place Machine Final Report	
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1. Introduction and Research

A pick-and-place machine is a robotic assembly machine that is used to “pick and place” Surface-Mount Devices (SMD) onto a Printed Circuit Board (PCB) [1] or in general, a pick-and-place machine should utilize a vacuum to lift a SMD off a piece of tape, orient said component, and place it on a PCB [2]. We first began our research by analyzing existing industrial pick-and-place machines. Through this research we learnt of 3 different mechanisms that can be used in said machines - the cartesian system, Delta, and SCARA. Details of these mechanisms will be explored later in the report.

Since the goal of this project was to develop a conceptual design for a desktop pick and place machine, to be used in an educational setting. As such, we narrowed our research by analyzing existing desktop pick and place (PNP) machines. This category of PNP machines can be split into two: wholesale or retail machines and hobby machines.

Through our research, we found that most - if not all - small-scale desktop PNP machines utilized a cartesian design - which is the final design chosen. The general size of these machines average to about 700 x 700 x 300 mm. These machines utilize stepper motors for movement. The “gantry” of the cartesian system utilizes stepper motors at the end of each “frame” to allow movement in the x-y axis and the “head” of the machine utilizes stepper motors to allow movement in the z-axis and rotation of the nozzles. Additionally, PNP machines tend to use cameras to identify parts.

We broke down our design into 4 sub-components - the bed, gantry, head, and feeder system.

2. Engineering Specifications

Based on the research that was conducted and comparison to the commercially available alternatives, it was decided that an affordable desktop Printed Circuit Board (PCB) pick and place machine was needed. The primary work environment for the design would be an academic setting such as a university. Its primary function would be to move Surface Mount Technology (SMT) components from a feed tape to any given location on a PCB. The design objectives are outlined in the table below:

Table 2.1. Detailed Objectives

Objectives	Details
Cost-efficient	The cost should be less than $10k
Quiet operation	A user should be able to work in the same room
Low vibration	It should not need to be attached to the table

Repairable by user	To a similar extent of most hobby 3d printers such as the prusa lineup

The objectives were seen as reasonable considering that commercially available alternatives range from $2,500 - the very simple alternatives - to $100,000 - more advanced and industrial alternatives. Operating with a budget of $10,000 or less allows for the provision of the basic features of a PNP machine such as assembly of PCBs with some additional features such as inspection of parts. The other objectives relate to the performance of the machine when in use. The design should not be noisy to unreasonable extents and should not vibrate. Vibration especially poses a threat to the maintenance of the machine, because the machine could potentially move and fall off the surface on which it was placed.

The design constraints are outlined in the table below:

Table 2.2 Detailed Constraints

Constraints	Details
Durability	Constructing the gantry frame with a strong corrosion resistant material
Size	Must be able to fit on a table top
Vertical Movement	The machine must be able to cary tall SMT components over the board
Minimum Build area	330mm x 450mm work area
Mounting precisions	~0.025mm

The design constraints relate to the longevity and optimization of the machine. The gantry frame being made of a strong corrosion resistant material ensures that the machine will be capable of handling loading conditions well out of its scope of use. This implies that there should never be an issue of failure due to agents such as plastic deformation or buckling. Another factor is the design being operated in open air, hence, using a material that limits corrosion is key. The gantry should also be able to lift and hold SMT components for a prolonged duration until it is able to navigate to the desired location on the PCB. Along with navigating, it must operate within a margin of error of ±0.025mm.

3. Candidate Designs

We landed on 3 candidate designs that are centered around the mechanism which the design will utilize.

3.1. Cartesian

In the common, industry leading Cartesian design, the head will be moved on a cartesian plane using stepper motors. A “head” is mounted on a lead screw connected to stepper motors for each axis.

