Pop Nozzle Assembly Jig

Lean On ME

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Abstract

Team Lean on ME produced a jig which assists in the assembly of a pop nozzle and consistently tightens it to allow no leaks. The nozzle is being assembled by employees of SW Resources in Parkersburg, West Virginia. SW Resources was contracted by Pepsi Cola to produce 4.5 million pop nozzles, provided by DuPont, within a year. Team Lean on ME developed an assembly jig within SW Resources' requirements and specifications. This report explains the design decisions that were made and how they were implemented. The results of the project came to be an assembly jig consisting of a base containing two holes for the insertion and assembly of parts, a Velcro attachment on the jig's bottom to the working surface, and a T-handle ratcheting torque wrench with a custom socket adapter.

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1.0 Introduction

1.1 Project Scope

The scope of this project is to provide an assistive technology to a customer with a disability allowing them to either improve the functionality of an existing task or perform a task previously impossible to them because of their disability. The purpose of team Lean on ME will be to design, manufacture, and provide a safe, reliable, efficient, and reproducible solution to the customer. The criteria for a successful project will include meeting cost requirements, providing the product in a timely fashion enabling it to be implemented, meeting all OSHA safety guidelines, and all other customer requirements which will be further described in Section 2.0.

For the project to be deemed successful a working prototype must be delivered by April 1st. After the customer receives the prototype feedback must be gathered and used to generate design refinements. After the prototype is refined a final, production ready, product must be constructed and delivered for continued use.

The project will be entered into the National Institute of the Severely Handicapped (NISH) competition. NISH is a non-profit organization that works to create employment opportunities for people with disabilities. The competition is designed to encourage creative uses of technology to eliminate barriers that prevent people with disabilities from entering or advancing in the workplace (NISH).

1.2 Customer

The customer for this project will be SW Resources located in Parkersburg, West Virginia. SW Resources' mission statement is "Our mission is to provide vocational services, employment and other opportunities for individuals who have disabilities enabling them to achieve their full potential" (SW Mission Statement). SW is a non-profit organization that provides unique services to the business community by employing people with disabilities. SW performs work for both large corporations and local business but always aims to increase the ability for people with disabilities to be valuable to the community and themselves. The work that is performed is generally the repetition of a physical task including stuffing envelopes, assembling, packaging, counting and bagging small parts, and labeling.

1.3 Manufacturing Task

1.3.1 Description

The task that was selected for this project is the assembly of a pop fountain nozzle. SW Resources needs to be able to provide 30,000 finished assemblies per day in 2009. The step of the assembly that this project focuses on contains four unique pieces. Figure 1.1 shows the shaft, the spring, the plug, and the outer casing. Figure 1.2 shows the fit of the four parts in the assembly. The white base that can be seen in Figure 1.2 is the current method for the assembly; it consists of just a base and all of the assembly needs to be performed by hand.

Figure 1.1: Four Unique Parts.

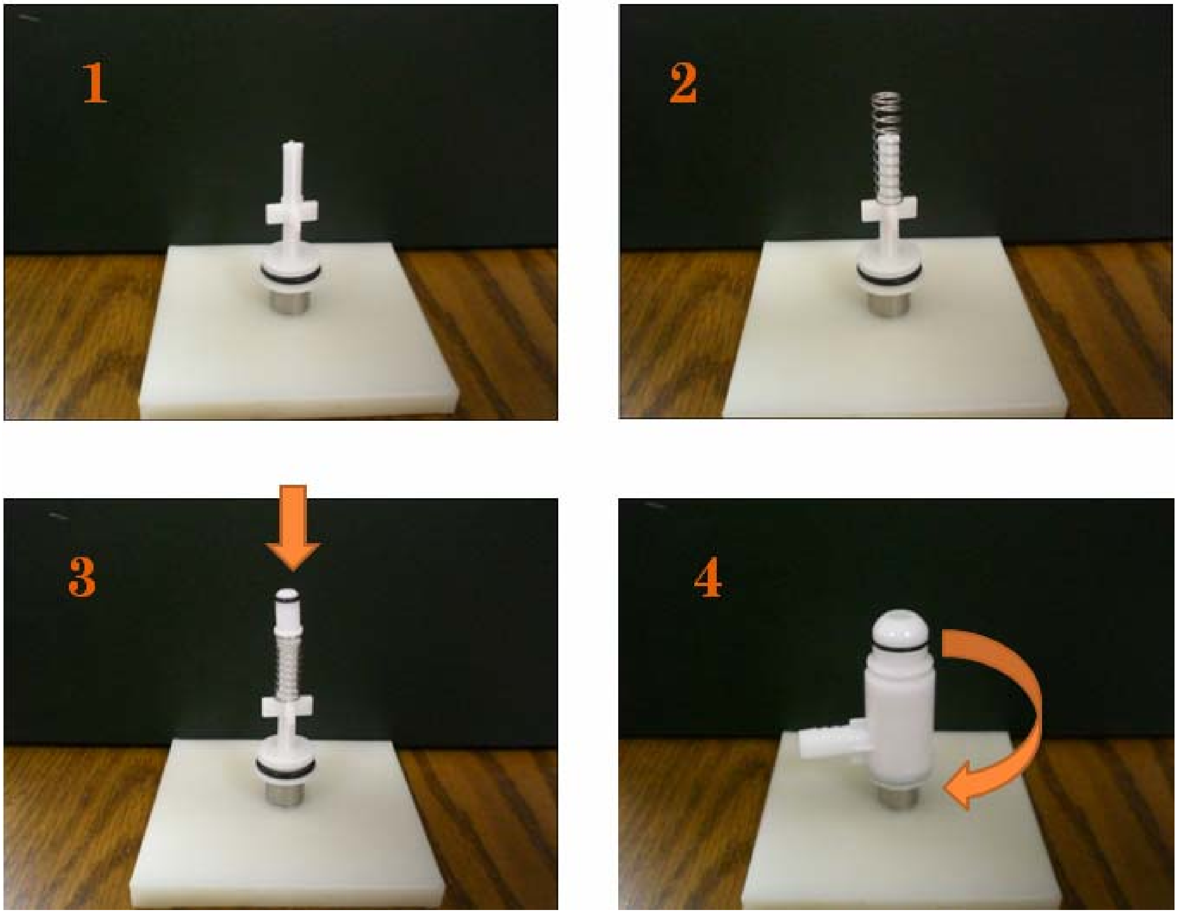

Figure 1.2: Four step assembly.

1.3.2 Problems

There are several problems that need to be addressed in the design of the assembly jig. The individuals performing this task, between 15 and 30 people, have a range of disabilities. These disabilities can lead to limited dexterity (problems handling the small parts), inability to determine when to stop turning (the part can fail if not sealed or over tightened), and inability to meet the desired production rate.

1.4 Proposed Solution

Team Lean on ME has decided to design and construct an assembly jig to assist with the assembly of the pop nozzle. This jig will enable the disabled employees of SW Resources to perform the associated task. These employees will be able to perform this task with greater ease and at a rate that will produce 30,000 per day. Section 4.0 will detail all of the concepts that were generated as feasible solutions to this problem and Section 5.0 will document the selection of a final concept.

1.5 Initial Needs Statement

The customer needs a device to assist with the assembly of the pop nozzle. Assistance can come in the form of increased efficiency or the number of people who can perform the task. The customer needs to produce 30,000 pop nozzles per day.

2.0 Customer Needs Assessment and Revised Needs Statement

Team Lean on ME contacted many customers such as SW Resources, Ohio Rehabilitation Services Commission, ATCO Workshop, Hocking Valley Industries, and First Capital Enterprises. The only organization to return our calls was SW Resources. So it was easy to choose an employer because SW Resources was the only company that showed enthusiasm in working with team Lean on ME.

SW Resources is a non-profit organization that is located in Parkersburg, West Virginia. This organization provides services to businesses in the Mid-Ohio Valley region. They employ 145 client employees with a wide range of disabilities. Their disabilities can range from minor to severe physical and mental imparities. Employees have the opportunity to make meaningful contributions to the community. Some of the tasks they perform include stuffing envelopes, assembling, packaging, counting and bagging small parts, and labeling.

Following the decision to choose SW Resources as a customer, visits were made to the organization through our contact, Kellie Conrad. Kellie Conrad is the Operations Manager at SW Resources and has been with them for twenty years. During the meeting with Kellie, she showed the team a few projects that she had in mind. The projects consisted of the following: counting and bagging small parts such as nuts, bolts, and washers; stuffing advertisements into magazines; organizing mail stamps and brail beads into their proper placement; and a new task of assembling a pop nozzle for Pepsi soft drink dispensers.

After viewing and discussing all of the project ideas that were presented to the team, the project that was chosen by team Lean on ME was to assist in the assembly of the pop nozzle for Pepsi soft drink dispensers. The reason for choosing this specific project was that Kellie informed the team that it was going to be the most important project that they were receiving. The project requires very high productivity and efficiency within a given period of time.

The team developed an approach for generating the customer needs list. The first strategy was to interview Kellie Conrad. Questions were asked pertaining to the normal operation of SW Resources, their plan for the specific task, sizes of facilities, flexibility with new strategies, types of disabilities, ideal outcome for working with us, and other similar questions. After interviewing Kellie the team took a firsthand look at the facility that would be provided. No equipment was set up but it was discussed where all of the assembly tasks would take place. While in the facility there was an impromptu interview with another SW employee who provided insight when asked a similar set of questions as were posed to Kellie. After the information gathering session was complete the team met and discussed all of the customer needs that had been brought to our attention throughout the course of the day. The initial customer needs list obtained from interviews and observations are shown in Table 2.1.

Table 2.1: Initial Customer Needs List Obtained from Interviews and Observations

Cost
Space/Size
Quality of Nozzle
Productivity
Safety
Ease of Use
Manufacturability
Durability
Working on tables with limited space
Thread o-rings resulting in no leak
Assembled nozzle cannot be damaged
Assembled nozzle must follow all sanitation codes
High Productivity
Safe
No pinch points
User friendly
No personal protective equipment required
Easy to reproduce
Small footprint
Easy Maintenance
< $200 per jig
4.5 million assemblies in a year

2.1 Evaluation and Weighting of Customer Needs

After discussing the customer needs, team Lean on ME ranked the information from least important to most important. Weighting of the customer needs is an important part of the decision making process. The team determined that the following were the applicable needs: cost, space and size, quality of nozzle, productivity, safety, ease of use, manufacturability, and durability.

Table 2.2 shows the weighting factors that were generated for each need selected above. The weights were generated from 1 being least important to 3 being the most important. Cost received a 1 based on the fact that the price wasn't really a factor in producing a design. The general price range to spend on a jig, according to Kellie, was "a couple of hundred dollars," and a specific jig for this assembly won't be that expensive. The space and size was also weighted a 1 knowing that the size of the table will be 3 ft x 8 ft. A table that size is very large compared to the scale of parts that are used in the assembly process. The quality of the nozzle is given a 3 because DuPont expressed the need for the parts to be assembled correctly with no damage. There is no room for error in this category. Productivity received a 3 as well because there are supposed to be 4.5 million of these pop nozzles made within a year. Safety was rated a 3 because the safety of the employees is the most important factor of all. Everyone that operates the jig should not be harmed in any way whether it is a pinch point or a shape edge on the fixture. Ease of use was weighted a 2 due to the fact that there is no certainty of how severe the mental or physical disability will be of the employee. Therefore it is unknown how simple the device must be to achieve the desired results. This rating can be revised after the workforce is more defined. Manufacturability was rated a 2 because the team wants the jig to have low maintenance and the ability to be easily reproduced by SW Resources. Durability was given a 2 based on the idea it should be able to withstand a drop off the table or dropped out of an employee's hand, which will be no more than 4 ft. This should not be a problem but may require some design decisions to select the correct material to make the jig.

