Gillette
Tri-grip Assembly Mechanism

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A Report Submitted To:
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Abstract

The goal of this project was to create a new assembly process for the Tri-Grip Assembly Machine in order to conserve time, reduce scrap, conserve machine space and reduce the number of steps needed to complete the process. In order to accomplish this, an initial computer analysis of the existing process was performed. Next, several concepts were generated, analyzed and presented to Gillette engineers for selection. These selected concepts were then brought to a prototype level and tested for effectiveness.

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Introduction

The work station on the Gillette TGAM machine that mates the Mach 3 razor handle with the three comfort grips is currently creating an undesirable amount of scrap. This is partially due to the current 3-step process of assembly used to mate the grips to the handle, which will be described in detail in the following paragraph. Additionally, with the current process each part must stop at three different stations to complete, respectively, loading, inspection and insertion. While this is not necessarily a problem, solutions that can reduce the amount of steps and/or machinery necessary to complete the assembly are more desirable than solutions that do not.

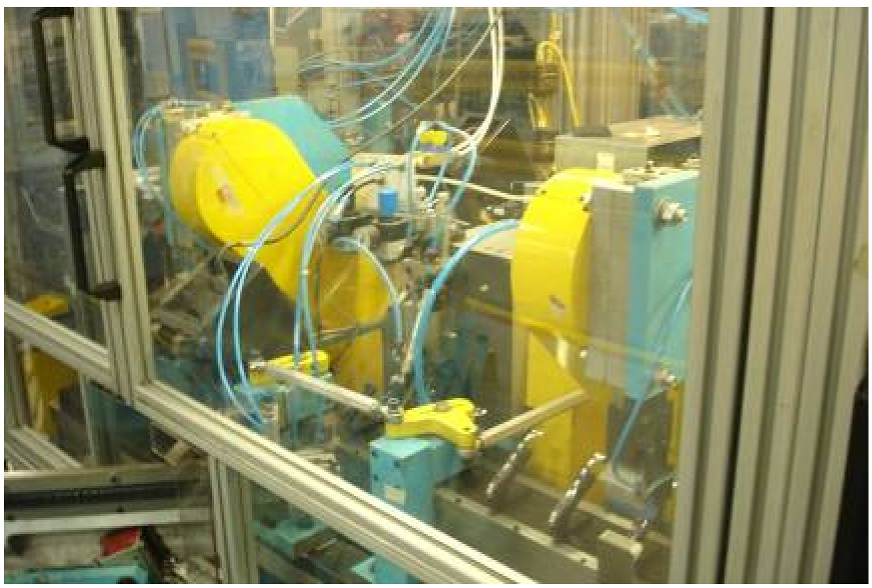

Figure 1: Current Tri-grip Assembly Mechanism

The current machine setup is shown in Figure 1. With this setup, the grip is first loaded into the handle in such a way that it is held in place by the closeness of the fit only (Step 1). Next, the assembled handle is moved to an inspection station to make sure that the grip is in place before more value is added to the part (Step 2). Finally, it is moved along the indexing track to the next station where the “legs” of the grips are inserted into the appropriate holes to hold the whole grip in place permanently (Step 3). The problem with the current process is that Step 1 does not securely affix the grip in the handle every time and some grips fall off during the move between Steps 1 and 3. For this reason, Step 2 (inspection) is necessary to notify the machine that the handle must either be scrapped or sent back through for another assembly attempt because the first attempt failed. This series of steps is repeated three times for each handle, once for each comfort grip. Obviously, the current process causes some undesirable results as it causes too much loss of time, parts and machine cycles.

While the assembly process itself is problematic, part of the issue with the current process is the nature of the grips themselves. Not only are they small and oddly shaped, they are quite flexible and thus hard to control. There are also variations from part to part due to manufacturing tolerances that also cause handling problems with the grips. Due to these complications the part is currently handled with a series of vacuum transfers from the pickup point (from a feed rail) to the loading mechanism and then from the loading mechanism into the handle. This too results in loss of grips and machine time if the grip comes loose from a vacuum or if the transfer between the two vacuum grippers fails.

Ideally a solution should be proposed that eliminates as many assembly and transfer processes as possible, while also being so robust as to remove the need for an inspection station and all of the expensive video hardware that such a process entails. Without limiting potential solutions, this should reduce the number of transfers, firmly hold the part in place until it is permanently affixed and, if possible, mechanically inspect the handle to make sure that the grip was properly inserted before it moves to the next station. Ultimately, the goal of this project is to re-design the assembly in such a way that it reduces the scrap rate of the process while also reducing the number of steps it takes to complete. The design should remain as reliable as possible so as to reduce or altogether eliminate the need for inspection. There are other caveats to the design that must be met that will be discussed in the next section, but the focus of the project is as described above.

Original Problem Statement

A fully-automated piece of assembly equipment assembles the three crescent-shape "comfort grips" to the top of the Mach3 family of product handles. The grips are produced from two types of plastic, a soft elastomeric coating that remains exposed after assembly, and a more durable underlying plastic substrate. Even so, the part is flexible and therefore difficult to control. Additionally, process variations contribute to dimensional differences between one component and the next, making a robust assembly operation difficult. The current method of assembly involves several transfers between vacuum grippers to pick the part from the end of a feed rail and finally place it onto the handle. All three grip assembly operations are similar. Each assembly operation is followed by an inspection operation to verify that the assembly was successful. It is desired to eliminate this inspection step and the expensive vision hardware used by designing a more robust assembly operation. The new assembly operation should be a cam-driven mechanism capable of moving the grip from the end of the feed rail, onto the handle, as reliably as possible.

Goal Statement

The goal of this project is to re-design a mechanism to place the grips on the handle of the Gillette Mach 3, with focus on minimizing both scrap and the number of required steps to complete the operation.

Task Specifications

1. Must run at 60 ppm
2. Operation must be completed in one station.
3. Must retrofit the existing machinery
4. Must be powered by current drive train
5. Must have a scrap rate of less than that of the current mechanism
6. Must have a MTBF greater than that of the current station
7. Must reduce number of pneumatic and hydraulic mechanisms as much as possible
8. Must place parts within a tolerance of ± 0.004 in
9. Must not damage handle or grips
10. Must be easily modified to allow the placing of all three grips
11. Must shut off when a damaged part or empty nest is on station
12. Must be able to sync with the machine from a cold start

Background

Existing Mechanisms Research

Although the specific nature of this problem limits the possibility of using an existing mechanism to achieve the desired results, preliminary research was performed to gain a broader understanding of various techniques used to accomplish similar tasks. This research revealed various ways which are standard methods of producing a 'pick and place' motion.

Probably the most prevalent solution to these problems is to use a simple linkage system. The correct combination of bar lengths can yield an infinite possibility of coupler curve motions, and software (such as SYMECH, discussed later) exists to make this process relatively simple. Powered by rotary motion easily derived from a machine's drive train, a linkage is a simple and reliable way to produce a desired motion. The addition of a driver dyad can be used in order to limit the range of motion over a small section of a coupler curve as required.

Another prevalent solution is to use a 'black box' approach as is currently implemented by Gillette. Several companies exist whose purpose is to provide apparatuses to produce desired motions. Usually cam operated, these systems are generally reliable but difficult to adjust and change after installation.

Other solutions encountered during the research included solutions using pneumatics, hydraulics, and even planetary gear systems. While many of these provide reasonable possibilities, this background research proved that perhaps the best place to start would be to consider a linkage solution to provide the motion necessary to pick the part off of the feed rail and load it into the handle.

In addition to motion generation, various pick and place mechanisms were researched in order to understand the most effective way to handle the parts being dealt with. While many devices exist to handle and move parts from place to place in assembly operations, very few patents were found that dealt with handling small, oddly shaped, and flexible parts. As such, the current Gillette method of using vacuum to grab and hold the grips is most likely the best option of dealing with the problem.

Tools and Methods

The primary tools used for the design modeling aspects of this project were the CAD packages ProEngineer and AutoCAD. In addition to using them for modeling the current TGAM machine, the SYMECH application for ProEngineer and the dimensioning capabilities of AutoCAD were also employed to model and simulate potential solutions.

ProEngineer

The primary method used to gain a full understanding of the project was to use ProEngineer to model the important machinery in three dimensions. Gillette currently has only two dimensional drawings of the TGAM assembly machine and its component parts. Although the two dimensional AutoCAD drawings contain all of the necessary information to model the machine, it is very difficult to use these drawings to visualize the setup in three dimensions. Creating models of the machines in 3D will allow easy recognition of usable space within the machine as well as defining hard points that can be used to attach potential designs. Gillette provided IGES files of the Mach 3 handle and the top grip being considered, which will be implemented in a final assembly. These are shown in Figure 2.

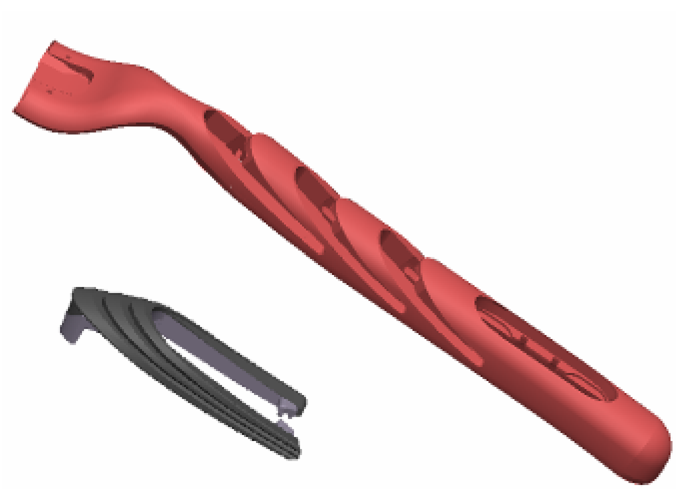

Figure 2: Handle and Grip models

The CAD work was divided into three sub-assemblies: Insert, Chassis, and Load. The final assembly of the TGAM machine was created by first modeling the components for each sub-assembly, creating the sub-assembly, and finally combining everything into a final assembly. It should be noted that for simplicity and efficiency, only the mechanisms used for inserting the top grip and the surrounding machinery were considered. Design Note: Any device created should be relatively easy to modify so that it may be used to place the second and third grips. A more detailed explanation regarding how the following mechanisms work together will be given in the next section.

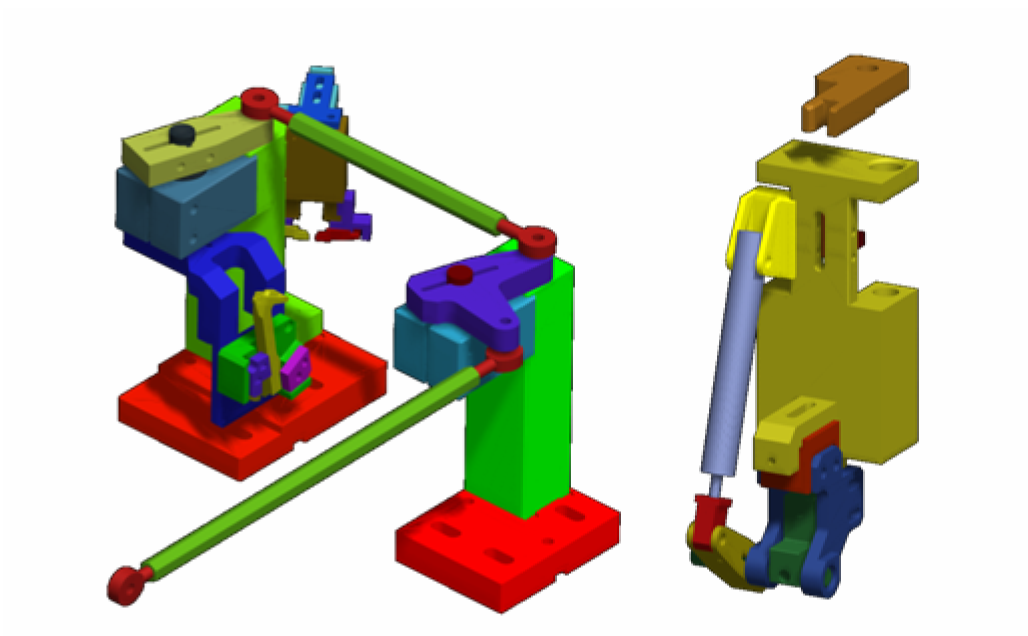

Figure 3: Load Sub-Assemblies

Load

The purpose of the load sub-assembly is three-fold: retrieve the grip from the vibratory feed rail, orient it relative to the handle, and finally place it into the grip slot. It is important to have a 3D model of this mechanism in order to generate a possible solution that only involves modifying this device to perform the additional task of inserting the legs, a task which would eliminate the need for the insert sub-assembly while simultaneously reducing scrap. This model is shown in Figure 3.

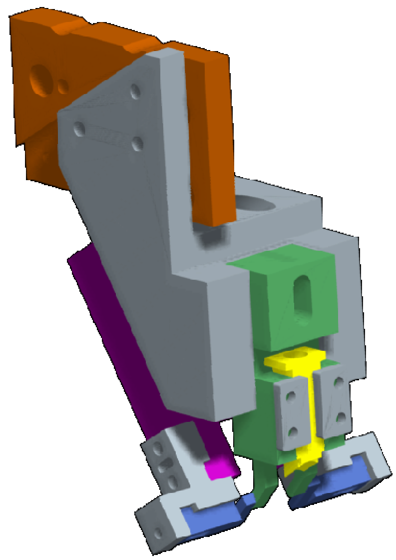

Figure 4: Insert Sub-Assembly

Insert

The purpose of this sub-assembly is to fully insert the 'legs' of the Mach 3 handle grips. When the part is moved to this station, the grip is held in place by closeness of its fit with the grip slot while the legs stick out to the sides of the handle. This assembly drops down on either side of the handle, holds it firmly and place and pushes the legs into position with two pneumatic punches. The 3D CAD model of this device is shown in Figure 4.

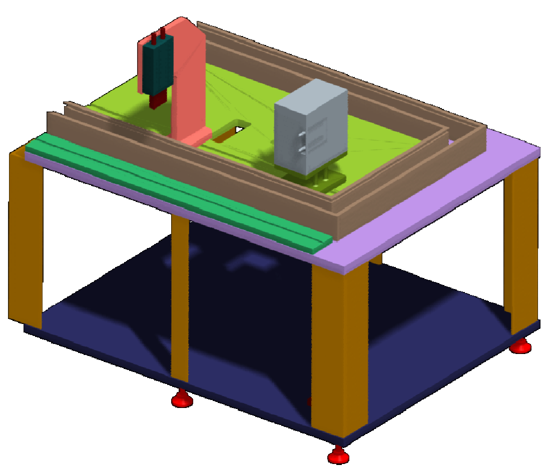

Figure 5: Chassis Sub-Assembly

Chassis

The components in the chassis assembly primarily consist of the support structure and drive train of the TGAM machine. The operation level of the machine is a set of pallets with high-precision holes for locating assembly stations, all of which are suspended above the driving mechanisms that power the machine with cams and belts. This sub-assembly was critical because it is necessary to know exactly where there is room for additional machinery, and it is not desirable to make any significant changes to the plates and support structures. This information was primarily obtained by the assembly drawings provided by Gillette. The CAD model created of the chassis surrounding our area of interest is shown in Figure 5.

Final Assembly

Once all of the sub-assemblies were completed they were combined into an overall model of one grip station. Using the data provided in the overall assembly drawings, their correct location was determined as well as the placement of connecting rods and other components. This is shown in Figure 6, and more detailed views are shown in a following section (Mechanism Explanation), as well as diagrams describing precisely how the process works, while Appendix B offers a few different and less cluttered views of the various assemblies.