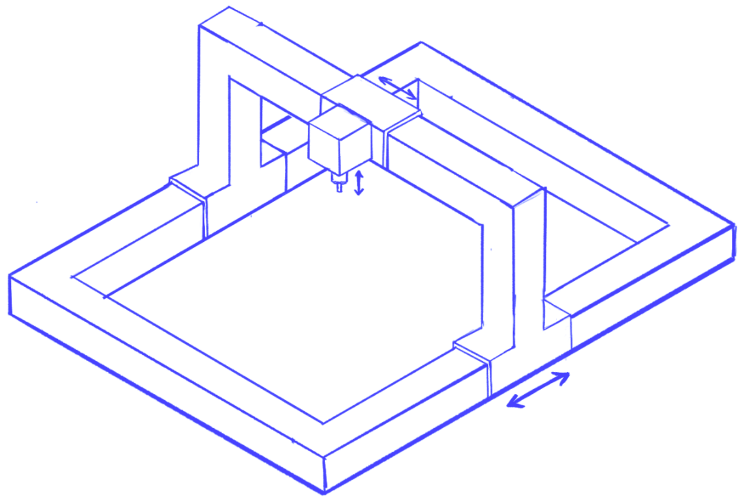


Figure 3.1 Initial sketch of Cartesian design

The “frame” - known as a gantry - will allow movement of the head in the x and y axes. The nozzle of the machine will be attached to a “head” that is attached to a carriage on the gantry. This will allow z-axis movement. The design will sport a large rectangular build.

3.2. Delta

Using the delta robot, the head will be suspended from 3 rods or “arms” that are capable of movement in any direction. This design is fast and has a small circular build area. The length of the arms result in a significantly tall build.

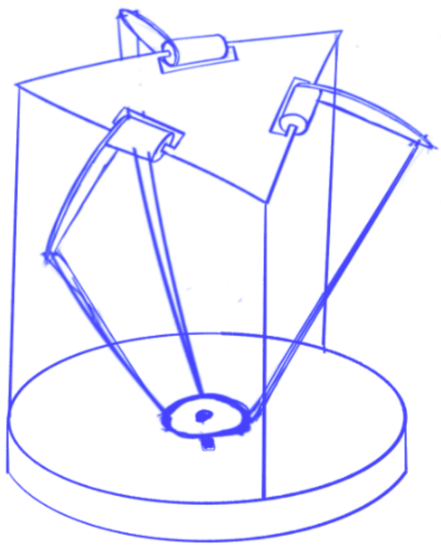


Figure 3.2 Initial sketch of Delta design

3.3. SCARA

The SCARA design - short for Selective Compliance Articulated Robot Arm - will have the head on the end of an arm with elbow and shoulder joints capable of rotating about the x and y axes. The head will be designed to allow z-axis movement. This design is relatively fast and sports a medium build area, circular around the arm.

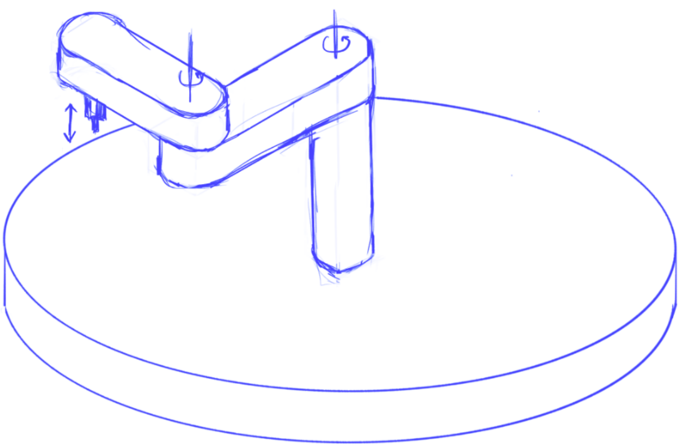


Figure 3.3 Initial sketch of SCARA design

4. Design Analysis and Description Simulation

Based on the candidate designs we outlined above, we concluded that the design that fit our project scope the most was the Cartesian design. The decision matrix used for selection is as follows:

Table 4.1. Decision Matrix for Cartesian PNP Machine

	Cost-efficient	Quiet operation	Low vibration	Repairable by user
Durability	Cartesian	SCARA	Delta	Cartesian
Size	Cartesian	SCARA	SCARA	Cartesian
Vertical Movement	Cartesian	Delta	Delta	Cartesian

Minimum Build area	Cartesian	SCARA	Delta	Cartesian

The selection process was done as a team vote, we individually voted for which candidate would be optimal in each scenario. For instance, when considering size and quiet operation, we voted the SCARA design would suit those conditions best. We then tallied the total amount of appearances for each candidate and decided that the highest tally would be our best candidate, which is how the Cartesian design emerged as our design.

It should be noted that the most common mechanism for small-scale and hobby PNP machines is the cartesian system. As such, resources for cartesian PNP machines are significantly more widely available, and thus factored into the feasibility of creating the cartesian design.

The designing of the PNP machine was divided into four sub-components where team members took on one each. They were divided into the gantry, feeder, head and bed for design analysis and description.

4.1. Gantry

The Gantry is the sub-component that is responsible for global positioning. Global positioning in this context refers to movement in the xy plane (i.e. length and width). The gantry does not include a z-axis because the head will be capable of all required movement on that axis. In order to achieve this kind of movement, linear actuation is needed on both axes, which is why a set of NEMA 23 stepper motors along with a lead screw was implemented. The motor acts as a source of rotational motion and the lead screw depending on the direction of rotation will propel a slider which has a screw system built into it forwards or backwards.

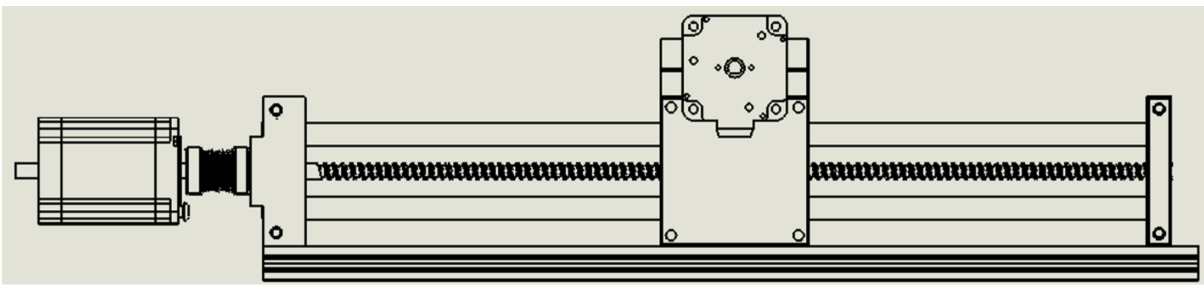


Figure 4.1.1. Cross sectional view of NEMA 23 motor along with lead screw and slider

In addition to that, the gantry is mounted on a set of rails that are 536mm x 20mm x 20mm. The NEMA 23 stepper motor has a 1.8° step angle (200 steps/revolution). Each phase draws 2.8 A at 2.5 V, allowing for a holding torque of 13 kg-cm (180 oz-in). The slider and lead screw system are accompanied by two guide rails to ensure the assembly is firm and positioning is accurate. The guide rails are to be made of stainless steel and will be lubricated slightly to avoid damage from friction. The holders at either end of the lead screw are equipped with ball bearings to minimize damage due to friction whenever the lead screw rotates. The gantry assembly has two motors on the y-axis as a precautionary step to ensure that motion in that axes is not lopsided.