Table 2.2: Customer Needs List (With Weighting Factors)

1. Cost (1)
    1.1 < $200 per jig
2. Space/Size (1)
    2.1 small footprint
    2.2 working on tables with limited space
3. Quality of nozzle (3)
    3.1 thread o-rings resulting in no leaks
    3.2 assembled nozzle cannot be damaged
    3.3 assembled nozzle must follow all sanitation codes
4. Productivity (3)
    4.1 high productivity
    4.2 4.5 million assemblies in a year
5. Safety (3)
    5.1 no pinch points
    5.2 no personal protective equipment required
6. Ease of Use (2)
    6.1 user friendly
7. Manufacturability (2)
    7.1 easy to reproduce
8. Durability (2)
    8.1 easy maintenance

2.2 Revised Needs Statement

SW Resources needs a device to enable workers with limited dexterity and mental capability to be able to perform the assembly of a pop nozzle which includes four unique pieces: a shaft, a spring, a plug, and an outer casing, at a rate of 30,000 assemblies per day.

3.0 Benchmarking, Standards, and Target Specifications

3.1 Benchmarking

A torque mechanism is needed for the assembly of the pop nozzle. DuPont required SW Resources to maintain good quality so that the o-rings are fully sealed, and the threads are not broken by being over tightened. Using a torque mechanism will stop any flaws in the tightening part of the assembly so it was decided that a pre-existing torquing mechanism should be used. Since the mechanism of the jig that is used to tighten the nozzle is pre-existing and the remainder of the jig is going to be machined and designed from scratch to meet specifications and requirements, the benchmarking will focus on the torquing mechanism. There are two types of torquing tools which include a torque wrench and a torque screwdriver. Figures 3.1 and 3.2 show two types of torque wrench that are adjustable to the required torque needed which will be calculated within a range from 5in-lbs to 50in-lbs. Figures 3.3 and 3.4 show two types of torque screwdrivers that can be adjusted to the required torque that will later be measured.

Figure 3.1 shows a micro adjusting torque wrench from Flexible Assembly Systems Incorporated. The price range is from $100-$300 dollars. The wrench holds a torque of 20-150 in-lbs. It also has a socket head drive of 3/8 in.

> "To set the desired torque simply pull down the lock ring and turn the handle to the desired torque setting. Once set the positive locking device locks in the torques setting. When the desired torque is reached an impulse can be felt through the handle along with an audible click." (Flexible Assembly Systems Inc.)

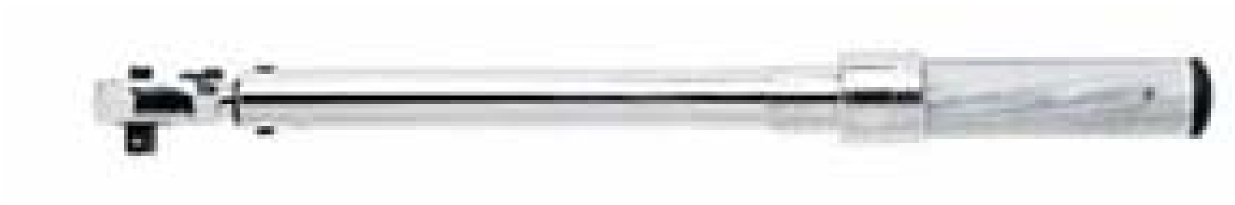

Figure 3.1: Micro Adjusting Torque Wrench (Flexible Assembly Systems Inc.)

Figure 3.2 also shows a torque wrench from Flexible Assembly Systems Incorporated. The price ranges from $99.00 – $207.00 depending on the style of torque wrench purchased. The torque wrenches hold a torque range of 5 - 108 in-lb. It has a shank size J.

> “CDI Pre-Set torque wrenches are designed for use on production lines and other applications where a specific torque is required for repetitive operations. The design, fabrication and materials used have been developed in coordination with major manufacturers in actual production use.” (Flexible Assembly Systems Inc.)

Figure 3.2: 5T-I Pre-Set Torque Wrench (Flexible Assembly Systems Inc.)

Figure 3.3 shows the 401 SM torque screwdriver from Flexible Assembly Systems Incorporated. The price is in the range of $100 - $200. The torque screwdriver holds a torque range of 5 – 40 in-lbs.

> “True to tradition of offering only the best in high precision tools, CDI presents its line of torque screwdrivers. The unique cam-over torque limiting design eliminates over application of force, thereby reducing damages, rejects in rework costs. The durable and accurate torque screwdrivers are user friendly design with a comfortable shape and nonslip grip. There are two styles available micro-adjustable and pre-set torque screwdrivers.” (Flexible Assembly Systems Inc.)

Figure 3.3: 401 SM Torque Screwdriver (Flexible Assembly Systems Inc.)

Figure 3.4 shows a torque screwdriver from Delta Regis Tools Inc. The price is in the range of $68 - $160. The torque screwdriver holds a torque range of 2 – 36 in-lbs. It has a drive of 1/4 inch.

> “Many fastener connections in service and industry need to be tightened to a precise torque to guarantee secure fastening. The adjustable torque screwdrivers can be adjusted in fine increments allowing for controlled tightening. A graduated scale on the shaft of the screwdriver indicates the selected torque setting.” (Electronic Screwdrivers and Torque Measurement - Delta Regis)

Figure 3.4: Preset Torque Screwdriver, in-line, 11-29 in-lbs (Electronic Screwdrivers and Torque Measurement - Delta Regis)

After reviewing all the tools that use a torque mechanism, a comparison of their size, weight, cost, and ease of use were compiled into Table 3.1. The features within table 3.1 are rated based on a relative scale comparison where a rating of 1 is the most acceptable to our criteria. This is to help quantify and make a decision of what the most suitable wrench would be to incorporate as part of the jig.

Table 3.1: Benchmarking of Products

Feature	Micro-Adjust Torque Wrench	5T-I Pre-Set Torque Wrench	401 SM Torque Screwdriver	Pre-set Torque Screwdriver
Size	2	2	1	1
Weight	2	2	1	1
Cost	3	2	2	2
Ease of Use	2	1	3	3

3.2 Standards

Health standards have to be followed for the pop nozzle assembly because consumable syrup will flow through the nozzle. Most of the standards that apply to the project are sanitation codes for food and drinks. Standards from the FDA state that equipment and utensils that come into contact with the food surface must be sanitary (US Department of Health and Human Services). The FDA also states how equipment must be sanitized and these codes must be followed by SW Resources when cleaning the equipment.

The materials that will be in contact with the pop nozzle may not allow the migration of harmful substances or impart colors, odors, or tastes to food. The material must also be durable, corrosion-resistant, and non-absorbent. The material must also require resistance of pitting, chipping, crazing, scratching, scoring, distortion, and decomposition from the pop nozzle (US Department of Health and Human Services). Team Lean on ME has a goal of designing a fixture that can be made with the materials that follow the FDA guidelines, and can also be sanitized by SW Resources.

3.3 Target Specifications, Constraints and Design Criteria

Customer requirements were researched so that the target specifications could be determined. The manufacturing price of the jig must be less than $200 to meet the cost requirement given by Kellie Conrad. To fulfill the space/size requirements, target and goal specifications were determined. Target specifications would be the minimum that must be met, and the goal would be an achievable specification that would have optimum results. The target for size was to fit 2 jigs per 3 ft. x 8 ft. table, but the goal was to fit 4 jigs on the same size table. Another specification was that 30,000 pop nozzles must be assembled per day. With 25-30 people working on the pop nozzles, the target specification is to complete the assembly at an average of 25 seconds given an 8 hour working day while assuming the minimum of 25 workers. The goal specification is to assemble the pop nozzle in an average of 20 seconds which will produce about 36,000 assemblies per work day. The durability factor of the jig was also investigated. The target specification states the jig must resist a 4 foot drop without damaging its functional aspects. Table 3.3 organizes the quantitative values of these specifications.

Table 3.3: Specifications

Specification	Target Value	Goal Value
Size	2 jigs/table	4 jigs/table
Weight	< 10 lbs	< 5 lbs
Cost	< \$200	< \$200
Production	25 sec/assembly 30,000 assemblies/day	20 sec/assembly 36,000 assemblies/day

Safety and quality are the most important aspects to the design of the assembly jig. Safety was a major part of the design because team Lean on ME feels that the safety of the user is crucial. Safety concerns would include no pinch points, no sharp edges, and that no additional personal protective equipment is required for the user. The quality aspects of the assembly jig include that the thread o-ring allows no leaks, the assembled nozzle cannot be damaged, and that the assembled nozzle must follow sanitation codes. In order to prevent leaking, an optimal value to preset the torque wrench will be measured. Presetting a torque wrench to this optimal value will ensure that the nozzles are properly tightened within specification. In addition, the optimal preset value of torque for the wrench will prevent damage to the nozzle by ensuring that it cannot be over tightened to the point of fracture. The material chosen for the jig will be such that it will follow the sanitation codes previously listed. The jig will also be designed to allow it to be cleaned every morning before the work day in a standard industrial dishwasher.

4.0 Concept Generation

4.1 Problem Clarification

The jig is intended to reduce and possibly eliminate the difficulty of the steps required in their current method which was previously illustrated in Figure 1.2. The first difficulty is in aligning the smaller pieces of the assembly with the base and with each other. It is difficult for some users to place the shaft onto the adapter of the base. In addition, it is difficult to align and fit the plug over the spring onto the shaft. A common occurrence for this step is that the plug and spring will pop off of the shaft and sometimes onto the floor where it is considered to be unsanitary. Another difficulty is in screwing the outer casing over and on to the sub assembly. SW Resources current method requires the user to guess when the nozzle is properly tightened. This guess work could possibly lead to under tightening or even over tightening the assembly. During SW Resources initial production of the assemblies, about 400,000 pop nozzle assemblies were recalled due to an issue regarding over tightening. In addition, this step has been known to cause hand cramps in the area between the thumb and index finger after repetitive tightening.

After examining the current pop nozzle assembly process, the required functions and inputs were identified so that the concept generation process could begin. For this assembly process, there are five functions required. The first is that the thread o-ring must be completely sealed so that the pop nozzle does not leak. The second is that the assembled nozzle must not be damaged. The third is that the assembled nozzle must follow all sanitation codes. The fourth is that the assembly jig must withstand a four foot drop without disturbing the ability of the other functions. The final function that the assembly jig must perform is that it must enable a worker to assemble a pop nozzle in less than 25 seconds.

Since the assembly of the pop nozzle will be performed by workers with different disabilities, there were other inputs recognized. The assembly jig must be easy to use, safe for the workers, have no pinch points or sharp edges, and no additional personal protection equipment should be required.