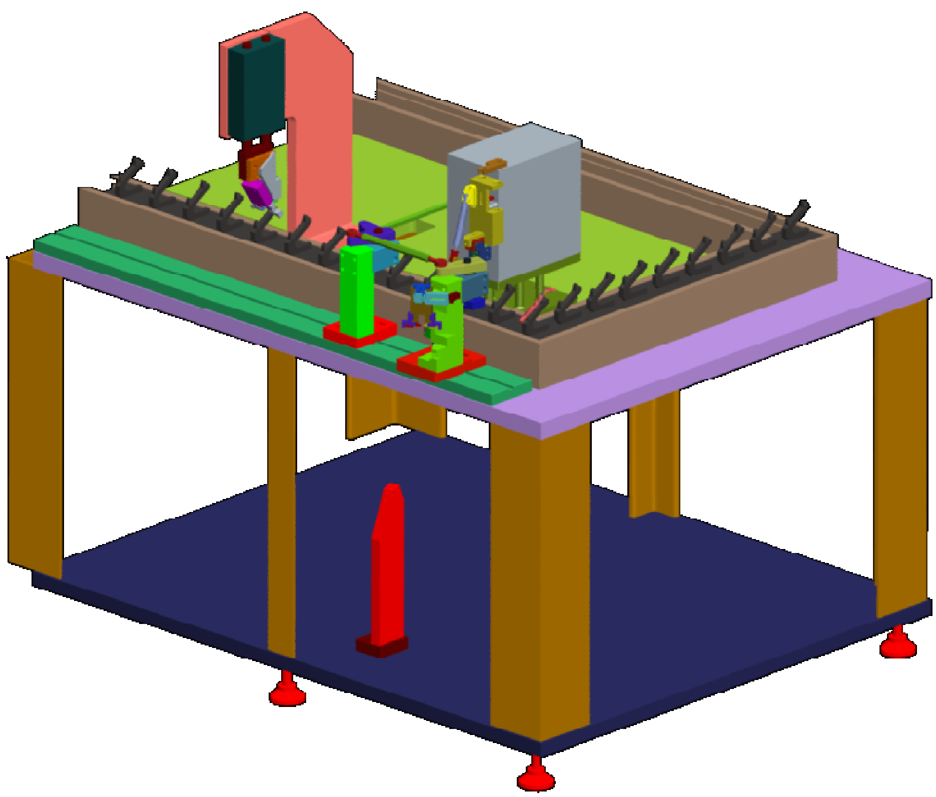

Figure 6: TGAM Assembly

SYMECH

Another useful aspect of creating 3D models of the TGAM machine in Pro Engineer is that it will allow the use of another ProEngineer application: SYMECH. SYMECH is a program that generates coupler curves and their resulting linkages (four, six, or multi bar). One potential solution to the problem could be to create a linkage provides motions to both place the grip into the handle and then push the legs in; it is believed that SYMECH could be a useful tool to generate such a solution. Before considering part placement in the overall assembly, SYMECH was used to create a simplified version of the grip in order to approximate a coupler curve that would produce the desired motion. One possible curve generated by this method is shown in Figure 7.

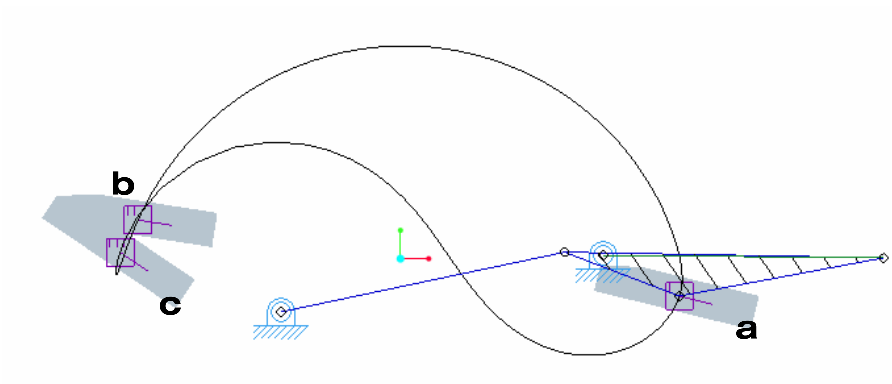

Figure 7: Preliminary SYMECH design

In this particular example, the trapezoid shape represents the basic dimensions of the grip. The three locations show the motion of the grip from (a) the feed rail to (b) a point just inside the grip slot and finally (c) being swung down into place. After an analysis of the CAD assembly is performed to see exactly what space is available for use, this application can be used to create a more accurate linkage solution with realistic ground link locations and driving options. In order to find three locations that the grip must pass through, a digital camera was used in conjunction with AutoCAD drawings and a test palette to articulate a grip into various positions on the handle. The results of this can be seen in Appendix B.

AutoCAD

The purpose of using the software package AutoCAD was two fold. Primarily, AutoCAD was used to read and dimension the machine drawings in order to turn them into a 3D model. In addition, the dimensioning features of AutoCAD were used to analyze the placement of the top grip. Using a digital camera, several pictures were taken of the handle in profile while a grip was being placed manually. These pictures were then uploaded into AutoCAD and dimensioned to scale. The results are shown in Figure 8.

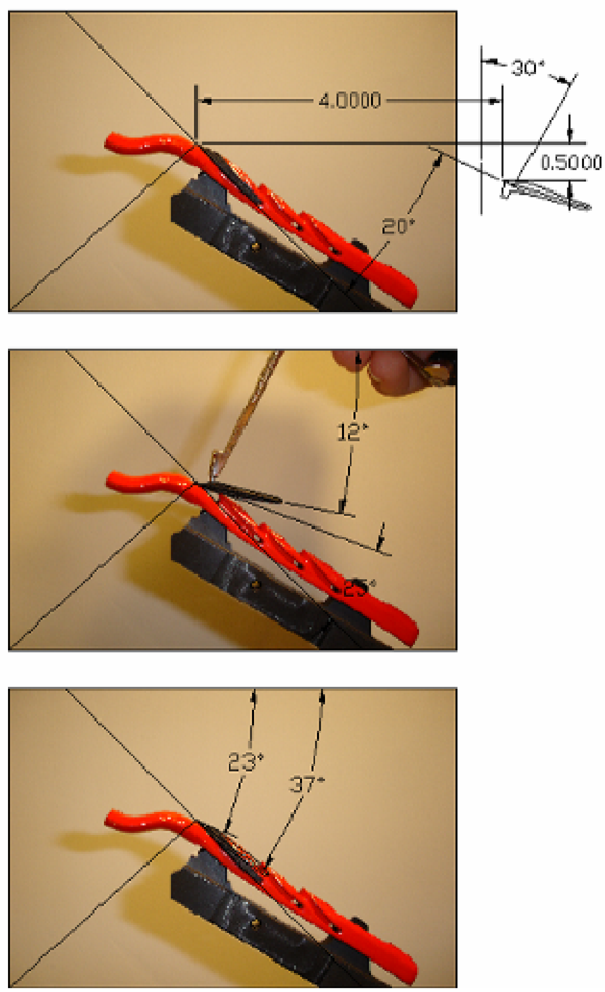

Figure 8: Photographic/CAD Motion Analysis

Mechanism Explanation

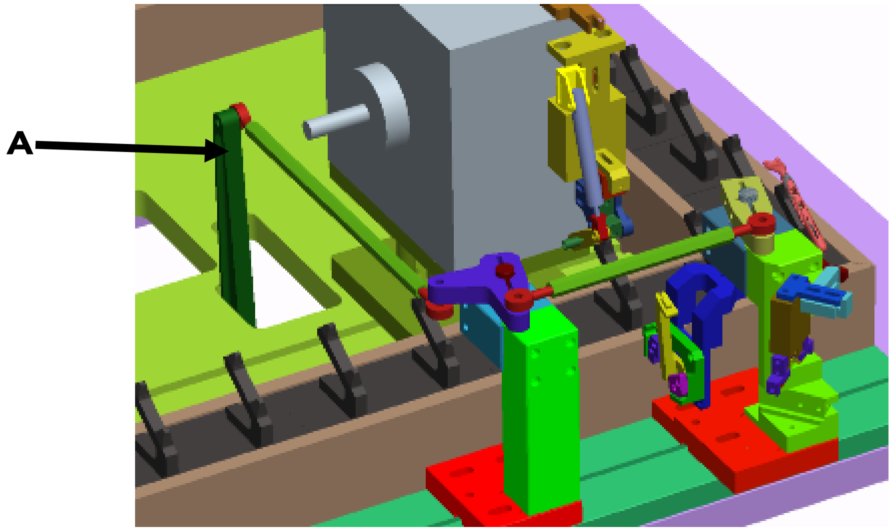

Figure 9: Load Mechanism on Chassis

There are two main steps to the assembly of each grip onto the Mach 3: the loading and the insertion. Figure 9 shows the loading mechanism for the top grip with respect to the track of indexed pallets. The main linkage system is driven by a cam from located on the main drive shaft. Power is sent up to the linkage system via a cam follower (A). As shown in Figure 10, this motion is directed by linkages in order to ultimately pivot station B about an axis. This can be better described by explaining the path traveled by the grip during assembly.

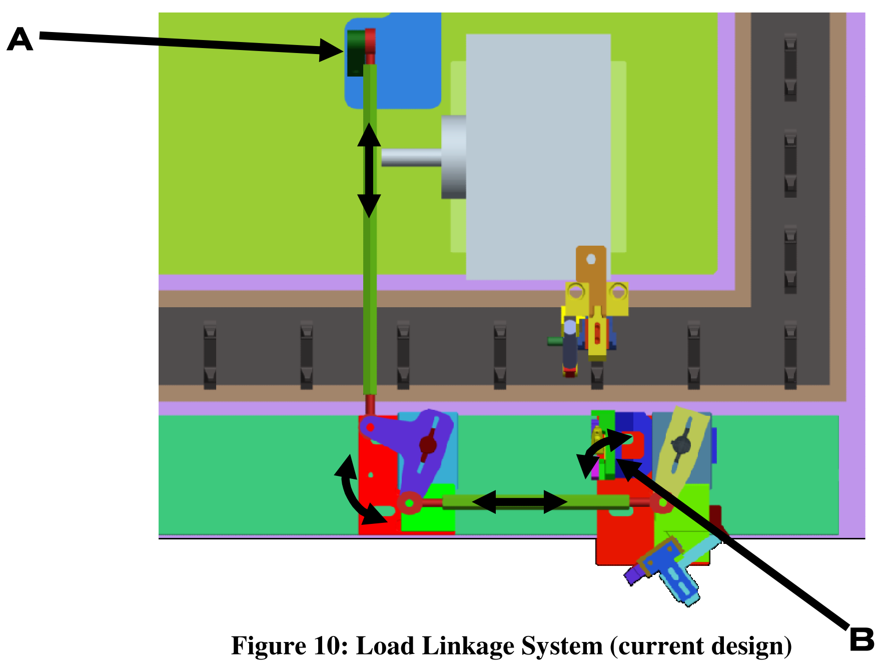

Figure 10: Load Linkage System (current design)

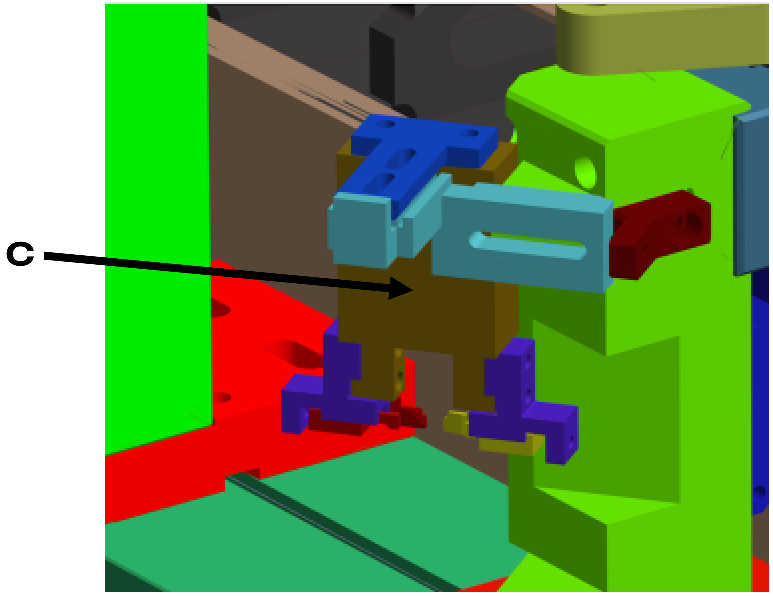

Figure 11: Grip Receiver (current design)

1. The grip travels down a track from a vibratory feeder into the casing of the TGAM chassis. It is stopped and held in place by the Grip Receiver C showed in Figure 11.

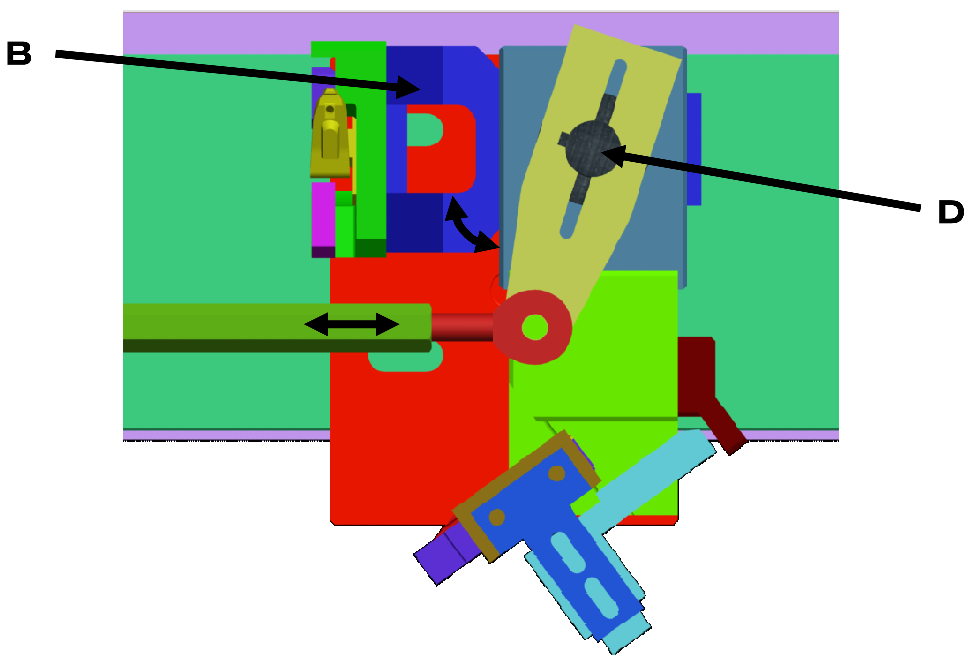

Figure 12: Pivoting Station

2. The Pivoting Station B rotates toward the grip about the Pin D as shown in Figure 12.

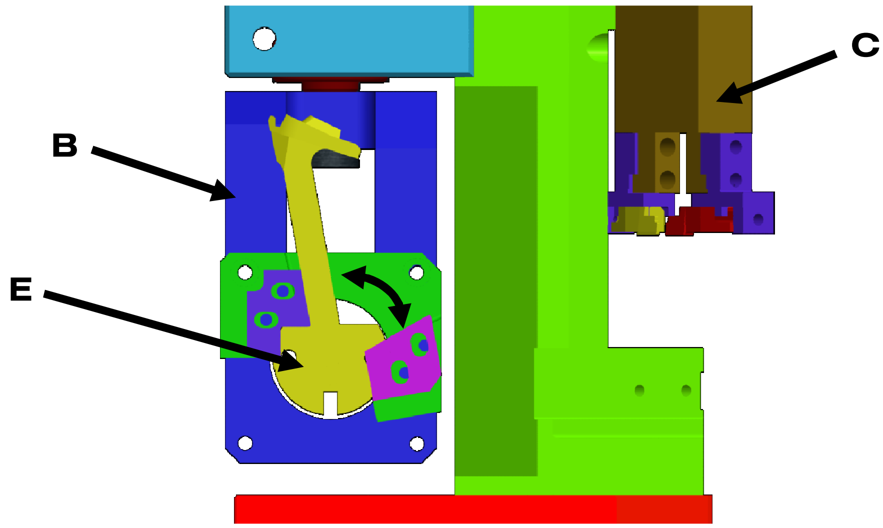

Figure 13: Side view of Pivoting Station and Mount

3. While Station B pivots across the table towards the grip receiver C, the mount E pivots downward. This allows the seat at the top of the mount to reach the grip in the receiver with the same orientation as the receiver holds it as shown in Figure 13.