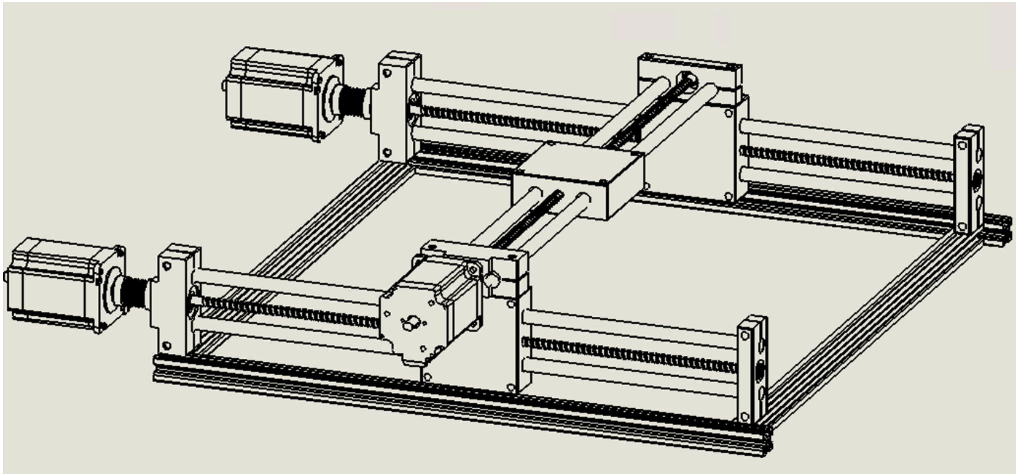


Figure 4.1.2. Full gantry view

4.2. Head

The main component of the head is a NEMA 17 stepper motor with a 64 in.-oz maximum holding torque. To allow movement in the z-axis, a 20 degree pressure angle gear (1 module, 16 teeth, 5 mm shaft diameter) - attached to the aforementioned stepper motor - is used for a rack and pinion mechanism.

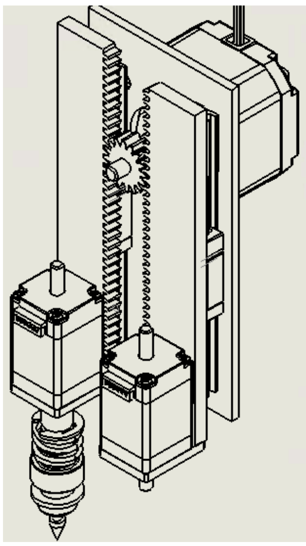


Figure 4.2.1 Isometric view of head design

A NEMA 8 stepper motor will be placed at the end of the rack using a plate. This rack is supported using a 9-mm wide rail and a 20-mm wide sleeve bearing carriage attached to the back of the rack. The rail is attached to a head plate that will support the entire build.

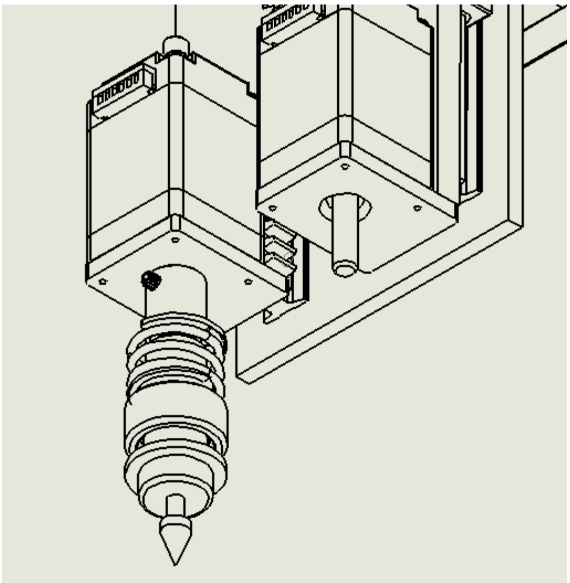


Figure 4.2.2 Close-up view of nozzle and stepper motor

The motors, gear, sleeve bearing and rail can be found on McMaster-Carr. The head dimensions are approximately 60 x 120 x 72 mm.

This design is modular, a user could choose to use one nozzle or two. If only one nozzle is used, only one NEMA 8 stepper motor will be required, which would cut the cost of the entire mechanism.