4.2 Patent Searching

For the pop nozzle assembly process a patent search was done regarding assembly jigs, pop nozzles, and threading assembly jigs. The search began by using Google's patent search utility. After searching the terms described above using this utility, nothing that was relevant to the project was found. The search then continued at the United States Patent and Trademark Office website. The same terms were searched for and again nothing relevant was found.

After patent searching for terms relevant to our project, it was concluded that since the pop nozzle assembly jig is such a specific assembly jig, there were no relevant patents that could be found to aid our concept generation.

4.3 Concept Generation

In the design process, team Lean on ME met to brainstorm alternative methods and designs for the assembly process shown in Figure 1.2 of the Introduction section. Several ideas were presented, drawn out, and discussed regarding feasibility. The group found a room in the engineering building with dry erase boards in order to present individual ideas to the whole. Each person presented his idea to the group and explained how it would work; then, the idea was open for discussion. Team members would add input to improve on the initial concept brought up by the individual in order to meet the design's main purpose of assembling a pop nozzle in the quickest and simplest method. After discussion, five concepts were chosen as feasible and were built upon.

The first concept was of a one-step assembly jig shown in Figure 4.1. The design of this jig was somewhat derived from a lemon press. The main components of this design include a lever, two part movable top-mount, rotating track, and a base with an included torque stop. The idea behind this design was to eliminate the need for precision assembly by having mounts for the pieces which would be assembled together by the operation of a single lever.

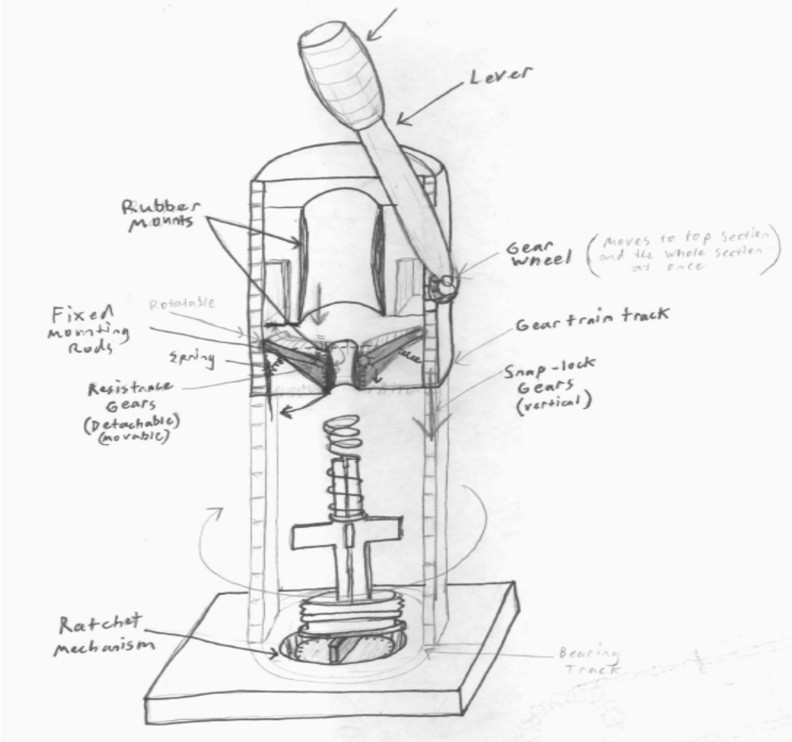

Figure 4.1: Design 1, Concept for a One-Step Assembly Jig

The second concept was designed to produce multiple assemblies in the same jig which is shown in Figure 4.2. The idea was based on a way to avoid using a torque wrench which would ensure proper tightening. In addition to assembling multiple pop nozzles at a time, this concept uses a resistance belt which should begin slipping, thus preventing further tightening, once the pop nozzles were tightened to their proper specification. The inside of the pop nozzle would be assembled in individual cavities of the jig, and then altogether tightened by the rotation of a handle protruding from the side of the jig.

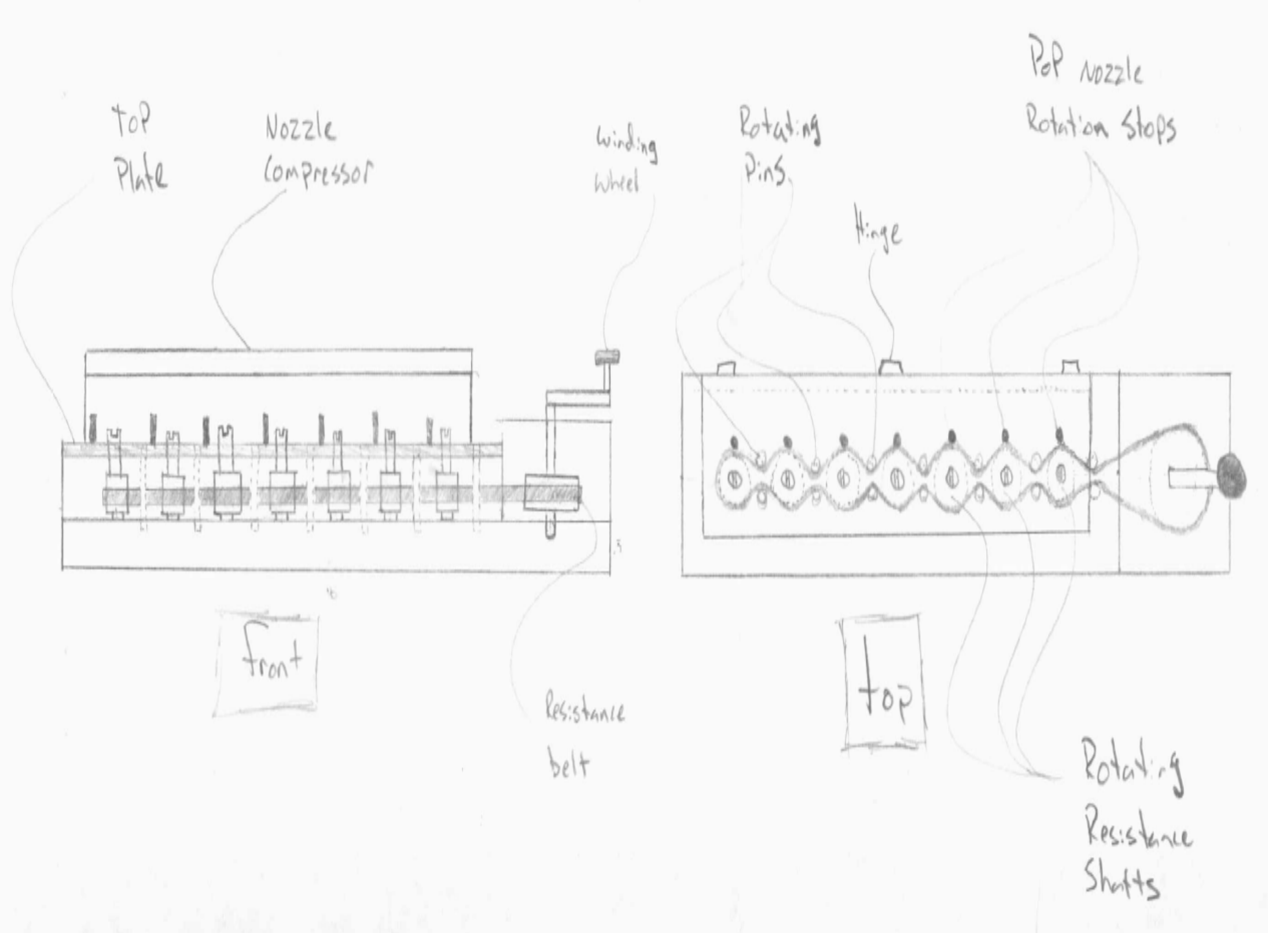

Figure 4.2: Design 2, Concept of a Multi-Assembly Resistance Belt Jig

The third concept was designed to be a three-step simplified plunger process shown in Figure 4.3. The idea behind this concept was to assemble the pop nozzle starting from the outer casing. The outer casing would be inserted into a molded cavity, and then the inner parts would be inserted into and assembled with a plunger mechanism, followed by a torque wrench to tighten the assembly. A key aspect to this concept's method is the thin-sleeve spring casing which would enable proper alignment for the plunging mechanism.

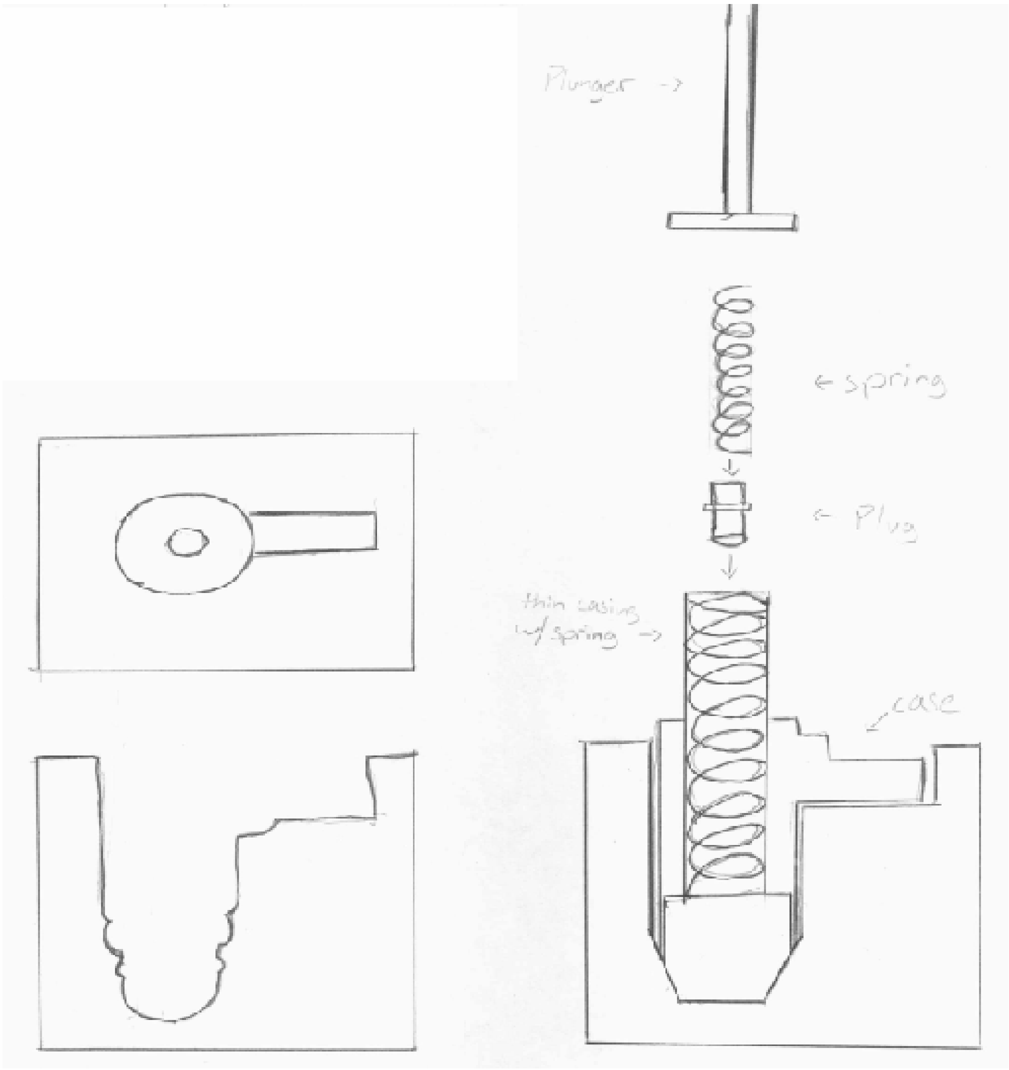

Figure 4.3: Design 3, Concept of a Three-Step Plunger Jig

Shown in Figure 4.4, the fourth design was also based on the idea of assembling the pop nozzle beginning with the outer casing but without a plunging mechanism. This design incorporates a jig with multiple outer-casing cavity molds with a torque wrench to finish the last stage of tightening the assembly together.