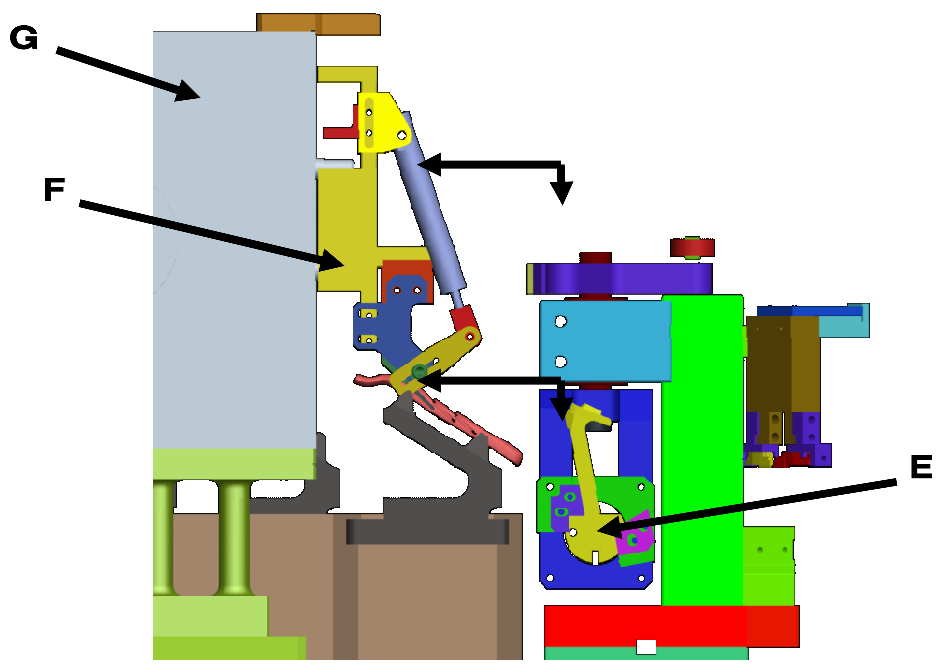

Figure 14: Grip Placement

4. Assembly F is controlled by push rods from the Cam Box G. This Cam Box produces a set 2 dimensional movement of Assembly F to pick up the grip off of Mount E. It then

follows the same path back to the handle where the grip is positioned and released as shown in Figure 14.

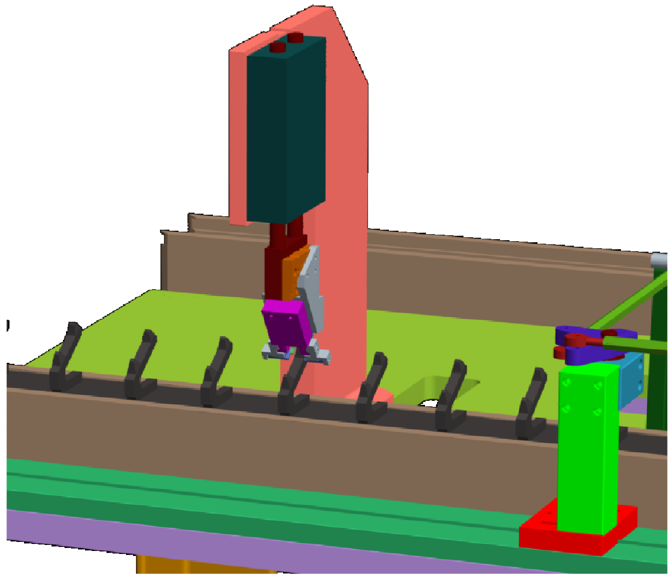

Figure 15: Insert Assembly on Chassis

At this point the grip has been positioned into the handle and is ready for the second stage of the assembly. Figure 15 shows the insert assembly with respect to the indexing track. This assembly is driven by a belt which runs to the drive shaft.

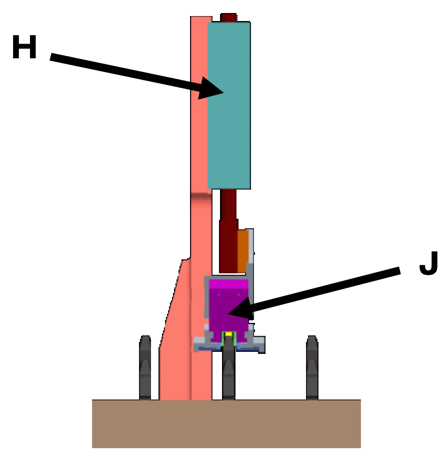

Figure 16: Insert Mechanism

5. Once the handle is in position under the insert assembly, Cam Box H drives the Mechanism J down on top of the grip. Figure 16 shows how it then squeezes the "legs" of the grip into their position inside the handle, releases, and retreats back up.

Concepts

Once the preliminary problem definition work was completed, it was time to begin developing mechanism concepts for potential solutions. Using the three dimensional model as a testing bed for design placement and functionality, various ideas were developed keeping in mind a certain design approach: develop separate solutions to the various stages of the task and then combine the best ones for each task. In other words, there were two main objectives performed by the current machine: move the grip onto the handle, and insert the legs. In order to better focus design efforts, separate ideas for each task were developed, keeping in mind that eventually the two mechanisms would be synthesized.

Ultimately, after presenting to the Gillette design engineers, it was decided that the current drive system on the existing TGAM machine was the most feasible option for implementing the following concepts. In keeping with this information, only the insertion concepts are presented in this section, while the locator concepts are located in Appendix C.

Pincher Concept

The idea behind this concept is to utilize the force caused by the grip being pushed down onto the handle as it is located into the slot. With this concept, the grip is held by a vacuum arrangement similar to the one currently utilized. However with the new arrangement, the part is held such that not only is the upper tip put into place, but the legs are also correctly lined up with the slot on the handle. The grip holding device pivots as a result of being lowered onto the handle. This motion in turn rotates two arms on either side of the grip which pinch the legs firmly into place. This is shown in Figure 17.

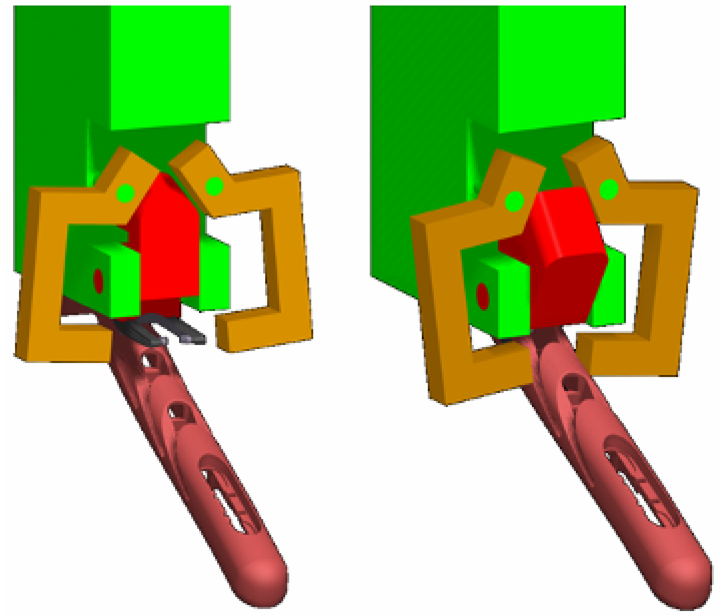

Figure 17: Pincher Concept

Roller Concept

Similar to the Pincher Concept, this design uses the downward motion of the insertion tool to activate a mechanism which inserts the legs of the grip into the handle. Holding the grip with a vacuum seal, the grip is pivoted down into place such that the legs line up with the slot. As the legs are lining up into place, the pivoting of the grip holding device activates a linkage which swings dual rollers down on either side of the grip. These rollers push the legs into place and then withdraw, leaving the grip fully inserted. This is shown in Figure 18.

Figure 18: Roller Concept

Methodology

With the preliminary work out of the way, generating realistic models in order to test various criteria became the next goal. In order to ensure that the concepts would be effective in achieving the goal of inserting a grip, the models had to be refined and prototyped. Additionally, a testing fixture had to be developed that would consistently and accurately represent the motion a Gillette TGAM machine, while eliminating other variables that could influence or bias the testing procedure. In order to accomplish these goals, the process was split into three tasks: refinement, prototyping and testing, the final including the development of a test bed for the prototyped devices. These steps were carried out in parallel in order to make sure that all three components could be synthesized upon their completion.

Refinement

Once Gillette had selected the two insertion concepts described earlier as their preferred options for implementation, work began in earnest to bring them to a level in Pro/Engineer where they could be prototyped. This involved increasing the refinement of the 3D models to include hardware and more practical geometry, while also taking into consideration realistic mechanism operation (as opposed to the idealized version provided by the CAD model).

These modifications were implemented in the pincher concept in multiple ways. First, the pinching links were greatly simplified in order to facilitate the manufacturing of the prototype. These simplified links also provided better surfaces as cam-followers, as they are rounded and provide smoother contact with the surface of the passive cam. Additionally, the cam and grip-holder were separated into two distinct pieces for a variety of reasons. Primarily, flexibility in the design was necessary to fine tune the mechanism during testing. Separating the blocks in this manner allowed the grip holder to be moved back and forth on the cam block to find the ideal position for inducing the passive motion with the right timing for the insertion process. The secondary result of this separation was to address concerns with the manufacturability of this part. By separating the two, the complexity of each piece was greatly reduced with little to no reduction in functionality. A third major change was the addition of a “backstop” for the rotating cam that stopped it from over-rotating while not being used to load a grip. This allows for proper retrieval of a grip because the cam is forced into the same position during every cycle through the use of a spring and the physical backstop. Finally, all of the hardware necessary to assemble the device was added to the Pro/E model. The final model can be seen in Figure 19 alongside the original conceptual model for comparison. It must also be noted that because the design process went through several iterations, some functionality alterations were made during the experimentation process that were later added to the model, but have not been discussed in this section (see the Prototype section of this chapter for further details).

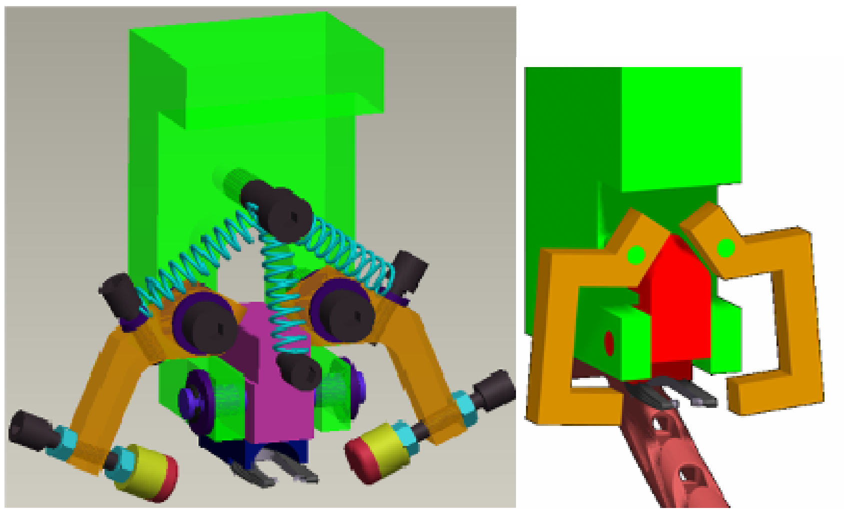

Figure 19: Final Pincher Model vs. Original Model

Similar alterations were made to the roller model. The separation of the T-shaped block and the grip holder was affected for the same reasons as the pincher concept (to provide testing flexibility and reduce complexity). Correspondingly, the links that were intended to hold the rollers were separated into two distinct parts. Several unnecessary aspects of the geometry were removed, including rounds, protrusions in the chassis and other extraneous features. Additionally, a set of eccentrics were added to limit the stroke of the mechanism if necessary to prevent the mechanism from entering a toggle position. Again, much like for the pincher concept, iterative changes were added to the model to make the digital model reflect the physical prototype. This model, along with the original version of the roller concept, can be seen in Figure 20.

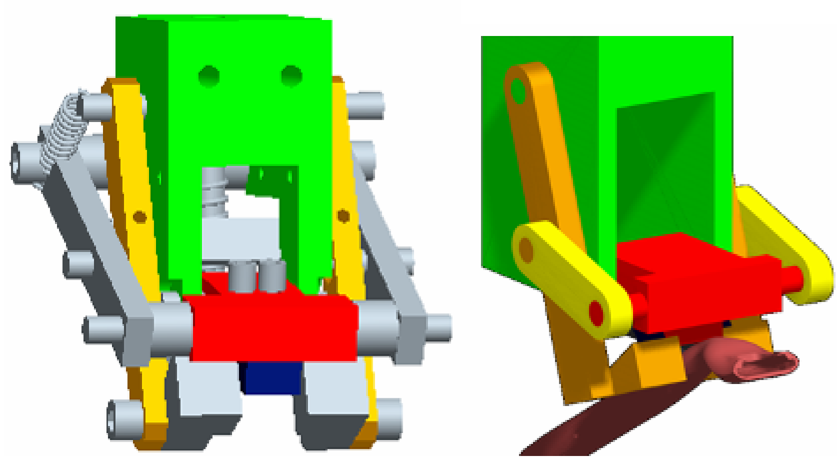

Figure 20: Final Roller Model vs. Original Model

Finally, these models were used to create a set of 2-D engineering drawings for use as a manufacturing reference during the prototyping process.

Prototyping

After the initial refinement of the models was completed and engineering drawings of all of the parts were made, various hardware items (such as springs, washers and bolts) were acquired and the first phase of prototyping the individual components began. At this point it is appropriate to separate the two concepts, as they took very different paths in the engineering process. As such, they will be discussed separately from this point. The Conclusion section of this report will bring them back together.

Pincher Concept

Although the initial prototyping of the individual components of this concept was uneventful in terms of design changes being forced by manufacturing realities, several problems became very apparent with this design upon its assembly. This assembly can be seen in Figure 21.

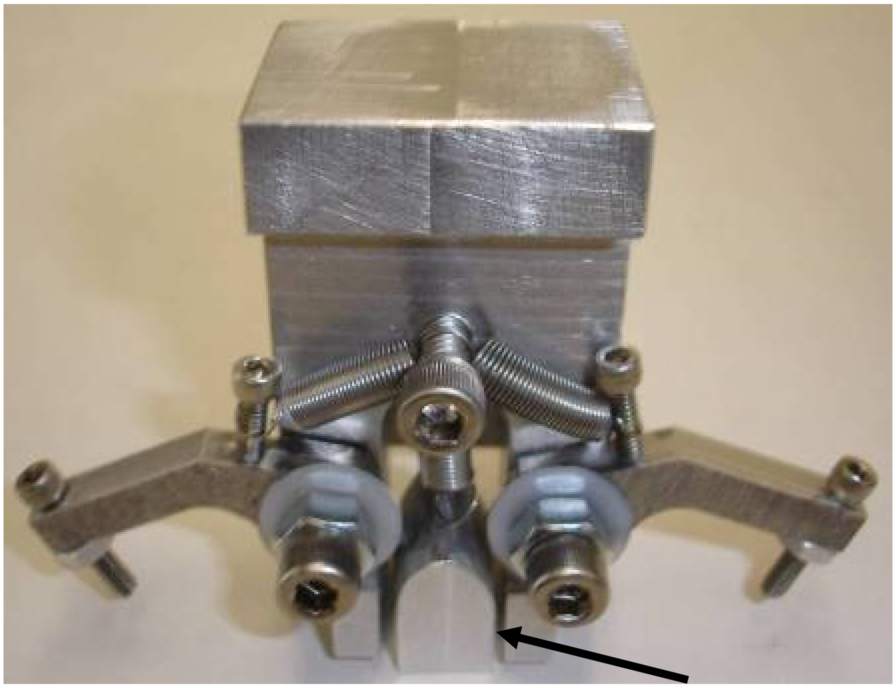

Figure 21: Pincher Concept Assembly

While this concept functioned admirably in the Pro/E model, manufacturing the parts to a tight enough tolerance for the actual device to function at a level consistent with the computer model soon appeared to be impossible. The cam piece (denoted by the arrow in the figure above) was impossible to accurately create from its digital counterpart, even using a CNC mill. Initial attempts at creating this piece caused the entire device to seize in place whenever it was assembled and no further movement was possible unless it was severely forced to do so. This presented a significant setback to further prototyping, because the cam piece is the most essential component in inducing the passive motion critical to successfully loading the grip into the hand and inserting the legs in place. However, design engineering is inherently an iterative process and this was not enough of a problem at this point to justify a complete rejection of this concept. Several more attempts at creating an effective cam, with varied results. The most successful of these can be seen in Figure 22, to the left of the original and in front of the overall assembly[1].