This design uses an outsourced nozzle holder. The entire design revolves around a functioning nozzle, a professionally designed and machined nozzle holder would perform much better than one designed by a student and a beginner that is not familiar with the complexities of a pick and place machine. The nozzle holder is supplied by Betz Technik Industries Ltd. and can be purchased from their website. The design supports Juki nozzles.

4.3. Bed

The design for the bed was based on some pre-existing pick and place machines. After looking at the dimensions for different machines and considering the scope of the project, an overall size of about 750 mm by 475 mm was decided on. The next two things to consider were how the PCBs would be held in place and how the components would be supplied to the feeder.

For the PCBs a screw-on type clamp was designed. It includes a clamp base on which the PCB would be placed and a small washer to screw on and hold the PCB in place. The height of the clamp base is 30 mm, and its radius is 20 mm.

This allows PCBs with different thicknesses to be loaded onto the machine. The bottom of the clamp base has a small magnet and the bed has a large metal area that would allow the clamp to remain in place. Being magnetic, the clamp can be easily adjusted to different areas, but will also not move once placed. This will accommodate for different PCB sizes and the height of the clamp base ensures that the magnet does not affect the PCB. The simple design of the clamp means that multiple of them can be produced and used, and it can easily be replaced if required.

To supply the components to the feeder, a tray was designed. It has 4 compartments of different sizes to accommodate for differently-sized component tapes. The tray compartments can hold component tapes of sizes 8 mm, 12 mm, 16 mm and 24 mm.

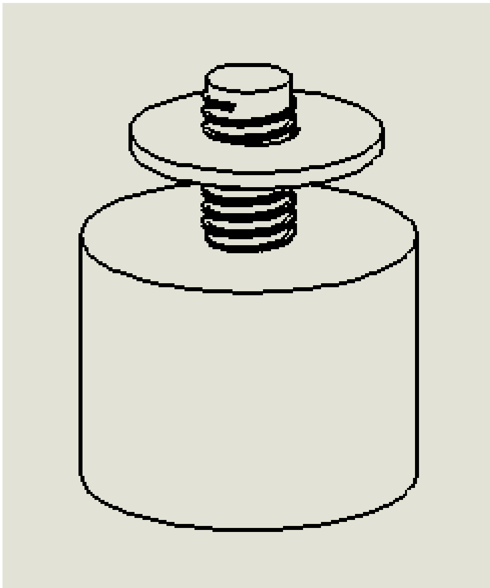


Figure 4.3.1: Dimetric view of the clamp.

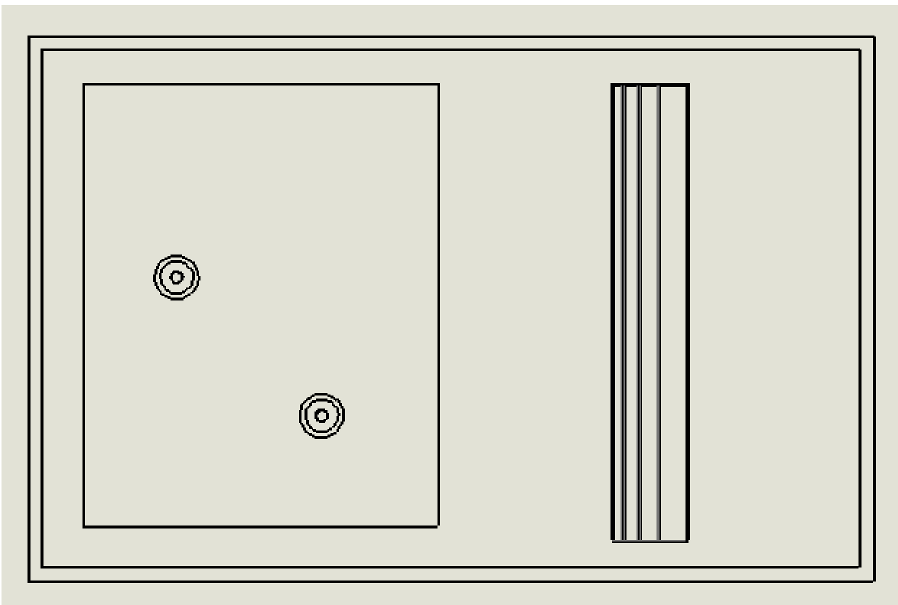


Figure 4.3.2: Top view of the bed, including the clamps and tray.