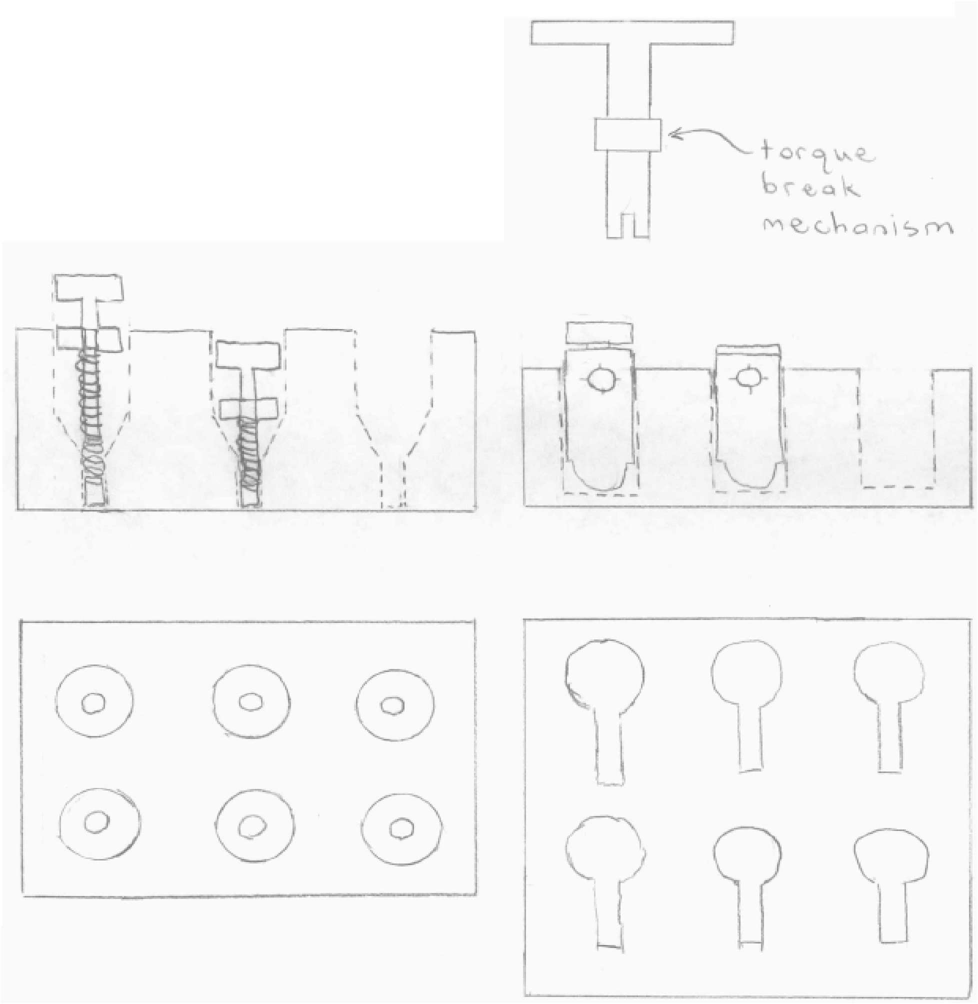

Figure 4.4: Design 4, Concept of a Two-Step Multi-Assembly Jig

The reasoning behind the concept shown in Figure 4.5 was to eliminate any dexterity issues when assembling the pop nozzle. The funnel-like sleeve shown in Figure 4.5 would sit atop the shaft of the assembly in order to guide the spring and plug into position before plunging and tightening of the outer casing. A second stage would be required to screw the outer casing onto the screw. This would most likely be included as a side-by-side structure.

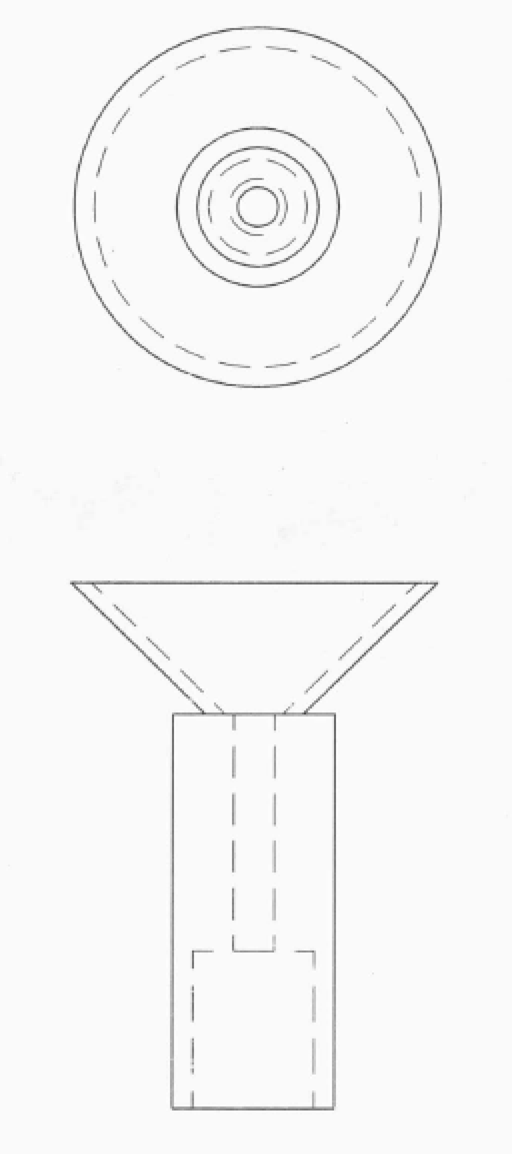

Figure 4.5: Design 5, Concept of a Multi-Stage Assembly Process

4.4 Concept Consideration

There are many design aspects to be considered for each design. The positive aspects of the Design 1 are the one step assembly process, ease for the operator, and the small table area. The negative aspects of the Design 1 are the difficulty in manufacturing and the complicated mechanics. Design 2 has several advantages including requiring no torque break mechanism (reduced cost), completing multiple assemblies at once, and ease of use for the user. Some negative aspects of Design 2 are difficulty of manufacturing and calibration, durability concerns, and its large size. The positive qualities of Design 3 are simplicity of manufacturing, small size, and good durability. Design 3's negative qualities are low productivity and the high dexterity required for use. Design 4 has many advantages which include little risk of injury, good durability, high productivity, and easy manufacturability. The negative aspects of Design 4 are large size and confusion working on multiple assemblies at once. Some positive aspects of Design 5 are ease of manufacturing, good durability, and having two steps in one structure. Design 5's negative aspects are possible low productivity and difficulty adding the second step.

Table 4.1: Concept Advantages/Disadvantages

Design	Advantages	Disadvantages
1	• One-step • Easy Operation • Small Table Footprint	• Difficult to Manufacture • Complicated Mechanics
2	• No Torque Mechanism • Reduced Cost • Multiple Assemblies at Once • Easy to Use	• Difficult to Manufacture • Requires Maintenance for Wear (over time) • Not Very Durable • Large Size
3	• Easy to Manufacture • Small in Size • Durable	• Relatively Low Productivity • Requires Higher Level of Dexterity
4	• Very Low Risk of Injury • Durable • Relatively High Productivity • Easy to Manufacture	• Large Size • Confusion during Multiple Assemblies
5	• Easy to Manufacture • Two Steps in One Structure	• Possibility of Relatively Low Production • Difficulty with Second Step

5.0 Concept Screening and Evaluation

5.1 Data and Calculations for Feasibility and Effectiveness Analysis

Within our project, effectiveness is determined by the design's ability to perform the intended tasks with no damage to the part in a manner that will produce 30,000 completed parts per day. Feasibility is determined by 8 different criteria which include cost, size, quality of the assembled nozzle, productivity, safety, ease of use, manufacturability, and durability. These criteria are shown with their weights in Table 5.1.

5.2 Concept Development, Scoring and Selection

Once the main concepts had been presented and drawn out, a feasibility matrix was used in order to determine which design appeared to be most feasible. Each specification was weighted in order of importance from 1 to 3. Each design was assigned a number from 1 to 5 for each specification: 1 being optimum and 5 being critical in relation to how the designs met the specifications. The weight of the specification was then multiplied by the assigned number for each design and totaled.

The number assigned for each category is the best estimate of the group from careful consideration of each design. The criteria for evaluating the cost included complexity, estimated costs of material, and manufacturing costs. Space was determined by discussing what dimensions each design would need to be to contain the parts of the nozzle and perform the intended function. Quality of the nozzle accounted for the probability that the nozzle would be out of specifications at the conclusion of tightening, for example the difficulty of calibrating Design 2 might lead to more nozzles under or over tightened. Productivity involved examining how many parts could be completed by a single user. Designs with multiple assemblies scored better because more nozzles could be produced. Safety examined possible pinch points in different designs and likelihood of injury occurring. No designs were inherently dangerous but Design 1 is the most complicated and involves lots of moving parts resulting in a higher likelihood of injury occurring. Ease of use was evaluated by considering how much dexterity was necessary to operate the design. Also it focused on if the design could be operated improperly to result in a rejected part. Designs 3, 4, and 5 require more dexterity as well as the possibility of improperly oriented pieces. Manufacturability strictly looked at the reproducibility of the design. More complicated designs scored higher. Durability considered the design's ability to endure a fall or other damage during normal use. Design 2 requires careful calibration resulting in a higher rating. Design 1 requires precision moving parts, also resulting in a higher rating. The other designs are mostly one solid block which would be difficult to damage to the point of decreasing the design's effectiveness.

As shown in Table 5.1, the fourth design totaled the least weighted number meaning that it was the most feasible of the designs according to the required specifications. The group then improved on the fourth design and redesigned it to better meet the specifications. The new concept is labeled as Redesign in Table 5.1. The new concept was then re-evaluated and inserted into the feasibility matrix. It then totaled an even lower weighted number than the old design. Most of the group endorsed this concept and it appears to be where future attention will be directed.