[1] Note: the bolt in the back of the original cam piece is for attachment of the spring shown hanging down in the center of the overall assembly.

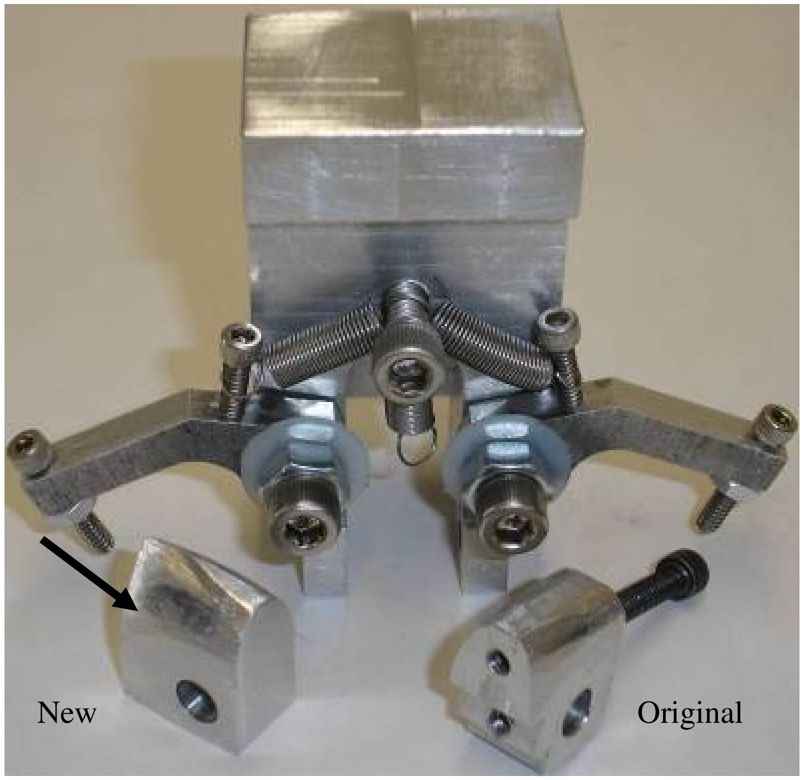

Figure 22: Assembly with cam iterations

The final version of the cam piece (denoted by the arrow) is taller and narrower than the original and was the most successful in creating motion in the rest of the mechanism. However, even this locked in certain toggle positions and could not be returned to a functioning status without extreme force or partial disassembly of the mechanism. Due to this immobility and the fact that even major modifications would still require unreasonable manufacturing standards, this concept was almost entirely abandoned for the time being.

The difficulties encountered with this design coupled with the relatively smooth progress which was concurrently being made with the Roller Mechanism (discussed in the following section) suggested that it would be more fruitful to give complete focus to the Roller. However, when time presented itself, a third modification to the cam piece was made which proved to be much more effective than the previous two.

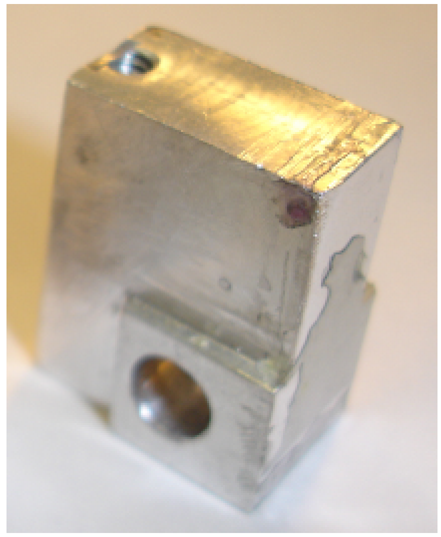

Figure 23: Square Cam

This new piece, shown in Figure 23 had relatively square corners which were rounded just enough to prevent excessive wear. It was soon clear that this change resulted in a dramatic improvement in the function of the Pincher Concept. Because of the smoother operations, it was now possible to get a range of motion which was superior to the previous attempts. However, there was still one major problem which presented itself: the pincher ends were interfering with the insertion of the grip. In other words, as the grip block was pushing the legs of the grip to line up with the slots, they were hitting the incoming pinchers, causing them to twist and prevent insertion. This phenomenon can be seen in Figure 24.

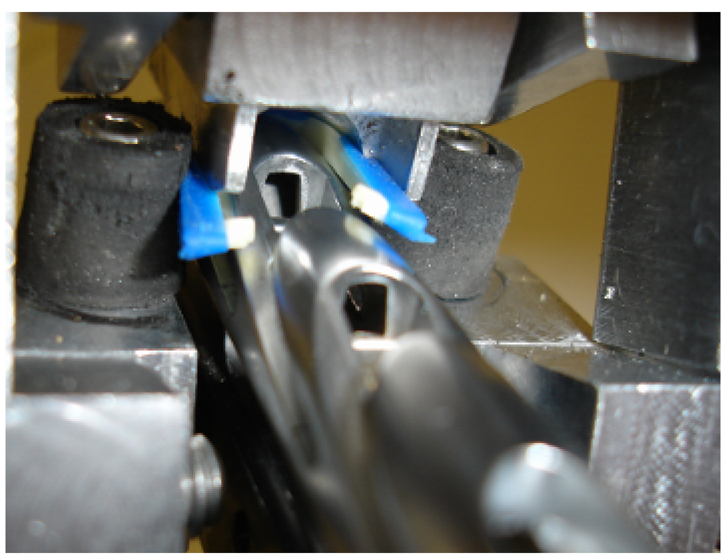

Figure 24: Grip Misalignment

The first attempt to counter this was to retract the pinchers slightly, but this resulted in the legs not being completely inserted.

The major hurdle here is that the motion of the pinchers and the motion of the grip holder block were necessarily coupled. This of course was seen from the beginning as one of the advantages of the design, because there would never be any timing issues and the mechanism would be greatly simplified by not requiring any other power source. However, the task of timing the mechanism so that the legs would not interfere with the grip too early and still have sufficient stroke to insert them fully proved to be daunting.

At this point it was realized that there needed to be a final motion independent of the grip location which would give the pinchers the extra movement they needed to completely insert the legs. It was noted here that the cam goes through several degrees of rotation *after* the grip is fully inserted. In other words, after a certain position, the grip will snap into place almost independently while the cam would still rotate. This 'over rotation' provided the opportunity for decoupling the motion of the grip and the pinchers.

By creating a new cam with a 'flare' at the corners which would move the legs only during the over rotation period, the legs would receive that extra push they need to fully insert the legs. This had an immediate and dramatic improvement of the operation of the mechanism. The new cam shape can be seen in Figure 25.

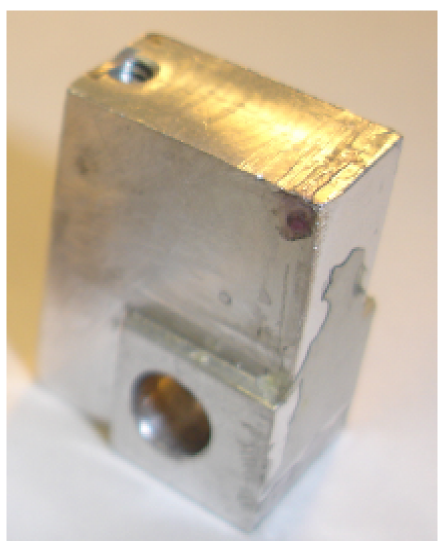

Figure 25: Flared Square Cam

In addition to the modified cam, it was determined that rubber might not be the best material to cover the ends of the pinchers (the part that actually contacts the grip). This is because the amount of force required for even a hard rubber surface to push in the legs was excessive and would cause unnecessary wear on the mechanism. Instead, small, smooth end aluminum parts were made which were accurately angled to facilitate proper grip insertion. These parts proved to be much more effective for consistent leg insertion. These are shown in Figure 26:

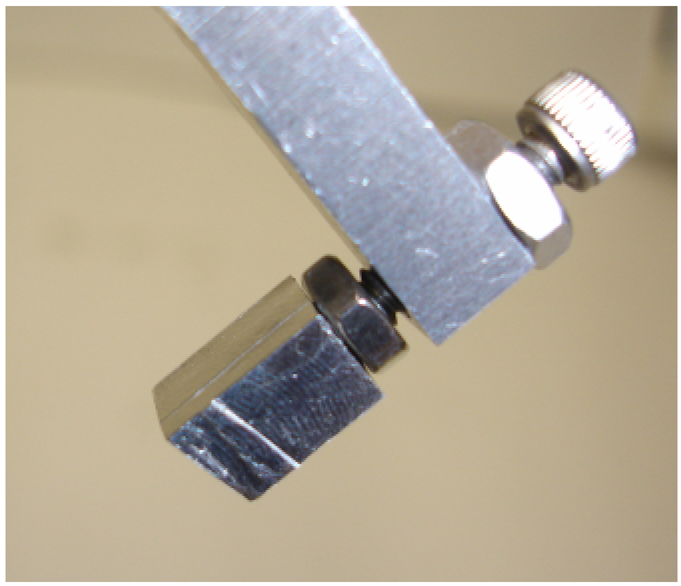

Figure 26: Aluminum Pincher Ends

Roller Concept

Prototyping the roller concept proved at first to be much more fruitful than the pincher concept. While some minor changes were necessary during the initial stages of prototyping, there were none of the severe design flaws that completely crippled the roller design. Once the individual parts were completed, the first assembly of the roller concept was constructed and can be seen in Figure 27.

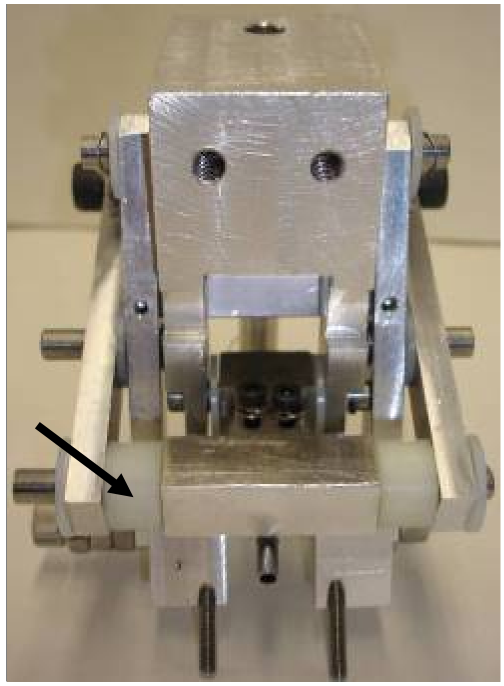

Figure 27: Roller Concept Initial Assembly

After some initial tests (recall that the test bed was being built concurrently with both prototypes), a few problems of varying severity were discovered. These included: mechanism slop, manufacturing tolerance limitations, material property limitations, minor design flaws and a few unnecessary components.

The first design problem that was addressed was slop in the mechanism. Due to the tolerance limits inherent to the manufacturing process (2.5 axis "Bridgeport" Vertical Mill), some of the rods were loose in their shafts and the whole mechanism wobbled from side to side while in use. This caused most of the serious problems in early testing, as consistent results could not be achieved.

The first attempt at solving this problem was using various spacers, washers and a different kind of shaft clamp in order to tighten up the whole mechanism. This was moderately effective, but did not relieve enough of the slop to provide sufficiently repeatable testing. Next, more iterations were attempted to solve this problem, one of which can be see in Figure 28.

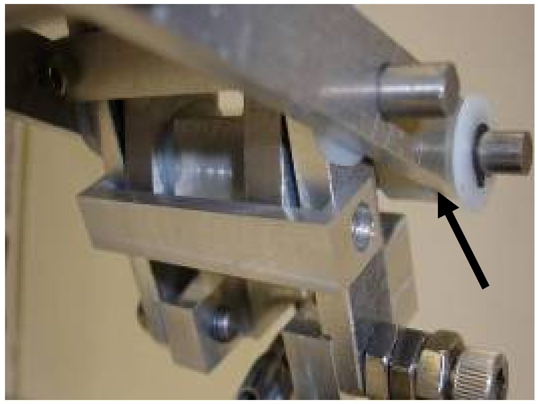

Figure 28: Slop removal; second iteration

This second attempt at removing this slop actually served a dual purpose. First and foremost it was intended to stiffen the whole mechanism in order to prevent wobbling by locking it at a certain width in two places (at the front pin shown by the arrow). However, as can be seen in Figure 28 there was an additional problem of interference with the full stroke of the mechanism

The next attempt at stiffening the system was a bracing bar that ran across the rear of two newly made links that were longer than the originals in order to provide a better attachment point that would not interfere with the stroke of the mechanism. This modification can be seen in Figure 29[2] (the spacer bar is highlighted by the arrow).

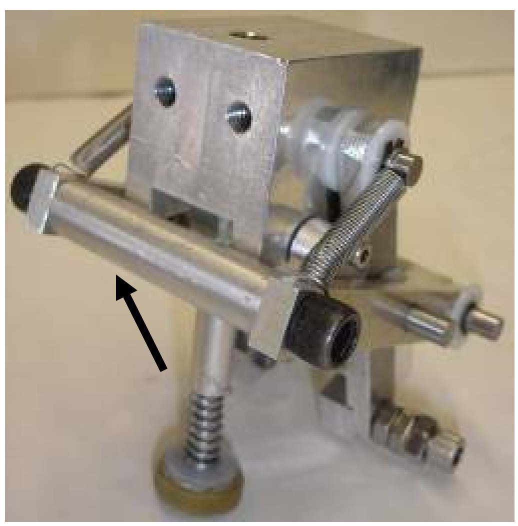

Figure 29: Slop removal; third iteration

[2] Note: The spring-loaded foot at the bottom of the device is a modification that will be discussed later, but is unrelated to the slop problem

This iteration, in combination with spacers and better pin attachment proved to be highly effective at solving not only the problem of slop, but also the problem of perfectly synchronizing the links.

Now that the mechanism was consistently replicating the desired motion path, a new problem emerged, that of holding the elastomeric grip itself. The initial attempt to hold the grip involved a molded casting of the grip made from two-part, liquid epoxy. This was immediately rejected as it would not cure in a shape large enough to be useful for the purposes of this project. Next, a similar casting was attempted with a putty epoxy that was reputed to behave like a metal once set. While it did create a perfect cast, it was very brittle, difficult to machine and delicate to handle. This was less than ideal as parts of the grip holder would chip off during testing, among other problems. The ultimate rejection of this grip holder came about when the threads used to screw it to the T-shaped block were stripped out and it had to be glued in place. This did not provide for sufficient flexibility in testing and this molded piece was replaced by a CNCed aluminum block.

In order to create a model for the new grip block which incorporated the shape of the grip, a Boolean operation was performed using the grip IGES file which was provided by Gillette. By subtracting the grip from a solid block at an appropriate angle, the shape of the grip was perfectly translated. However, it quickly became clear that some of the contours would be impossible to machine, and the model had to be modified slightly to allow for manufacturability. Keeping in mind that the smallest mill bit available was a 1/16" ball end mill, the part was re-designed and subsequently machined.

The aluminum was much more reliable and effective, as well as being easier to modify and much more robust when it came to handling and testing. It did have one drawback, in that it was not a perfect inverse of a grip, like the molded piece. This proved to be a moot point, however, because the suction provided by the vacuum source was more than enough[3] to hold the grip in place, regardless of the shape of the grip block.[4] Eventually, further modifications to the grip block had to be made in order to properly place a grip, while still allowing for the legs to be inserted into the handle. First,

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[3] A larger vacuum source was later used for convenience in testing, because using the minimum vacuum level made holding the grip more difficult in higher speed testing. This merely entailed an upgrade from a small, battery powered pump to a large, AC powered pump.