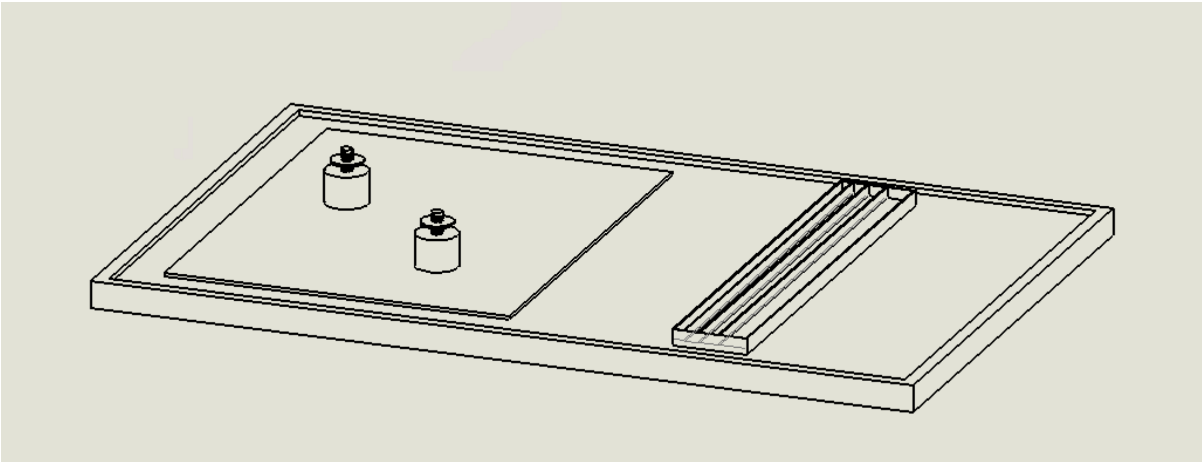
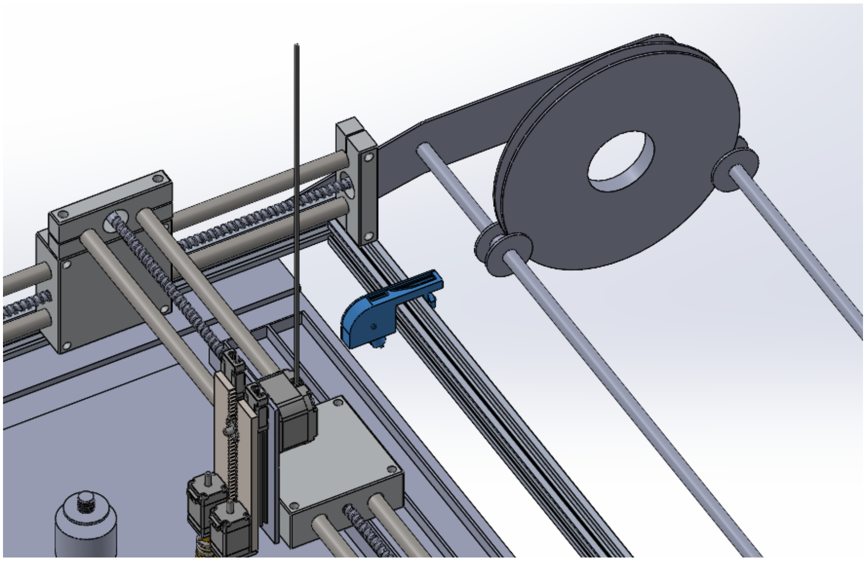