Table 5.1: Feasibility Matrix

	Weight	**Design 1**	**Design 2**	**Design 3**	**Design 4**	**Design 5**	**Redesign**
Cost	**1**	**5**	**4**	**3**	**3**	**3**	**2**
Space/Size	**1**	**2**	**5**	**2**	**3**	**3**	**1**
Quality of Nozzle	**3**	**1**	**3**	**2**	**2**	**2**	**2**
Productivity	**3**	**3**	**1**	**3**	**2**	**4**	**3**
Safety	**3**	**3**	**1**	**2**	**1**	**2**	**1**
Ease of Use	**2**	**1**	**1**	**3**	**3**	**3**	**2**
Manufacturability	**2**	**5**	**5**	**2**	**3**	**3**	**2**
Durability	**2**	**4**	**4**	**1**	**1**	**2**	**1**
Weighted Total	**NA**	**48**	**44**	**38**	**35**	**46**	**31**

Design 4, shown in Figure 4.4, was then redesigned in Figure 5.1 in order to improve upon the original design. The redesign combined the two separate assembly molds into one jig, while using a torque mechanism with a custom machined socket. Positive aspects of this design are the low risk of injury, ease of manufacturing, good durability, and the small size. The negative aspect of the redesign is a possible sacrifice in production from Design 4. Seeking customer feedback on the redesign of the assembly jig will allow us to make even more modifications.

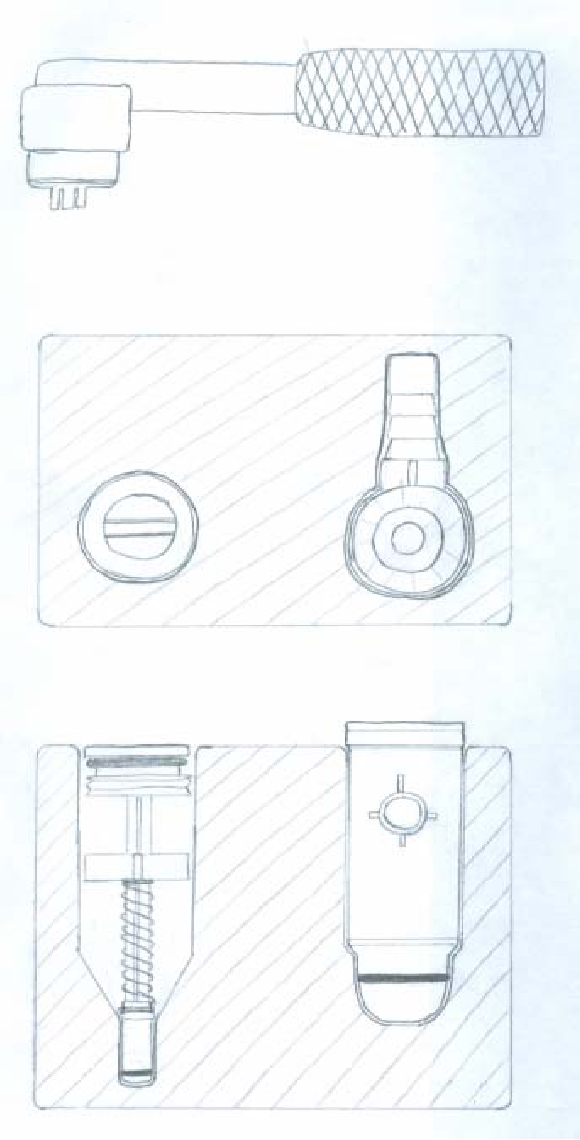

Figure 5.1: Redesigned Concept

5.3 Customer Feedback

In order to get feedback from SW Resources we met with Kellie Conrad to discuss our design choices and final design decision. Meeting with Kellie yielded some important new modifications to our initial design selection. These design modifications include: drainage holes, ability to attach to the table, easier grip accessibility, and being dishwasher safe. The drainage holes are for aiding in the sanitizing process, meaning it will be easier to wash. Attaching the device to the table will make it easier to operate the torque wrench. We must ensure that it can be easily removed for sanitizing and reattached. Easier grip accessibility will be obtained by creating slots for the user's fingers. The device needs to be fabricated from a dishwasher safe material because SW may use a dishwasher for sanitizing.

The advantages and disadvantages of having multiple assemblies in one unit were discussed with Kellie. After comparing and contrasting the single vs. multiple assembly designs it was decided to focus on a single assembly design. The understanding was that if the single assembly design worked well but was not as efficient the design could be modified into a multiple assembly device to increase productivity.

6.0 Final Design Concept

The final design concept is shown in Figure 6.1. This design incorporates all the aspects of our redesign as well as the added features discussed in the concept screening meeting with Kellie Conrad.

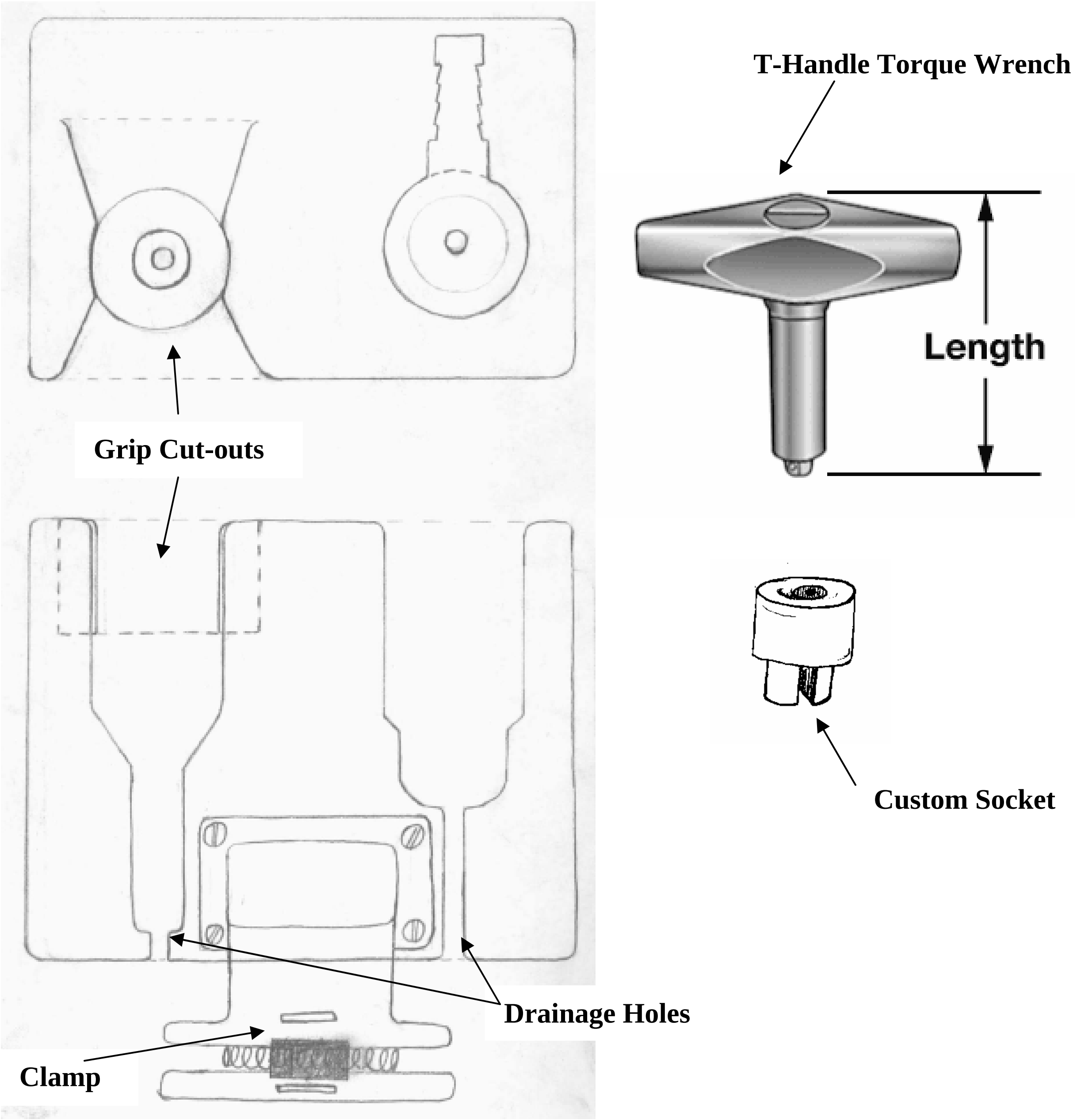

Figure 6.1: Final Design Concept

The final design concept incorporates a T-handle ratcheting torque wrench with a jig. The torque wrench will ensure a proper seal for the assembly which when held under water will not reveal any air bubbles. This is made possible by specifying a preset value of which will be measured on the pop nozzle to DuPont's requirements. The custom socket creates the connection between the torque wrench and the shaft to make the tightening process possible. The jig utilizes recessed guide holes for the components and outer casing of the pop nozzle assembly. The grip cutouts shown are for the purpose of removing the nozzle after it has been fully assembled. A clamp is shown which has the purpose of fixing the jig to the table for stabilization during the torquing process. This method for fixating the jig to the table I s subject to change since the clamp could potentially be bulky and impede on the operation of the jig. Drainage holes allow water to pass through the jig during the cleaning cycle in an industrial sized dishwasher. The material chosen for the jig will be made from a plastic with a low coefficient of friction, FDA approved for food production, wear resistant, and capable of withstanding temperatures of 150° Fahrenheit – the standard dishwasher temperature.

The operation of the jig is as follows:

1. Fix to the table
2. Outer casing is inserted into the right side hole
3. Plug – oriented with the open face upwards – is inserted into left side hole
4. Spring is inserted into left side hole on top of plug
5. Shaft inserted into left side hole through the spring and plug
6. Shaft is pressed down to bond the sub assembly
7. Sub assembly is removed from left side hole and inserted into outer casing in right side hole
8. Shaft sub assembly is screwed into outer casing using T-handle torque wrench
9. Pop nozzle assembly is removed from the right side hole and placed into bin

7.0 Prototype Design, Development, and Testing

7.1 FMEA

After the prototype's initial design was determined the method of FMEA, failure modes and effects analysis, was applied. FMEA consists of brainstorming all of the potential failure modes for a system, in this case the assembly jig, and generating a risk priority number to determine which failure would be the most severe. To determine the risk priority number each failure mode is assigned three values, one for the potential effect of the failure (severity), one for the potential causes/mechanisms of failure (probability of occurrence), and current controls for detection and prevention (probability that the failure is detected and prevented). The risk priority number is then found by multiplying the three values together. After a risk priority number has been found for each failure mode they can be compared together, the higher the number the greater the risk.

Each of the risk category values range from 1-10 but have different criteria for evaluation. Some of the criteria for the evaluation can be seen in Table 7.1. The numbers in-between the values listed in Table 7.1 are used but not described. For example if a failure mode made operation of the jig less efficient but did not pose any danger to the user it might rate as a 3 in severity.

Table 7.1: Rating Criteria

Rating	Severity	Probability	Detection/Prevention
1	Still works, no performance impact, no danger	No chance, lots of operating experience, low uncertainty	100% chance to detect and avoid
5	Inoperable but no danger	Good information, no operating experience and minimal testing	Some chance to detect and avoid
10	Inoperable, serious danger	Wild guess, no testing, little information	No chance to detect and avoid

The worksheets that were completed during the FMEA analysis can be found in Appendix A. The worksheet is used by first describing the failure mode. Then the operating mode in which the failure would occur as well as the failure mode is listed. Each of the three categories was then initially rated. After the ratings were assigned sections 1-4 were completed below the chart describing justifications of ratings and recommended actions. After the actions were taken the values were then revised in the far right column. The last action that was taken was completing section 5 of the worksheet to discuss the new ratings and risk priority number.