[4] For further calculations on the necessary vacuum pressure to hold a grip, see Appendix D

a nipple was added to the front of the grip holding block to allow it to receive the vacuum hose and the "legs" of the block were lengthened in order to fully snap the grip into position for later insertion, while also protecting the grip from premature contact with the rollers. The evolution of the grip block is depicted in Figure 30.

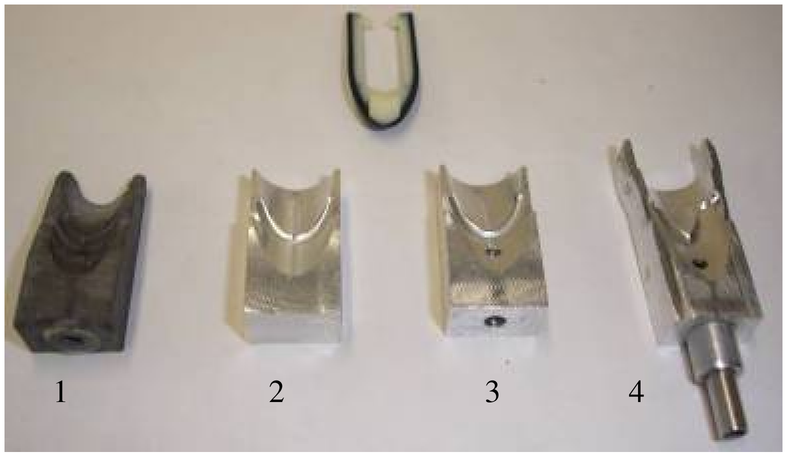

Figure 30: Evolution of the Grip Block

The original molded piece can be seen on the far left of the figure (block #1), with more recent generations being depicted to the right, with a grip shown for reference. The final version of the grip block can be seen on the far right. The protrusion on block #4 is the nipple used to attach the grip block to the vacuum source that holds the grip in place through a hole on the face of the block (also shown). While the shape does not perfectly match that of a grip, it is close enough to hold it consistently in place during testing, while also allowing for more robust and flexible experimentation. Not shown are two tapped holes on the back of the grip block that are used to attach the grip block to the slots in the "T-shaped" piece on the mechanism.

The next problem discovered by the prototyping process involved the rollers themselves. With the previous problems solved, more minor problems began to present themselves. One in particular was that of compliance in the rollers. It was noticed that when a grip failed to snap into place for insertion, the rollers would jam the grip against the side of the handle and prevent further motion of the mechanism. It became obvious that this would be very problematic in a large scale assembly machine with no built in intelligence. This particular issue would not only cause scrapped grips and handles, could potentially damage the entire mechanism itself if forced to continue its stroke without a place to relieve the stress caused by a misplaced grip. As this was obviously unacceptable, various adaptations and materials were used to find an ideal roller size, material and shape. The criteria for the new rollers are shown in Table 1.

Item	Criteria
1	The material must be rigid enough to transmit force to the grip during leg insertion
2	The material must be flexible enough to avoid catastrophic failure of the mechanism
3	The roller must not noticeably wear when rolling on its shaft
4	The roller must not mark, scuff or otherwise damage either the grip or the handle

Table 1: Roller Selection Criteria

Using this list, a material and shape for the grip was chosen after various attempts to create an acceptable roller. The results of this can be seen in Figure 31

Figure 31: Evolution of the Roller

The various rollers shown here represent a fraction of the various roller types tested during the prototyping process. However, the three examples above do show the three main classes of rollers (right to left); solid plastic, plastic with rubber coating, and solid rubber. The roller on the far left most closely resembles the final roller currently on the device prototype.

The next problem that arose during experimentation was the fact that the handle was lifting up out of the nest during the attempts to place the grips in the top slot. It was felt that this was a realistic problem that would also occur in the TGAM machine at the Gillette factory. In order to solve this problem, several concepts were generated, but ultimately only one was built and implemented. This concept merely involved a spring loaded foot that ran through a shaft in the chassis of the roller concept. The spring was chosen to have a high enough constant (k) to hold the handle down, while not damaging the product in the process. The device can be seen in Figure 32, as shown by the arrow.

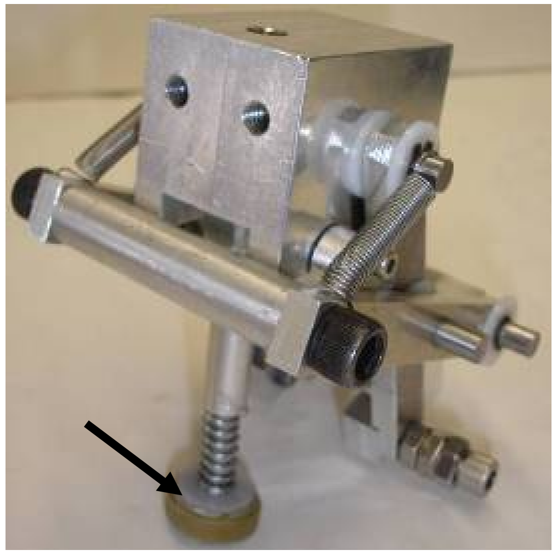

Figure 32: Spring Loaded Securing Foot

As is shown in Figure 28, the foot is merely a spring loaded piston running vertically in a drilled hole in the prototype's chassis. Initially, this held the handle down, but also limited the stroke of the device when the spring was fully compressed. This was later solved by simply trimming the spring enough to allow for both the natural stroke of the machine to be reached and to reduce pressure on the handle during the grip loading process. The hole seen in the top of the device is the path through which the piston passes. For now, nothing holds the piston from falling out when the device is on the test fixture in order to allow for quicker disassembly during testing, but eventually the piston will be secured from the top to keep it from falling out of the chassis and keep it out of the way of retrieving a grip from the feed mechanism. It should be noted that this will only be necessary for the insertion of the top grip; for the other two grips, a force down on the grip slot does not result in any tipping of the handles in the nest.

Once the rest of these key issues were solved, one final obstacle remained: the timing of the mechanism during the transition from loading the grip to inserting the legs. This problem only became apparent through testing and presented a significant challenge to the validity of this concept as a solution to the design goals. The issue was that the rollers were hitting the grip too soon, thereby preventing the grip from completely loading and as a result either the grips broke or failed to insert. Several design changes were necessary to iterate to an even remotely viable solution. First, the links that held the rollers themselves were lengthened in order to delay their contact with the grip, while still allowing the rollers to force leg insertion at the end of their stroke. The original link and its updated configuration can be seen in Figure 33. The newer link is on the left and the old on the right.

Figure 33: New and Old Roller Links

This change had only moderate success, as the movement of the rollers was limited by the stroke of the mechanism. Additionally, the unpredictable nature of the elastomeric grips themselves made consistency in loading the grips an issue. With this in mind, further modifications were necessary to ensure proper loading and insertion. This was partially achieved through further modification of the grip holder block, as shown in its final iteration in Figure 30 (grip number 4). The added length and altered geometry of the block forced the grip into place during loading, as opposed to depending on snap-in and also protected the top of the grip's legs from being struck by the rollers too early. Ultimately, however, a linkage solution would be ideal for adjusting the time of the mechanism, however this would require completely remanufacturing the prototype and the necessary time was not available to accomplish this within the scope of the project.

Finally, some minor issues arose during the iterative design process, mostly centering on extraneous parts of the mechanism that did not add to the functionality of the device. Primary among these were a set of eccentric stops mounted on the side of the chassis that were intended to artificially limit the stroke of the mechanism. These were eliminated from the design because the full stroke of the device was necessary to achieve loading and insertion in one step and the presence of the eccentrics actually hindered this process. Very few other changes deserve individual mention, but various pieces of attachment hardware and other assorted bits were added to and removed from the design over the course of the project.

While the final version of the prototype is not a production level version of the product, it certainly proves the validity of the concept. In addition, the prototype provides a robust and useful testing platform for improving the design and bringing it to a point where it could be effectively implemented in a high volume assembly operation with mostly minor adjustments. Some of these changes can be found in the Recommendations section of this report, while other possibilities certainly exist. Figure 34 shows a picture of the final assembly of the roller concept as mounted on the test fixture.

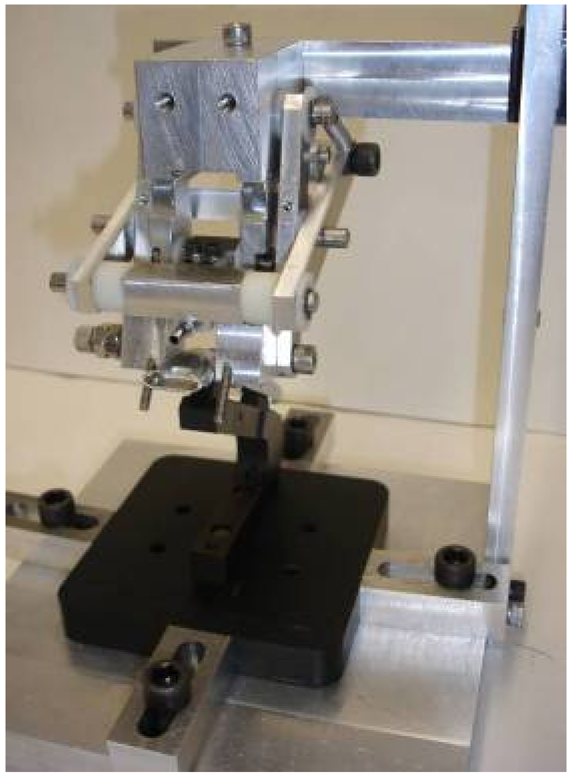

Figure 34: Roller Concept; Final Assembly

Test Fixture

In addition to building prototypes of the concepts themselves in order to test their validity, a robust fixture was needed to allow for legitimate experimentation. This test fixture had to meet several requirements, which are listed in Table 2.

Item	Criteria
1	Must provide a robust testing base for the prototyped concepts
2	Must eliminate extraneous variables, such as handle location and grip path fluctuations while still allowing for fine tuning during experimentation.
3	Must replicate the motion of the critical sections of the cam profile

4	Must allow for rapid and simple adjustments to prototype and fixture
5	Must allow for rapid and simple placement and removal of prototype from fixture

Table 2: Test Fixture Criteria

In order to provide a robust platform for testing and experimentation, aluminum stock was chosen for the material that would make up the test fixture. A heavy base was required to anchor the fixture in place and serve as a stable foundation for the rest of the fixture. To achieve this, an aluminum block of approximate dimensions 8 inches by 8 inches by 1 inch was milled out of a piece of stock. Several tapped holes were drilled into one side of this block at ½ inch intervals in order to mount the rest of the test fixture as can be seen in Figure 35. Additionally, four holes were drilled into the top surface of this block at the center of each side, approximately one inch in from the edge. These holes were also tapped and were used to mount clamping blocks to the base that would hold the test palette (provided by Gillette) in place. These clamping blocks were slotted to allow for easy relocation of the palette, while still holding it firmly in place when locked down with bolts.

After the base was completed, an aluminum riser was created that would hold a vertical slide bearing. This riser provided an attachment point for a set of springs as well, whose function was to return the concept to its original position after each test. The slide-bearing on this riser provided consistent, unidirectional vertical motion, while preventing deflection and binding during the testing of the two concepts. It was determined that a purely vertical path was an accurate representation of the actual TGAM machine through the analysis of the cam profiles provided by Gillette. During loading and insertion, the shape of the cam imparts linear motion onto the end effectors, leaving the more complex motion for different periods of the cycle.

Finally, a horizontal arm was mounted to this vertical slide and attached to the springs on the riser. This arm then had two holes drilled in the other end to hold the prototype roughly over the center of the base for testing. A picture of this test fixture can be seen in Figure 35, with labels for each of the components.

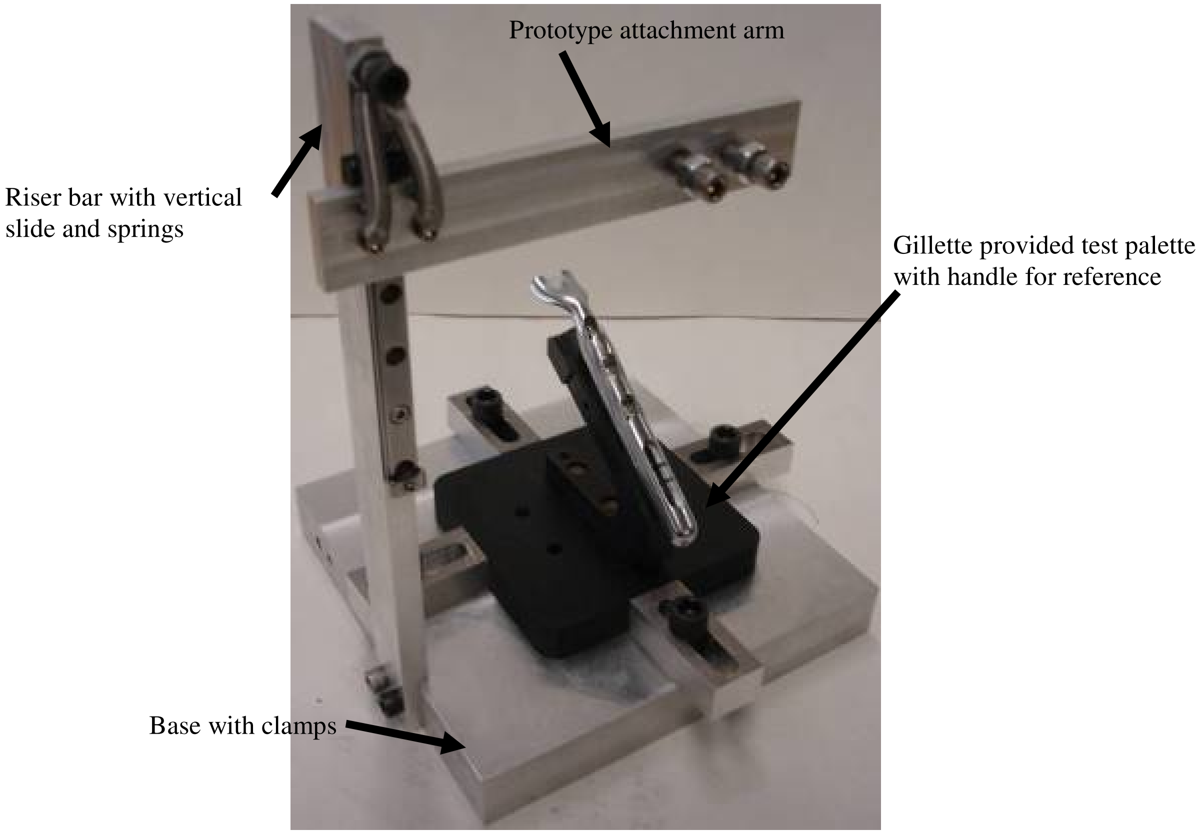

Figure 35: Test Fixture

As a final note, scaled and dimensioned drawings of every part in the prototypes and test fixture are provided on the CD included with this report, along with the physical prototypes and test fixture.

Testing Procedure

In order to determine the effectiveness of each concept, a standardized test procedure was developed. To prevent any bias from entering in the testing, the exact same procedure was used for the testing of each concept, using the same metrics for success. In order to be considered a successful insertion, a list of conditions was developed. These are displayed Table 3.

Item	Criteria
1	Grip must be fully inserted and unable to be removed without pushing legs out from back
2	Both grip and handle must be completely undamaged and unmarked
3	Insertion must be completed in one smooth downward stroke
4	Entire insertion must be completed in .5 seconds or less

Table 3: Successful Grip Insertion Criteria

The actual testing procedure was simple. First, the prototype was mounted onto the test fixture and the handle nest aligned directly below. Second, the vacuum pump hose was attached to the nipple and turned on. Next, a grip (always a brand new one) was carefully loaded into the grip block, with special care taken to ensure that it was straight and that the front of the grip was flush with the surface of the grip block contour. Finally, the prototype was pushed down in a swift, controlled, smooth motion and released immediately after grip insertion.