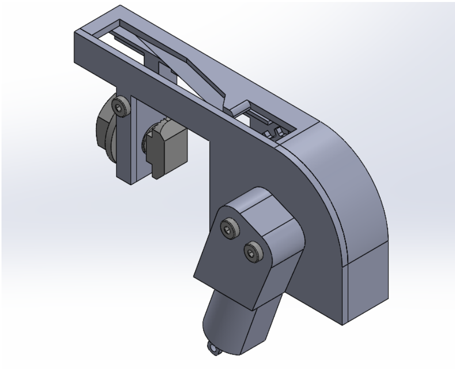
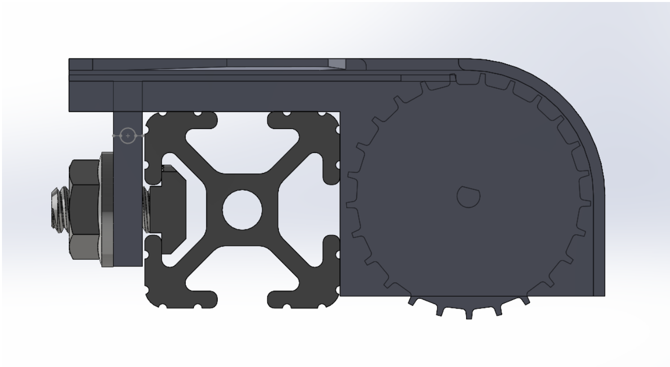
Figure 4.3.3: Dimetric view of the bed, including the clamp and tray.

4.4. Feeder

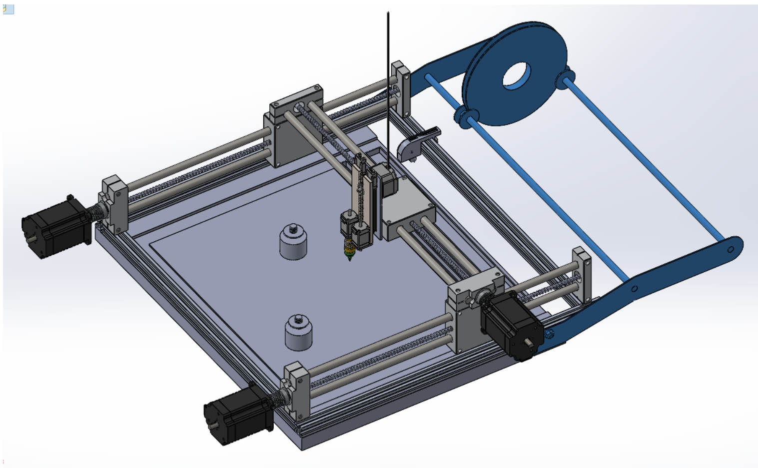


The feeders are responsible for making the SMT components accessible to the head for selection. There are many feeder designs on the market, ranging from ones that require the user to manually place components in a tray for the head to ones which take in components on a paper or plastic tape and remove them from the tape for the head automatically.

Through market research, it was determined that our feeders would need to be fully automatic to compete. Our feeder design uses a 90° n20 motor on a custom gear to pull the component tape through a channel which strips the plastic layer off the top before making the component available in a window for the head to grab. Below are pictures of the final design.

The tape comes off reels which can be mounted on top of rollers in the rack.



As many feeders as the user wants can be mounted on the machine, provided they all fit.

5. CAD Drawings

References

[1] "Top 10 Smt Assembly Brand Machines," *RayMing*, 30-Sep-2022. [Online]. Available: https://www.raypcb.com/smt-machine/.

[2] N. Seidle, "Electronics assembly," *Electronics Assembly - SparkFun Learn*. [Online]. Available: https://learn.sparkfun.com/tutorials/electronics-assembly/pick-and-place.