7.1.1 Failure mode 1 – O-ring Unsealed

This failure occurs when the shaft is getting screwed into the outer casing. If not enough torque is applied then the o-ring will remain unsealed. During the initial FMEA analysis the major factor in the risk priority number was the probability of occurrence. The reason this number was high is because there was no information to justify a lower number. After the gauge R&R study there was justification to reduce the RPN from 105 to 20. The justification was ✓ based upon the repeatability of the task with the torque wrench. The only way for this failure to occur after the adjustments were made would be improper use by the user. In our study of the operation we have seen no indication that the torque wrench will be used improperly.

7.1.2 Failure mode 2 – Breaking the Part

This failure occurs when the shaft is getting screwed into the outer casing. If too much torque is applied then the casing of the part will deform and eventually break. At the point of deformation the case changes shape enough that the nozzle is no longer sealed. During the initial FMEA analysis the major factor in the risk priority number was the probability of occurrence. The reason this number was high is because there was no information to justify a lower number. After the gauge R&R study there was justification to reduce the RPN from 105 to 20. The justification was based upon the repeatability of the task with the torque wrench. There is no way the torque wrench can over tighten the nozzle. The only way for this failure to occur would be if the user found another way to tighten the nozzle, bypassing the torque wrench.

7.1.3 Failure mode 3 – Safety of the User

This failure occurs at any point during the handling of the jig, cleaning, setting up, use, or tearing down. If there are any sharp edges or pinch points on the jig or any of the tooling the user could be hurt. The highest factor in the initial evaluation was severity. This is because the failure would harm the user as well as ruin parts. It was decided there was no way to reduce the severity of the failure. The factor that was reduced was probability of occurrence. This number started as a 5 because there was little data as to how dangerous the jig would be. After the prototype was produced and discussed with supervisors it became clear that the jig was not a danger to the user. The RPN was reduced from 140 to 28 after the changes were made. OK

7.1.4 Failure mode 4 – Not Meeting Production Rate

This failure occurs during the assembly process. If the production rate, currently 20,000 completed assemblies per day, is not met than there is a danger of SW Resources losing their contract with DuPont. The major factor in the initial evaluation was the probability of occurrence. It was rated an 8 because there was no information to justify a lower rating. It was unknown whether the goal was attainable, the current process had not been put into full scale operation, and it was unknown if our jig was feasible for reducing the time of assembly. After actions were taken the number was reduced to 1. This is because SW Resources is already meeting the production goal with the current process and the jig has been proven to slightly reduce assembly time. Therefore, it is extremely unlikely that our jig will not meet the desired production rate. This resulted in a reduction of the RPN from 160 to 20.

7.1.5 Failure mode 5 – Sanitation

This failure occurs during the cleaning and operation of the jig. If steps are not taken to keep the jig sanitary the quality of the nozzles could be decreased. It is very important that all of the nozzles and assembly process is compliant with FDA standards. After the initial evaluation the recommended action was to take bacteria cultures of the jig after use and ensure that no bacteria are growing. This action was never preformed so the after action ratings are the same. The RPN remained at 140 for this failure. Even with the high RPN Team Lean on ME is not concerned with the sanitation. The material is FDA compliant and the jig is regularly cleaned by

SW Resources. The reason the RPN is high is because there is no actual data that has been taken to prove that the jig is sanitary.

7.1.6 Failure mode 6 – Durability of the Jig over Time (Wear)

This failure occurs during the operation of the jig. This failure describes the situation where the jig is deformed enough over time that it can no longer be useful to the customer. Originally the probability of occurrence was rated a 9 because there was no information on wear of the material or test results on the jig itself. Since the initial ratings a full FEA analysis has been performed on the jig. The jig has been observed for wear after the testing was preformed and there are no visible signs of wear occurring. Based on these results the factor was reduced to 3, resulting in a reduction of the RPN from 54 to 18.

7.1.7 Failure mode 7 – Calibration of the Wrench

This failure occurs during the torquing of the nozzle. This failure describes the situation where the torque wrench becomes out of specifications without the user knowing it. This originally had a probability rating of 8 because little was known about the torque wrench. The probability of occurrence has been reduced to 2 for several reasons. First, gauge R&R has been performed on the torque wrench. The results of that study prove that the torque wrench holds a tight tolerance. Also, during testing of the required torque to seal the nozzle there was a range of acceptable torques. Therefore, even if the wrench was slightly out of specification it is unlikely that the quality of the part would be affected. This reduced the RPN of this failure from 160 to 40.

7.1.8 Failure mode 8 – Mis-orientation of the Plug

This failure occurs during the operation of the jig. This failure describes if the plug was oriented upside down and jammed the jig. This originally was a very significant failure. It was severe, rated a 5, because it would render the jig inoperable. The original design was for the jig to be bolted to the table and there would be no way to get the plug out. It was also rated high in probability, a 9, because there was no information to prove that this would not happen often. After actions were taken the severity was reduced to a 1. The rationale for this is the quick release feature of the jig that was incorporated. This allows the plug to easily be dumped out.

The only outcome of this failure now is a slight decrease in productivity, which is negligible throughout the course of an eight hour work day. Also the probability was reduced to a 2. This is because after studying the workers it seems very unlikely that they will mis-orient the plug. After all of our testing and trials that we observed we never saw a worker mis-orient the plug using the current process or our jig. These reductions resulted in the RPN changing from 315 to 14.

7.1.9 Conclusions of FMEA

Team Lean on ME examined 8 unique failures. Actions were taken on all but one of these failures after the initial ratings. This resulted in the reduction of the risk priority numbers in seven of the failures. Table 7.2 shows the change in the RPN based on the actions taken. From the table it can be concluded that FMEA was an effective strategy for decreasing the failure rate of the assembly process. Team Lean on ME feels that all of the RPNs are acceptable. If time allowed it would be recommended that bacteria cultures still be taken to reduce the RPN for sanitation. The only reason this was not performed is because it was deemed time ineffective because the sanitary properties of the material are already known.

Table 7.2: Results of actions taken by FMEA

Failure	**Initial Evaluation**	**After Action Evaluation**
O-ring Unsealed	105	20
Breaking of the Part	105	20
Safety of the User	140	28
Not Meeting Production Rate	160	20
Sanitation	140	140
Durability of the Jig	54	18
Calibration of the Wrench	160	40
Mis-oriented Plug	315	14

7.2 Computer Modeling

Team Lean on ME made Solid Edge models of all of the parts that were designed as well as the parts in the nozzle. These were modeled for testing purposes as well as to assist with keeping an up to date model of the design. Table 7.3 shows a list of all the parts that were modeled related to this project.

Figure 7.1 shows the assembled view of the model. Figure 7.2 shows the transparent assembly with all of the hidden lines. Figure 7.3 shows an exploded view with all of the parts visible.

After all of the models were made, associativity was added to the parts. For example, the diameter of the bolt holes in the T-slot is related to the diameter of the bolt used. If the diameter of the bolt changes, the holes will update automatically. Similarly the T-slot and the T-cutout on the jig are associative.

Table 7.3: Parts List

Main Assembly					
Item	File Name	Description	Material	Quantity	Lead
1	Revised Part.Par	Our Jig	UMHWPE	1	Matt
2	Case.Par	Casing of Nozzle	HDPE	1	Jeremy
3	PlugShaft.Asm	Plug Shaft sub-assembly	HDPE	2	Chuck
4	T slot.Par	T Slot to hold the Jig	UMHWPE	1	Chuck
5	Screw.Par	Screws for T Slot	Stainless	3	Chuck
6	Socket.Par	Socket for Torque Wrench	Stainless	1	Matt
PlugShaft.Asm					
Item	File Name	Description	Material	Quantity	Lead
1	Shaft.Par	Shaft of the Nozzle	HDPE	1	Chuck
2	Plug.Par	Plug of the Nozzle	HDPE	1	Jeremy