Upon completion of these steps, the handle was inspected to determine the effectiveness of the test. If every item on the success criteria table was met, then the experiment was repeated under the same circumstances to ensure repeatability.

Results

As new iterations of the Roller and Pincher designs were developed, testing was performed to gauge the effectiveness of the various changes. For the most part, the success or failure of each iteration became immediately apparent due to the concepts' ability or inability to meet the successful insertion criteria developed in the Methodology section.

Roller Concept

As was discussed in the methodology section, it first appeared that the Roller concept was going to be more effective than the Pincher concept. Encouraged by the initial success achieved with the Roller Mechanism, multiple versions of almost every component (grip block, rollers, etc) were created in the hopes that minor changes would affect a positive result. The primary issue with this concept was that the rollers were contacting the legs of the grip too soon. This interference was causing the legs to contact the handle and twist (and occasionally break), preventing proper alignment and successful insertion. This issue is displayed in Figure 36.

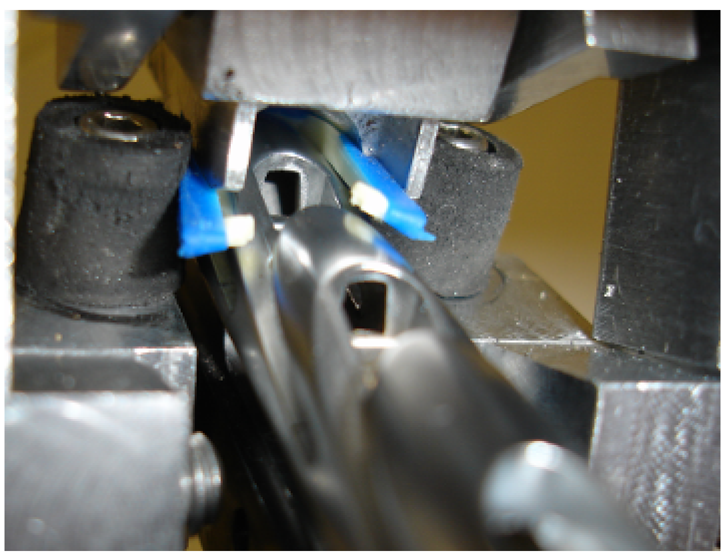

Figure 36: Roller Interference

This timing issue was identified early in the testing process and each modification was an attempt to address it.

Some of the modifications which were performed included changing the linkage pivots, changing roller size and material, and modifying the grip block. Each iteration seemed to improve the function of the mechanism; however a consistently successful version was never achieved. Ultimately, it became apparent that in order to implement this concept successfully, a sweeping overhaul of the design would be necessary.

The fundamental problem facing this concept was that the motion of the grip block and the motion of the rollers were too closely coupled. In order to fully address this problem, the roller links would have to be altered to include a dwell period during which the grip would be aligned before the roller motion was initiated. However, this modification would require a massive redesign effort and was ultimately not attempted.

Pincher Concept

Initially, the Pincher concept seemed to pose problems even more intimidating than those of the Roller concept. In fact, the initial design did not function at all in the manner as the mechanism created in CAD indicated it would. Fortunately, the changes made to this mechanism proved to dramatically enhance its function. Ultimately, the final changes to the prototype discussed in the Methodology section (especially the flared cam and aluminum foot changes) yielded a very successful working prototype.

Early versions of this mechanism experienced the same problem that was experienced with the Roller concept: the timing. Much like the rollers were interfering with grip location, the ends of the pinchers were striking the grip too soon and preventing proper alignment. Fortunately, thanks to the ability to drastically change the motion of the pinchers by simply changing the shape of the cam, it was possible to rectify the problem without a massive overhaul. The fourth iteration of the cam (with the ‘flares’ to move the legs during the over rotation period) was able to move the grips enough to achieve a full insertion without ever interfering with the grip placement.

With the addition of aluminum feet (instead of rubber) to the ends of the pincher legs, the mechanism proved to be extremely effective at achieving the criteria for successful insertion. In fact, this iteration has yet to fail to insert a grip when properly adjusted.

Conclusions and Recommendations

Based on the testing and analysis performed during the course of this project, there are two possible recommended actions: implementation of the Pincher Concept, or modification of the current loading mechanism. Both possibilities would achieve the ultimate goal of the project: to reduce the scrap rate of the process.

Recommendation #1: Pincher Mechanism Implementation

Based on the results discussed in the previous section, it was determined that the Pincher Concept was the superior of the two solutions. Not only was the Pincher Concept more successful at inserting grips, but it proved to have greater flexibility while also being more robust. The Roller Concept, while initially showing greater promise, proved to be fundamentally flawed to the point where a severe redesign would be necessary to create a successful prototype. Ultimately, the most significant issue was the fact that the critical motions of the Pincher Concept were not as inextricably linked as they were in the Roller. Because of the additional flexibility inherent to the Pincher Concept, this timing issue could be (and was) overcome, whereas the Roller Concept provided much less margin for error. With further testing by Gillette engineers to determine the effective life of the tool and to flush out failure modes related to industrial usage, it is believed that the Pincher Concept could realistically not only replace, but improve the current assembly process.

If the Pincher Concept is to be implemented, there are some initial changes that would be necessary in order to create a more realistic manufacturing station, as opposed to a proof-of-concept prototype. First, instead of springs to return the mechanism to its original position, pneumatic cylinders would provide more controlled and robust motion over the life of the tool. The tendency of springs to wear over time causes their properties to change, which can lead to fluctuations in the performance of the tool. Additionally, the fatigue life of springs in very low when considered in light of the number of cycles that the TGAM goes through, especially at the hooks. This same concept would also be applied to Y-directional compliance. In order to provide for tolerances in the palettes' placement, a certain amount of pliability must exist in the mechanism to ensure that neither the assembly station nor the product is damaged. Again, pneumatic cylinders (which already exist in great quantity on the machine) provide long-term, controlled force dampening.

In order to achieve controlled, synced and repeatable pinching motions, a new cam piece for the Pincher Concept is suggested. This new cam provides the exact timing and motion necessary to successfully insert a grip, while also exhibiting superior wear characteristics. By providing the proper geometry, the cam profile allows for a set of rolling followers as opposed to the edge-on-surface rubbing utilized in the prototype. This new cam shape is shown in Figure 37.

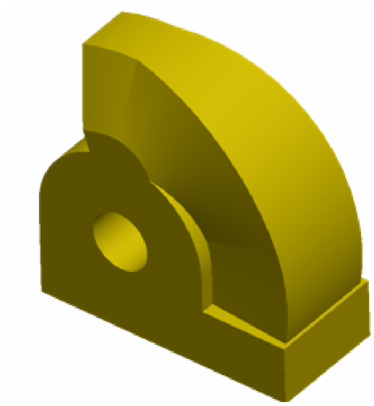

Figure 37: Proposed Cam Block

Additionally, this new cam can be seen in Figure 38 as it would be assembled in the overall Pincher Concept. This image also shows the rollers that would follow the cam surface (depicted by arrows).

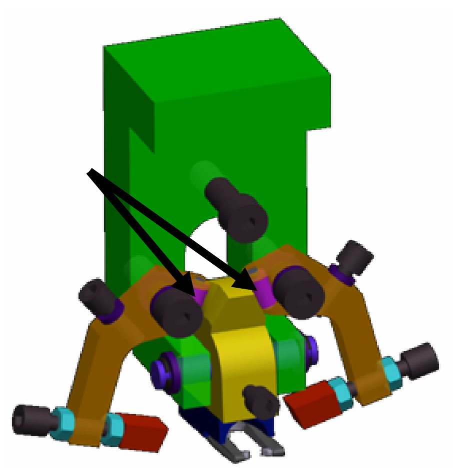

Figure 38: Proposed Assembly with Cam and Rollers

A final assembly of this concept on the existing TGAM can be found in Appendix D.

Recommendation #2: Modification to Current Loading Mechanism

Another option that could be taken to improve the current process is to modify the current loading mechanism slightly to provide a better initial fit into the handle. With the current process, the grip is initially only partially loaded onto the handle. While the front part of the grip is relatively firmly seated, the legs are not lined up with the slots, and as a result it is very easy for the grip to pop off, especially considering the acceleration during the nest indexing motions. In fact, the grip can easily be shaken off with a minimal effort. However, when the grip is rotated enough such that the legs are fully lined up with the slot, the grip is much harder to unseat and it is highly unlikely to become displaced while moving to the leg insertion mechanism. When the grip was loaded in this way, even vigorous shaking could not dislodge it. These two different leg positions are shown in Figure 39 and Figure 40.

Figure 39: Partially Loaded Grip

Figure 40: Fully Loaded Grip

The obvious solution to reducing the scrap rate of the current process would be to have the grip loading mechanism achieve a full loading as opposed to the current partial one. This could be done by making a relatively simple change to the current mechanism: altering the component which holds the grip. This component, shown in Figure 41, could be redesigned to improve the scrap rate.

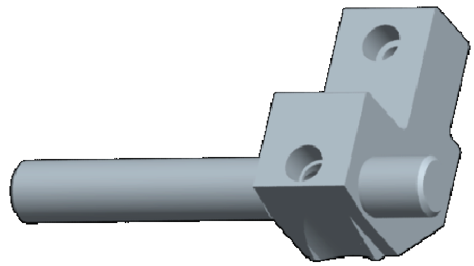

Figure 41: Current Grip Holding Component

The only part of this component which needs to be altered is the area directly contacting the grip. Through experimentation, a grip block shape was developed which can fully load the grip in one smooth motion (this shape is the same as is employed in the Pincher mechanism). This grip block shape could be imposed onto this component. If done, the final version of the component would be as displayed in Figure 42.

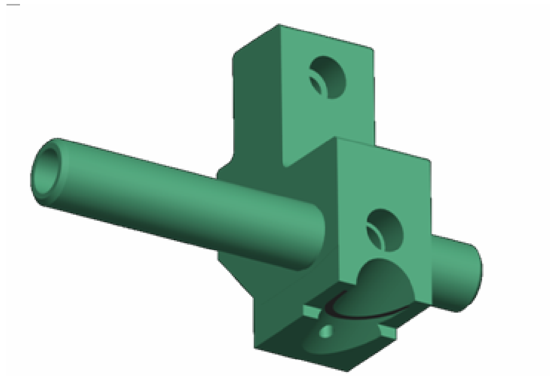

Figure 42: Modified Grip Holder Component

The advantages of this option are that it would be a simple, quick, and cost effective solution to the current high scrap rate issue. However, it would not truly reduce the number of steps in the process unless it was effective enough to eliminate the need for the inspection station.

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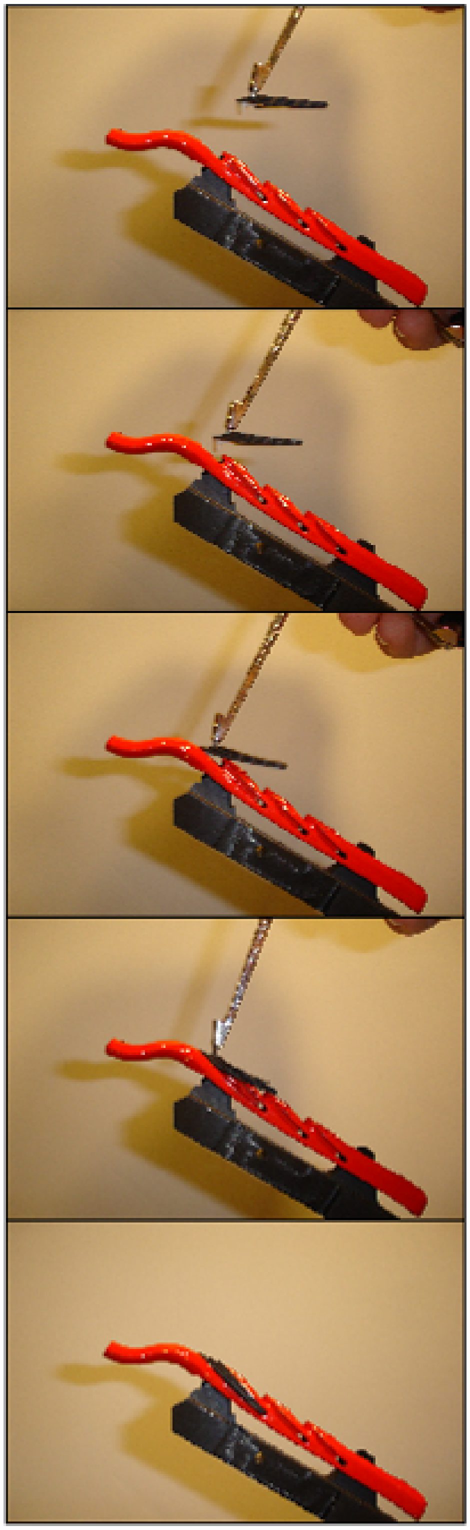
Appendix A: Experimentation



As the figures to the left show, some minor experimentation was done to test the various ways that the grip can be loaded and inserted into a Mach3 handle. In addition to revealing the various angles and approach paths that the grip can take before loading, this test showed two positions that the grip must pass through in order to be properly loaded into the handle. These positions can be used in conjunction with the feed rail pickup point to generate a linkage system and coupler path to load the grip using SYMECH.

Figure 43: Photographic Motion Analysis

Appendix B: 3D Model

The following figures show the 3D CAD model generated from the 2D drawing from Gillette and also provide a comparison to pictures of a TGAM machine in Gillette's Boston facility. Figure 44 shows a profile view of the load sub-assembly as it exists in the overall model, while Figure 45 shows an isometric view of the same.

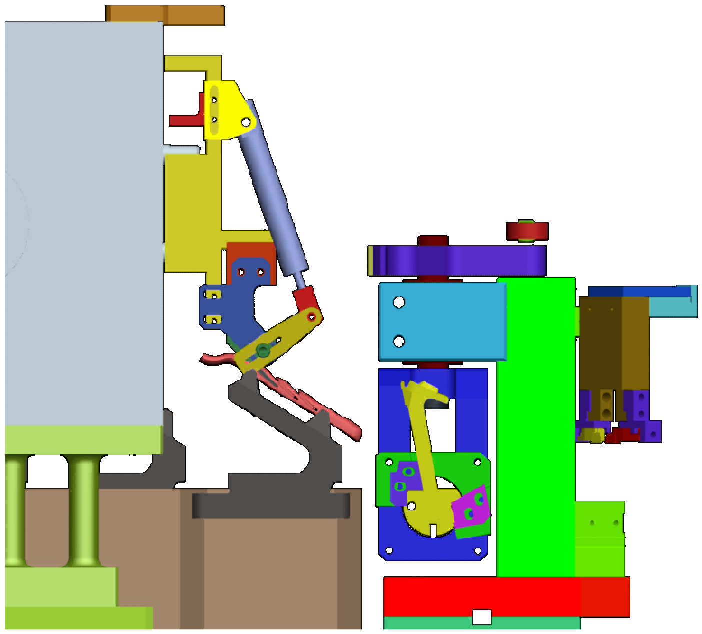


Figure 44: Load Sub-Assembly – profile

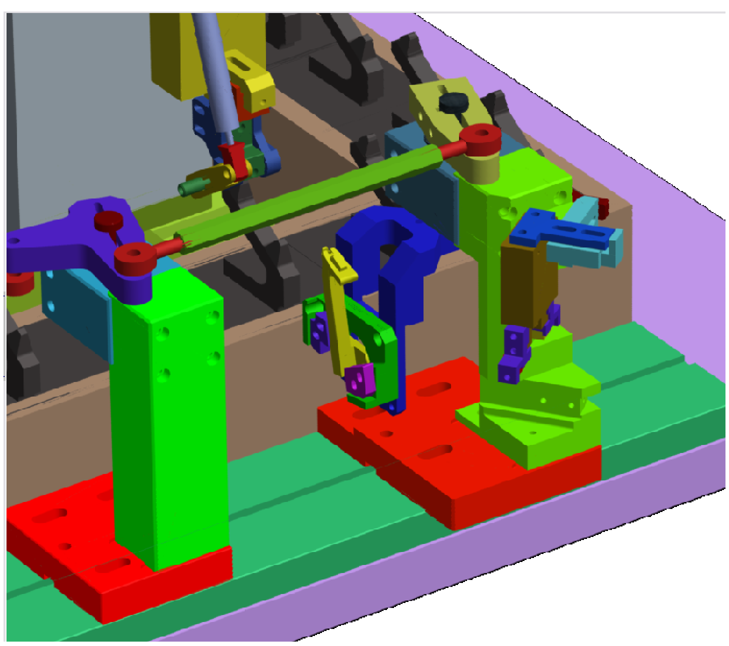


Figure 45: Load Sub-Assembly – isometric

Figure 46 and Figure 47 show a comparison between an actual TGAM machine (looking at the load assembly) and the 3D model generated with the AutoCAD drawings. Although the model and picture are slightly out of phase in the cycle, all of the essential parts are present and properly placed.

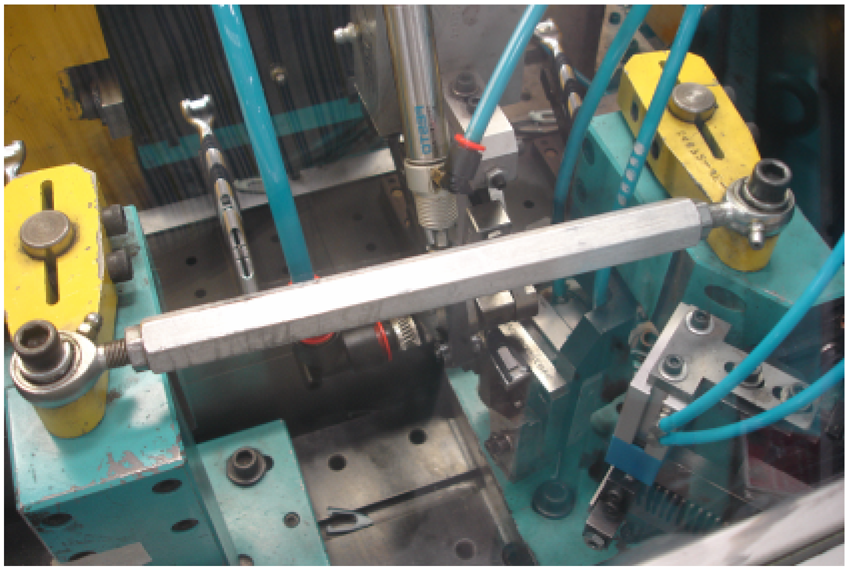


Figure 46: Model Comparison - picture

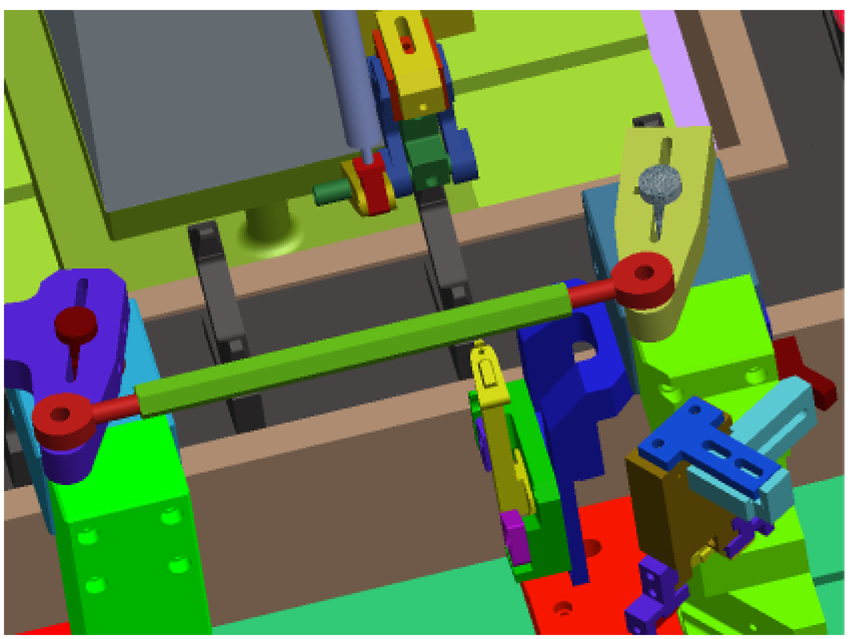


Figure 47: Model Comparison – model

Figure 48 shows a rear view of the insert mechanism, giving a clearer view of the articulating parts the do the actual work of inserting the legs into the handle.

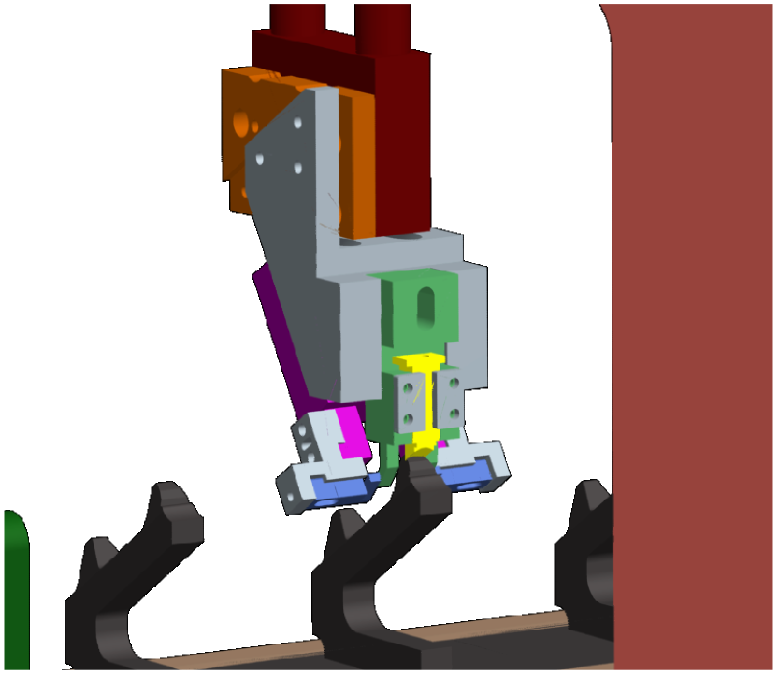


Figure 48: Insert station – rear

Finally, Figure 49 shows an overall assembly combining all of the sub-assemblies and showing some model palettes on the indexing track.

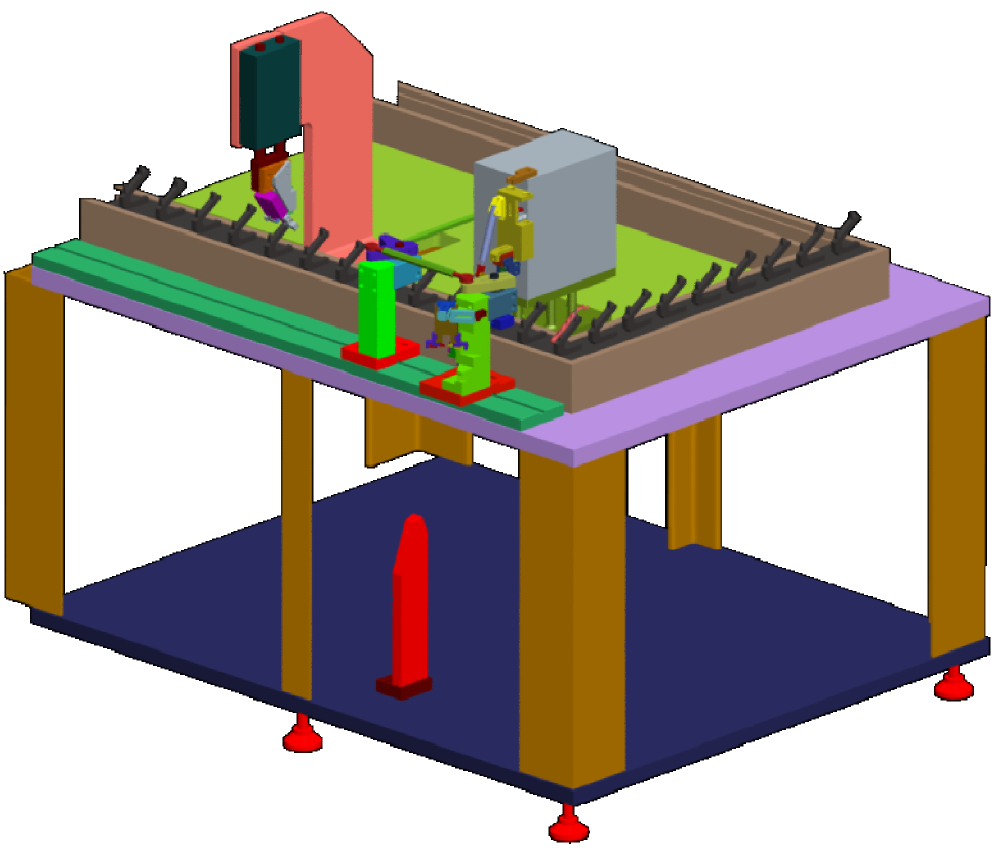


Figure 49: Overall Assembly

Appendix C: Grip Locator Concepts

This section will cover concepts to accomplish the task of moving the grip from the rail un-loader mechanism to the appropriate slot on the handle. This mechanism must smoothly and consistently place the grip within a reasonable tolerance. These concepts were generated while keeping in mind that the actual device which holds the grip and inserts it into the handle is yet undetermined. As such, any concept will be modifiable so that various grip holding devices can be implemented.

Dyad-powered Linkage

This concept would replace the current mechanism which utilizes the Stelron box to create the necessary motion. Using SYMECH, a coupler curve was generated which would move the grip from the pickup point to where it must be located to be inserted into the handle. After experimenting with various linkage combinations, the following linkage solution was created. A cam would be generated to move connector rod A back and forth in the directions shown. The linkage is created such that only a small translation of A is required to produce the required motion of linkage B. Due to the fact that the linkage would be cam driven this design would have the advantage of being purely mechanical and having a relatively smooth operation. Additionally, it would always be in perfect time with the rest of the machine because it would only move when the drive train rotates. Some potential disadvantages of this solution are the relatively high number of linkages and the fact that implementing this idea would require almost a complete overhaul of the current machine. This concept is shown in Figure 50.

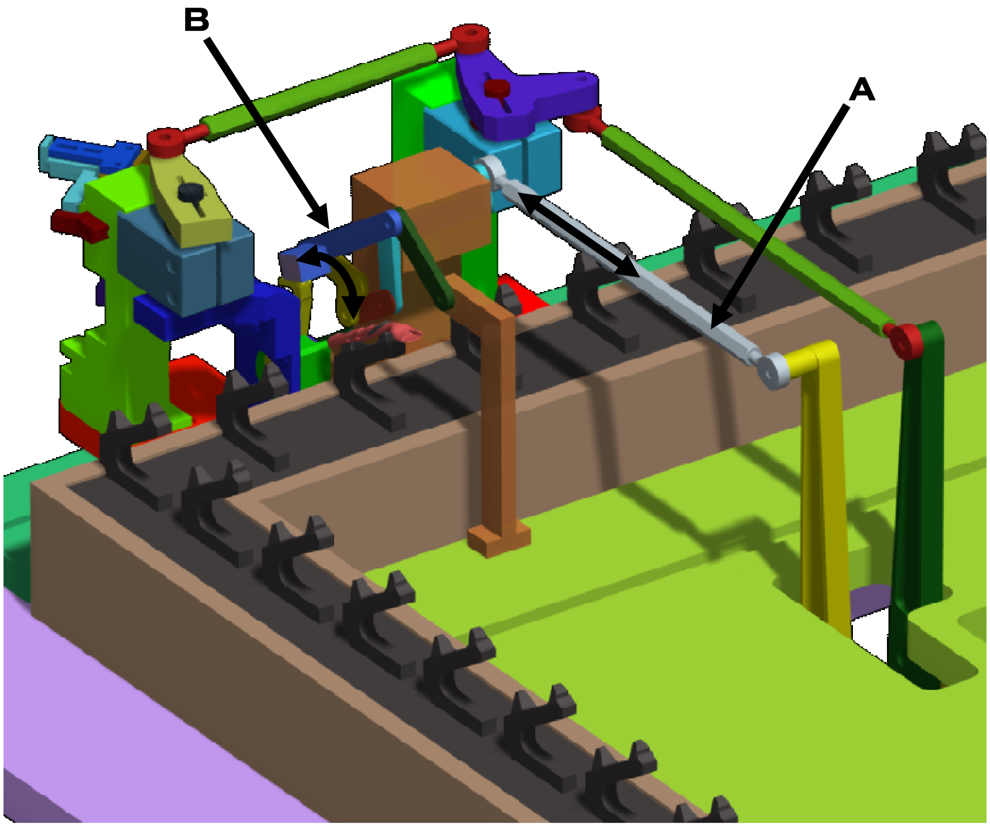


Figure 50: Dyad-Powered Linkage Concept

Pulley-powered Linkage

Much like the previous concept, this idea utilizes the same four bar coupler curve. Instead of being driven by a dyad system however, this concept uses a pulley configuration to input the correct crank rotation. To do this, a belt or chain is wrapped around the crank of the four bar linkage (B) and then looped around a larger wheel (A). This larger wheel is in turn rotated as shown by a cam-follower setup. Because of the larger diameter, it is possible to gain the large output angle of the crank while inputting a relatively small rotation on the wheel. This design has the advantage of being purely mechanical and always in time with the machine. Disadvantages include possible slip and wear of the belt or chain, as well as requiring a significant overhaul of the machine. This concept is displayed in Figure 51.

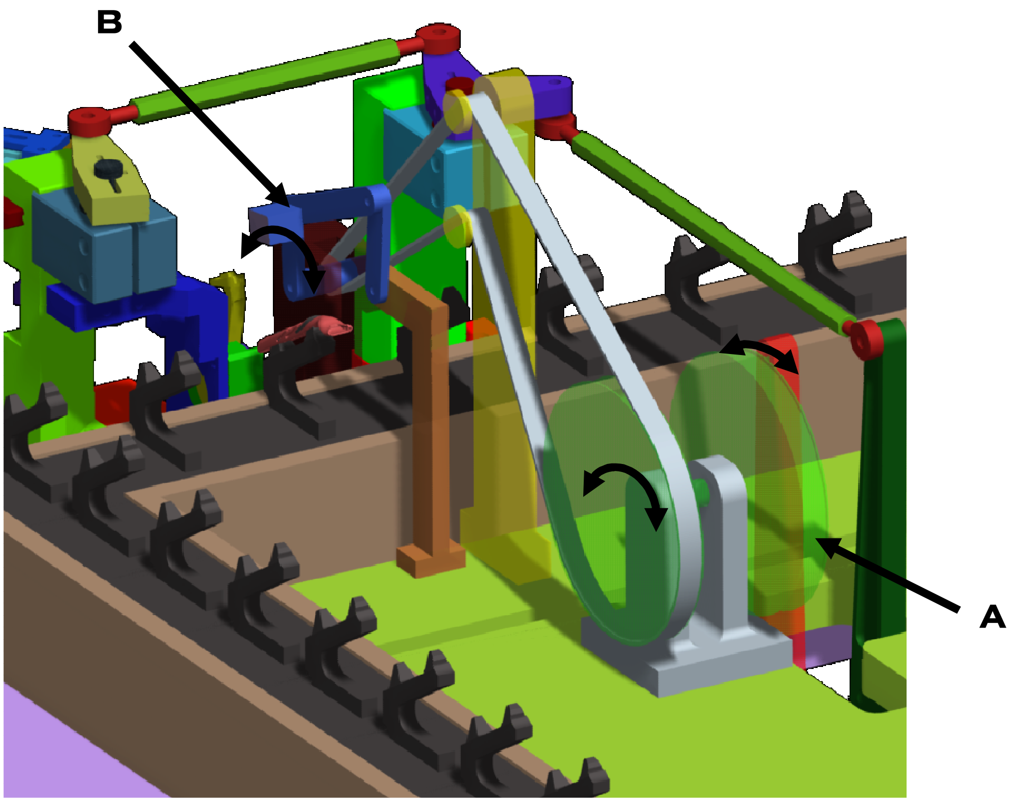


Figure 51: Pulley-Powered Linkage Concept

Servo-powered Linkage

Much like the previous concepts, this mechanism would use the same coupler curve generated by SYMECH. However, instead of being powered by a mechanical system, the crank would be powered by a servo motor (A). This motor would directly turn the crank shaft and would be programmed to input the required angle at the required velocity. The advantage of this system is that it would be relatively simple, consistent, precise, and not necessarily require a massive rework of the current machine. However, a large disadvantage is that because it is not purely mechanical and powered by the drive shaft, it is possible to fall out of time with the rest of the machine and would require inputting servo controls into the system. Additionally, employees would have to be trained in the operation of the servo controls which would also have to be installed. This concept is displayed in Figure 52.