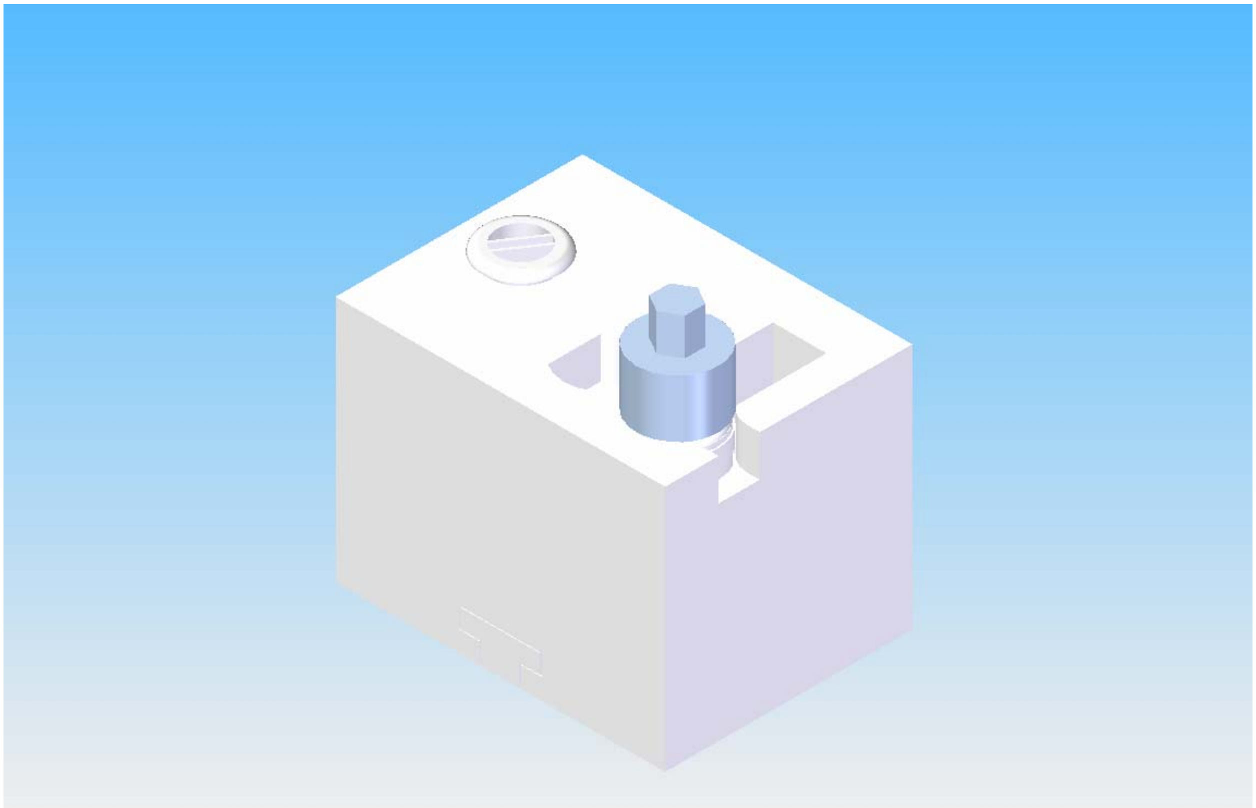

Figure 7.1: Solid view of the assembly

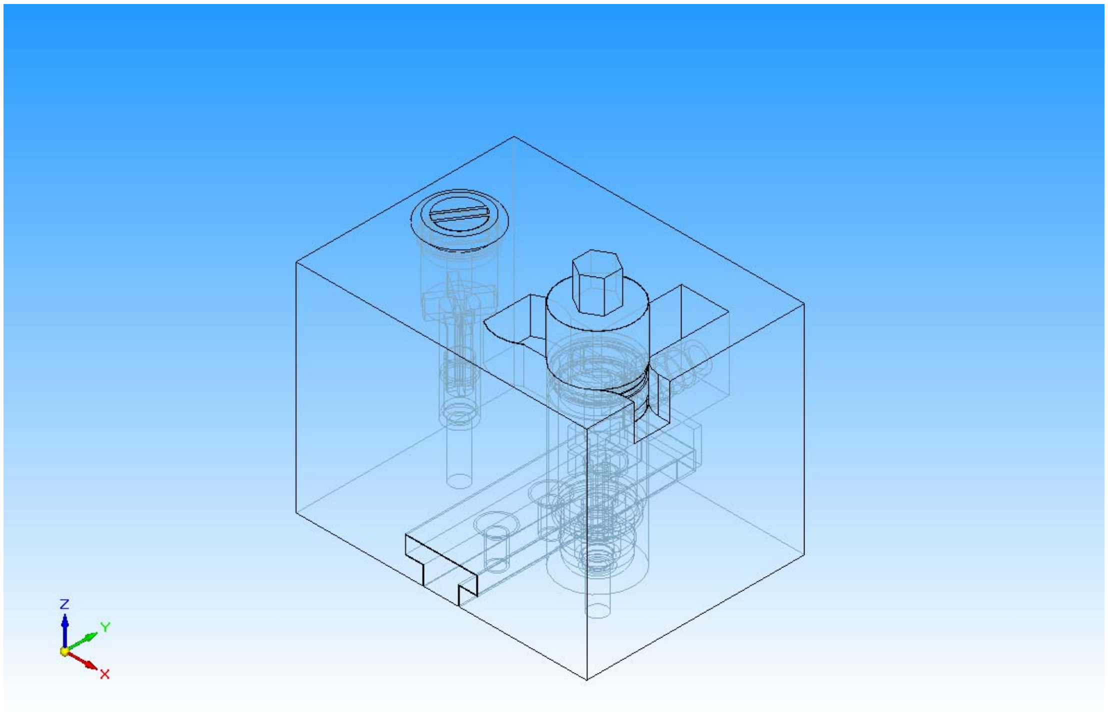

Figure 7.2: Assembly with hidden lines.

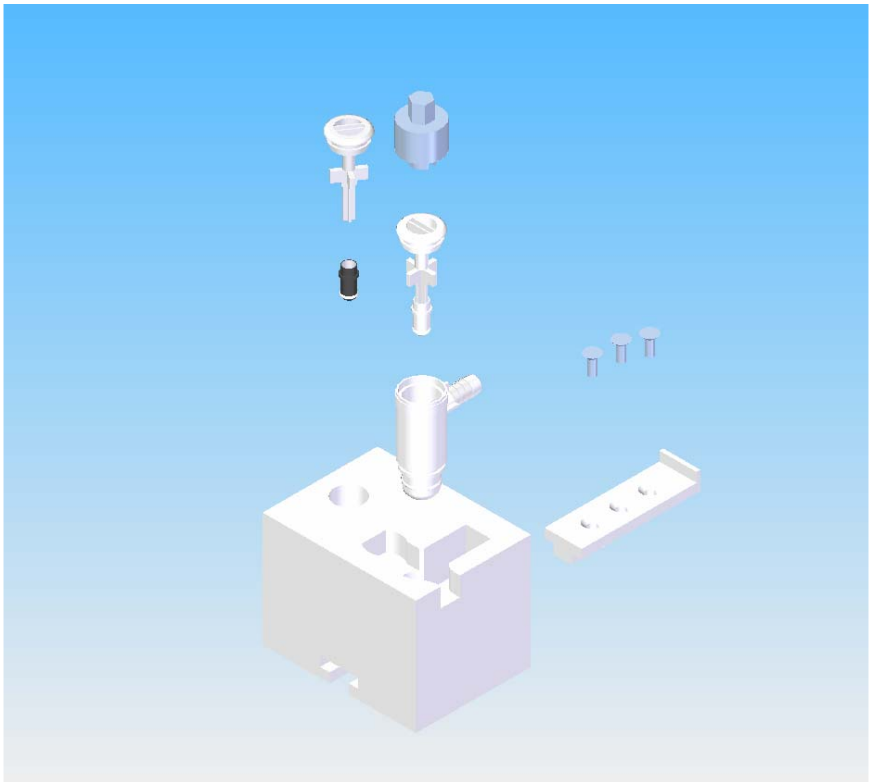

Figure 7.3: Exploded view of the assembly.

The DuPont parts, the case, the plug, and the jig, are all modeled within .001" of the parts provided to us. The parts given to us were measured by calipers to obtain the dimensions. We used these dimensions to design proper clearances in the assembly holes. The model has been checked and there are no physical overlaps between parts in the assembly.

7.3 Design Analysis

The major tool used for analysis prior to construction of the prototype was finite element analysis (FEA). This tool was used to predict stress based on the materials that were selected. The material selection process was based upon FDA compliance and cost. Team Lean on ME did not think strength of the materials would be much of a factor because of the very low stresses involved in the assembly task. FEA was the tool used to prove this assumption. There were four areas of concern identified by the group. Each of these areas was run as a separate case in analysis. The details of these cases can be found in the following subsections

7.3.1 Case 1 – Outer Casing

This case examines the failure of either the case or jig at the contact that occurs during torquing. To save on processing time, only the part of the jig that contacts the case was analyzed, along with the case. The full case was not analyzed either, it was cut on the bottom surface and on the nozzle. All of the cut surfaces of the jig were constrained in their respective directions and the bottom of the jig was fully constrained to simulate the T-slot constraint. A surface contact was created between the wall of the jig and the contacting surface of the case. The 15 inch pounds needed for the torque wrench was converted into an equivalent 17 pounds applied to two opposing nodes on the top of the case (all shown in Figure 7.4).

Table 7.4 shows the data from the 5 runs that were performed. After the stress artifacts from the nodal forces were hidden, the maximum von Mises stress at the contacting surface converged around 155 psi (shown in Figure 7.5) using a .03” mesh with a .007” refinement point. The stresses in the last two runs have a percent difference of 2.6%, proving that the stresses converged. This 155 psi max stress is well below the HDPE’s yield strength of 4.8 Ksi.

Table 7.4: FEA results

mesh	nodes	max stress (psi)	Aspect ratio
.05 mesh	14364	45	9.1
.03 mesh	58071	71.3	7.1
.03 mesh with .01 refinement (.15 radius)	64639	125.5	8.9
.03 mesh with .008 refinement (.15 radius)	76426	150.4	6.9
.03 mesh with .007 refinement (.15 radius)	82125	154.5	6.9

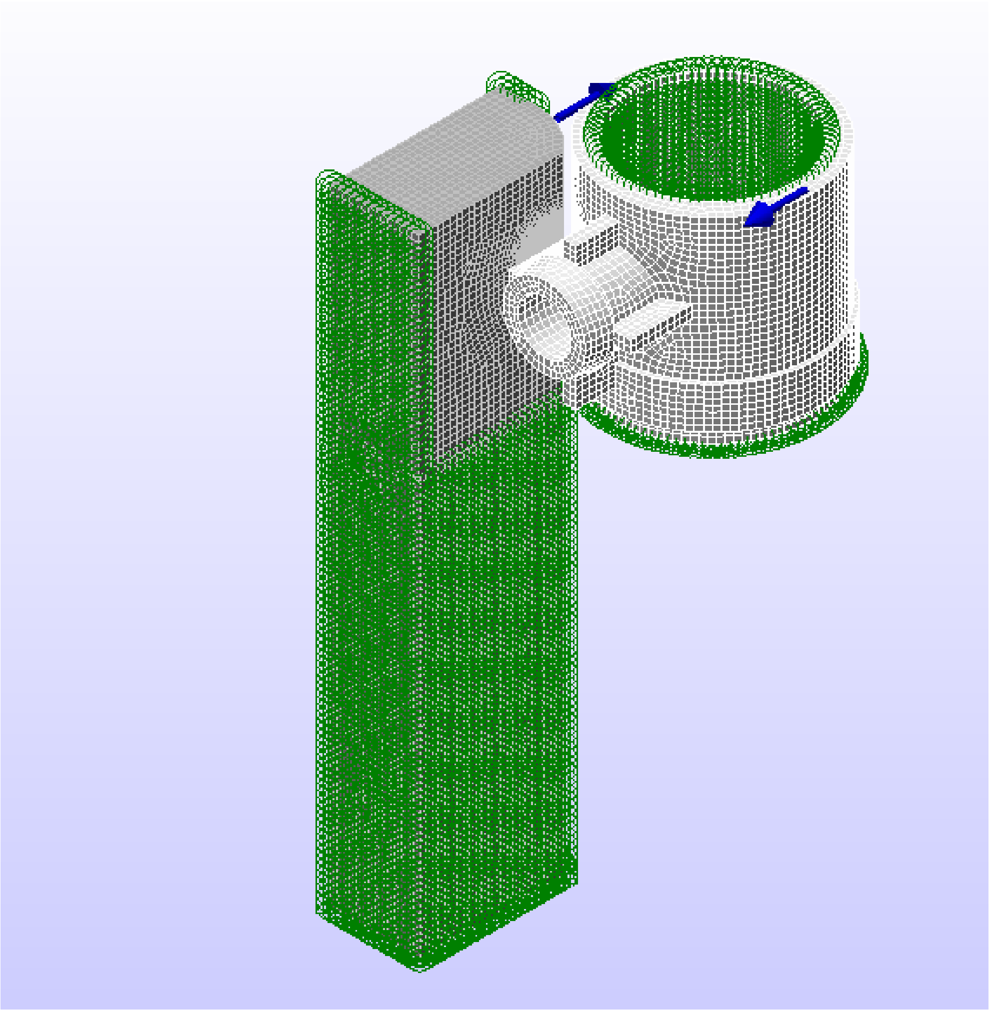

Figure 7.4: 0.03” mesh with a 0.007” refinement point at the contact surface (showing constraints and applied forces.)