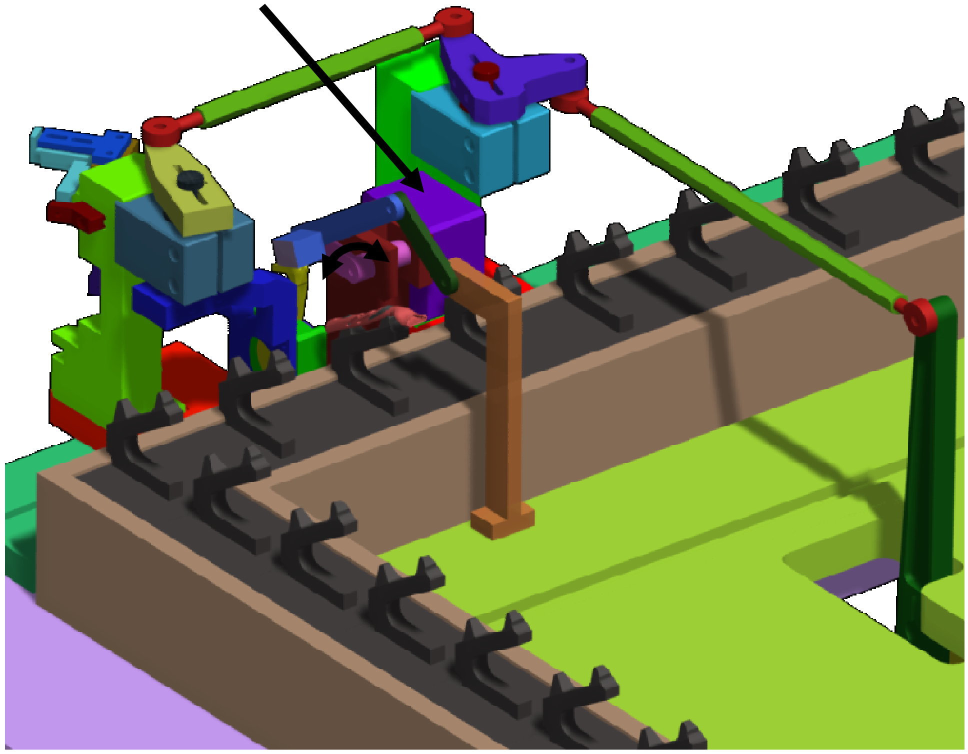


Figure 52: Servo-Powered Linkage Concept

Appendix D: Final Proposed Assembly

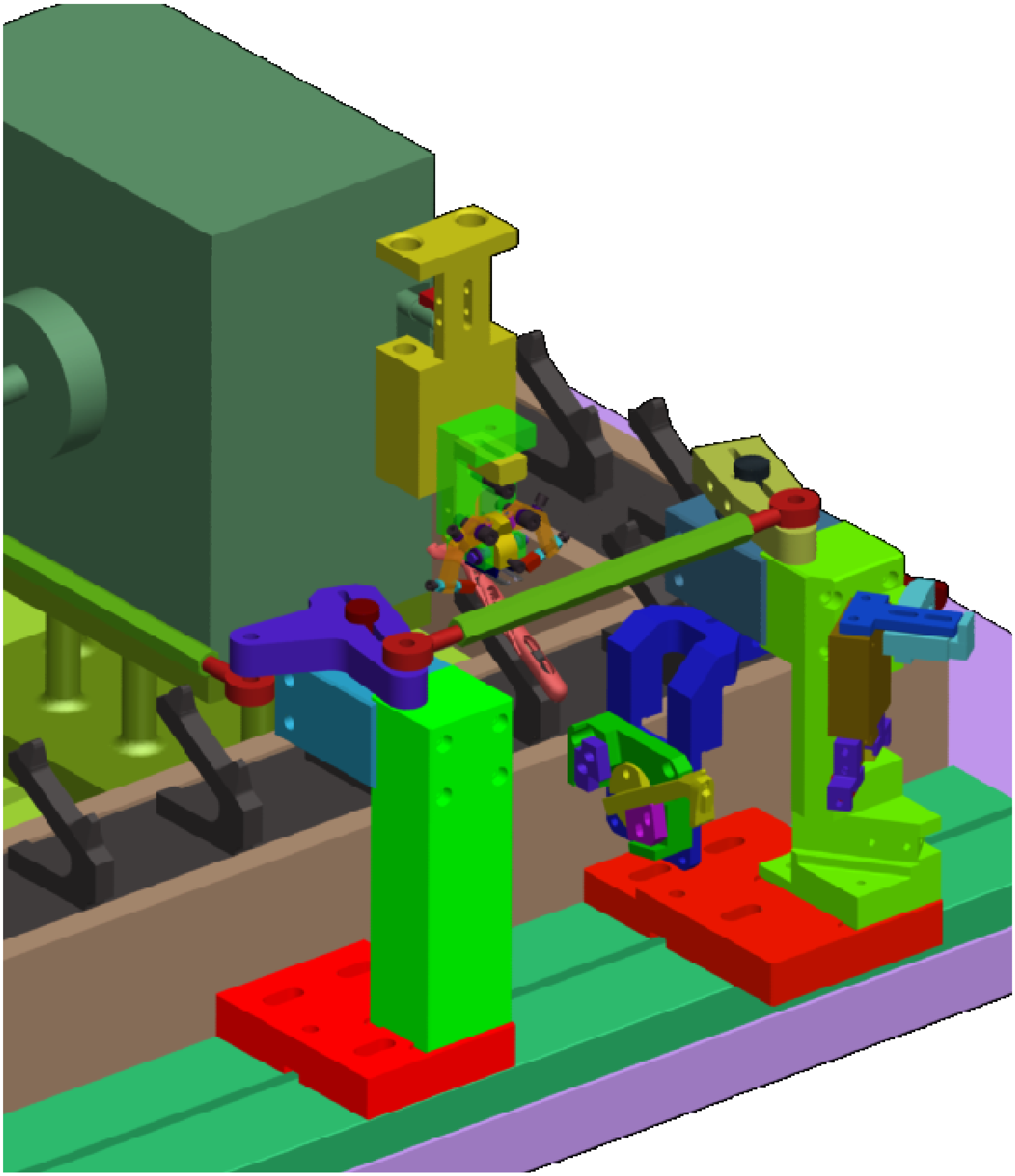


Figure 53: Proposed Assembly; View 1

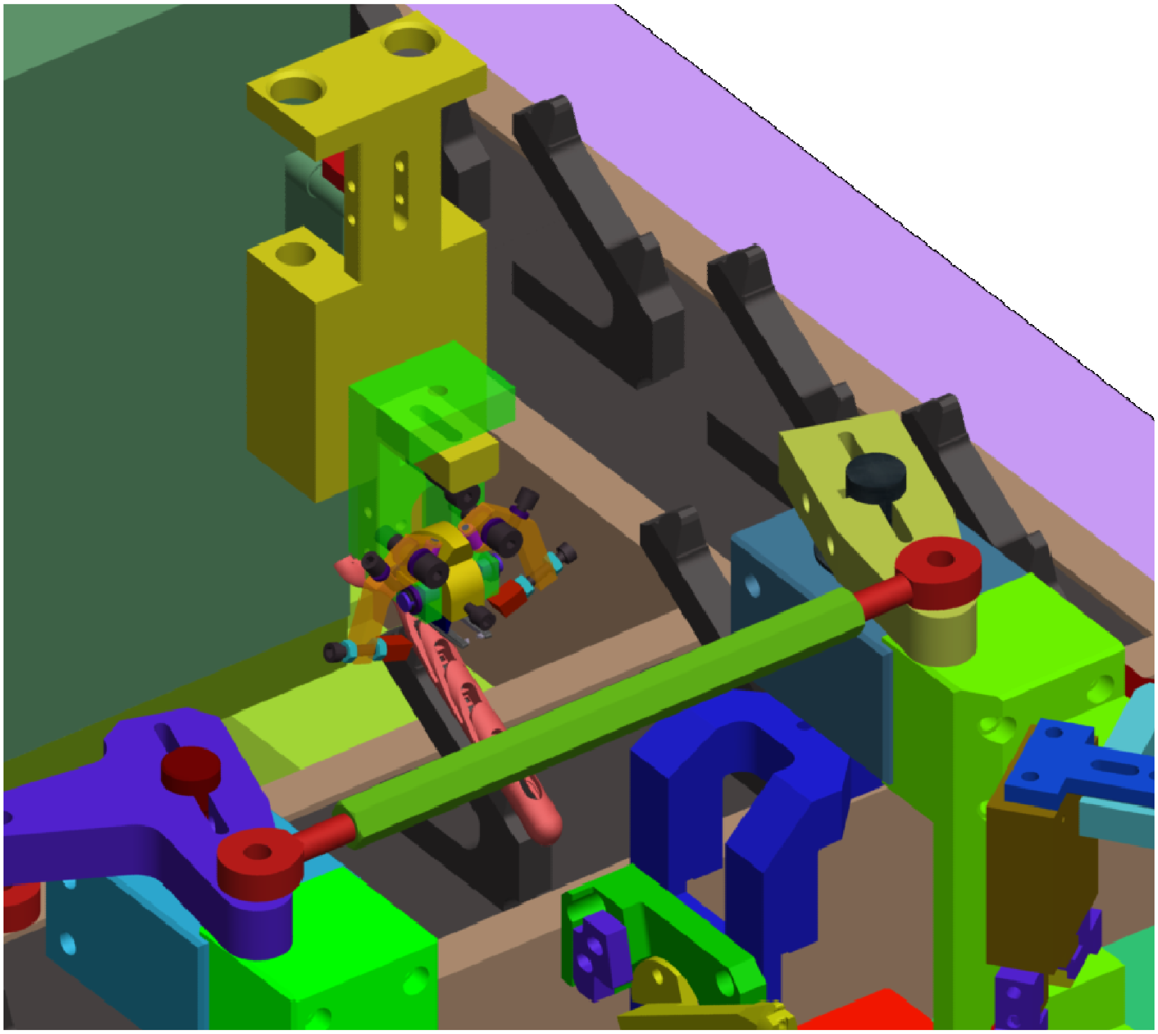


Figure 54: Final Proposed Assembly; View 2

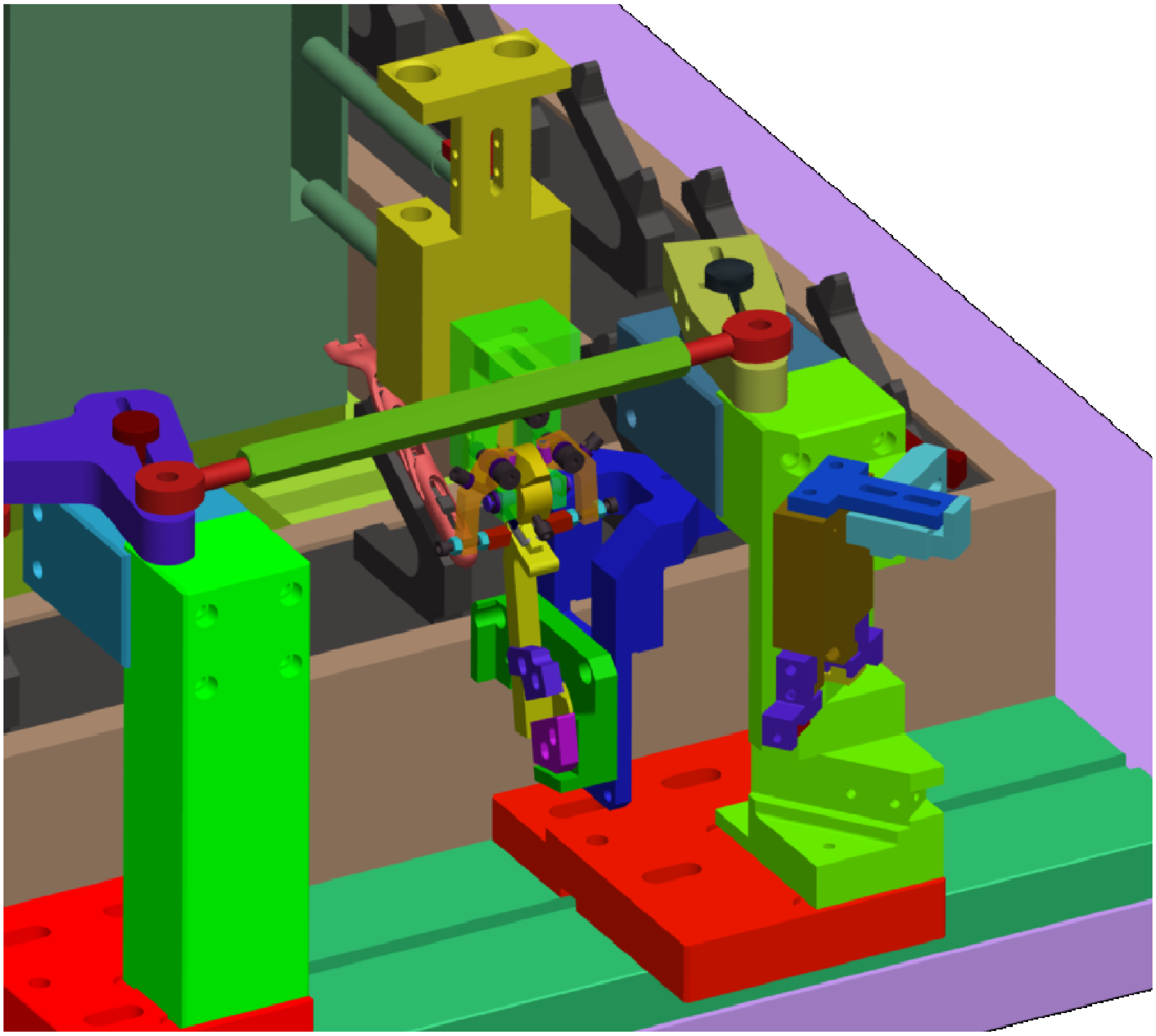


Figure 55: Final Proposed Assembly; View 3

Appendix E: Vacuum Calculations

Calculation of Vacuum Pressure Needed to Hold a Grip

Known Data

$mass := 0.34635gm$	$mass = 3.463\times 10^{-4}\ kg$	mass of grip
$h := 0.422in$	$h = 0.011m$	approximate height of usable surface area on grip
$w := 0.321in$	$w = 8.153\times 10^{-3}\ m$	approximate width of usable surface area on grip
$sa := \frac{2}{3}\cdot h\cdot w$	$sa = 5.826\times 10^{-5}\ m^2$ $sa = 0.09in^2$	approximate surface area of grip
$weight := mass\cdot g$	$weight = 3.397\times 10^{-3}\ N$	weight of grip

Calculations

Force per unit area $P := \frac{weight}{sa}$ $P = 58.296Pa$ $P = 8.455\times 10^{-3}\ psi$

Number of holes $n := 1 .. 4$

Hole diameter $d := \frac{1}{32}, \frac{1}{16} .. \frac{1}{4}$

Total area available $A_t(n, d) := n\cdot\pi\cdot\left(\frac{d\cdot in}{2}\right)^2$

With one hole of 1/32" diameter, a vacuum pressure of approximately 2 psi would be necessary to hold the grip in place (given a factor of safety of 2). This calculation was later proven to be accurate during testing, although a more powerful vacuum was later used for convenience.