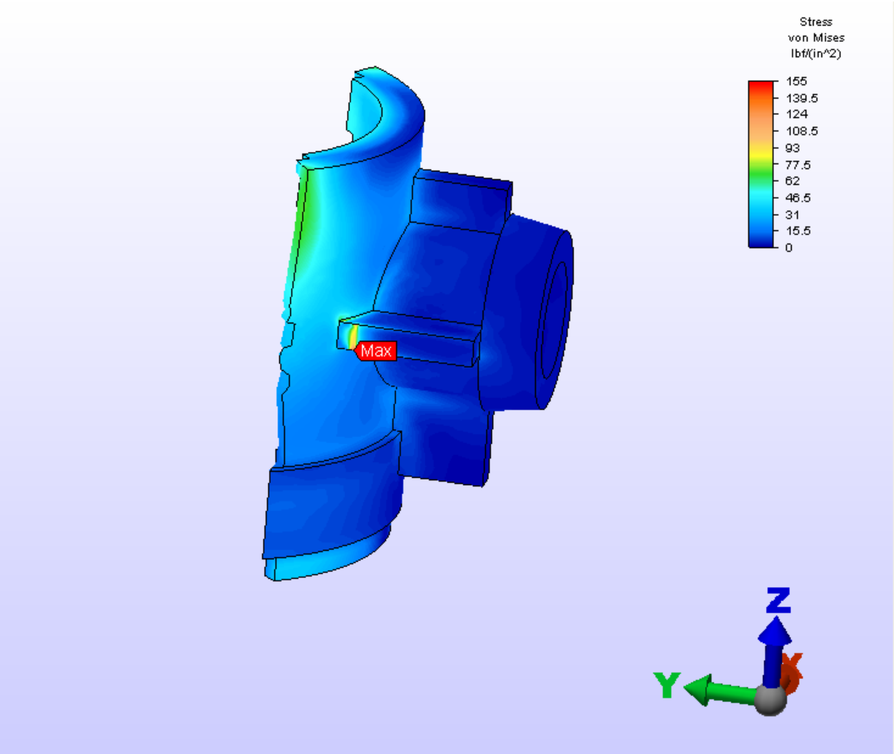

Figure 7.5: Maximum stress on final meshing

7.3.2 Case 2 – T-Slot

This case was the analysis of the T-slot. For the actual analysis just the area around the slot was used, 1 inch from either side of the slot on the jig. The slot was also used in the FEA. The ideal mesh lengths were on the order of about .05”. This value was determined based on the size of the part. The material for both pieces, as seen in Table 1, was ultra high molecular weight polyethylene (UHMW). The properties for UHMW can be seen in Table 7.5.

Table 7.5: Properties of UHMW

Density (lb*s^2/in^4)	Modulus of Elasticity (PSI)	Poisson’s Ratio	Shear Modulus
0.001056	125000	0.46	42810

The loading and constraining of this model can be seen in Figure 7.6. It can be observed that the bottom of both of the jig and the slot have a T_Z applied to them. This is to simulate the table not allowing the jig to move in that direction. Also the holes in the slot are fixed. These are fixed because the screws would be holding the holes in place. All of the sides of the slot and jig have surface contacts applied to simulate the surfaces sliding but not penetrating. The edge loads are applied in opposite directions and have the magnitude of 30 lbs to simulate the 15 inch pound load applied to the nozzle.

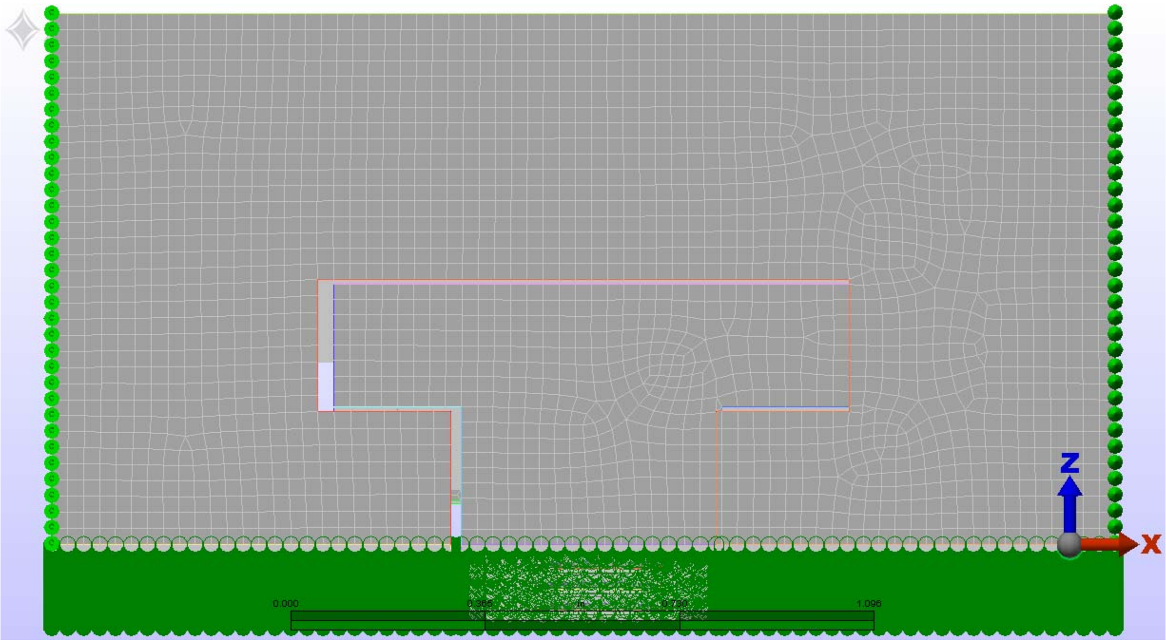

Figure 7.6: Loads and constraints for the T slot

Figure 7.7 shows the stress results from the Algor analysis. This figure is cut to focus on the area of max stress. Also the T slot that was present for the analysis is hidden in this view to provide a better look at the maximum stress.

This model converged after running several different mesh sizes. Table 7.6 gives a summary of the Algor runs. The model behaved as expected with the stress increasing as the mesh size decreased. It is clear the model converged because at a small mesh size, .03 inches of ideal element length, the number of nodes increased by over 50% and the maximum stress increased by less than 1%. Also, the aspect ratio for the finer meshes was low, all under 10, which doesn't raise a warning flag for the model.

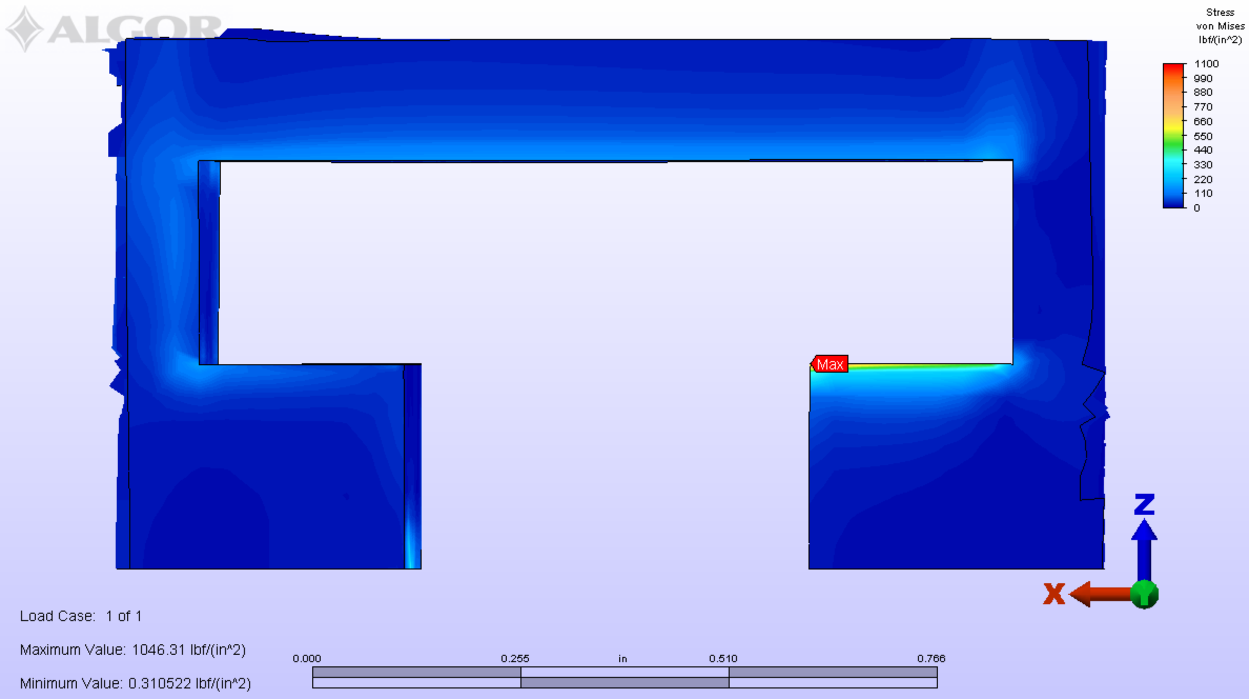

Figure 7.7: Maximum stress of the T slot analysis.

Table 7.6. Convergence of the T slot

Mesh Size (in)	Nodes	Max Stress (PSI)	Max Displacement (In)	Aspect Ratio	% Nodes	% Stress
0.1	8672	435	0.00209	21		
0.075	18914	463	0.00211	9.5	118.1%	6.4%
0.05	57769	761	0.00211	9	205.4%	64.4%
0.04	106412	856	0.00211	7.25	84.2%	12.5%
0.035	155731	1040	0.00211	5.9	46.3%	21.5%
0.03	237856	1046	0.00211	4.68	52.7%	0.6%

The strength of the material is what is important for this analysis. The maximum stress that was observed was in the back corner of the jig opposite of the contact of the T slot. This is observable in Figure 7.7. This is a realistic place for the maximum stress to occur because it has nothing supporting it and this section is exposed to opposing forces. The maximum stress was found to be a little over 1000 PSI and the yield strength is 6500 PSI. This results in a factor of safety of over 6. This method of holding the jig will clearly be acceptable for this project.

✓

7.3.3 Case 3 – Socket

This case is the analysis of the socket. The socket is a very small part. It is no more than 1.25 inches in length and has a maximum diameter of 1 inch. Performing the FE analysis for this part was done using very small meshes. When the FEA was done the original mesh started at .1 inches. After several finer meshes were completed, the final mesh was .025 but with refinements points. The final test was run with a mesh of .025 inches and refinement points on the corners of the half moons where the high stress was found. The refinement points had a radius of .0015 and a refinement mesh of .0015. To find convergence meshes were run that more than doubled the nodes and the stress only increased for a few psi.

The material that Team Lean on ME used for this FE analysis was 309 stainless steel. The materials that were discussed included stainless steel and ultra high molecular weight (UHMW) polyethylene. The concern with using the UHMW is that over time the material will deform and not be able to perform in the production line. Therefore stainless steel was chosen. The material is strong enough that stresses should not cause wear and also is FDA safe for the standards given by DuPont.

The overall design of the socket is very basic and simple to model. The socket has a hexagonal shaft on one end so it can be connected to another socket that can be connected to the torque wrench. The force was put on the hexagonal shaft to make the FE analysis run smoother. The distance from the one edge on the hexagonal to the opposite side is .430 inches. The overall torque that our torque wrench is set to is 15 in-lbs. So in order to calculate the force to put on the edges opposite to each other Equation 7.1 was used.

$$T = F \times r \tag{7.1}$$

T = 15 in-lbs, R = .430/2 = .215, F = 35 lbs

The force of 35 lbs was applied to two edges on the hexagonal shaft in the opposite directions to act like a torque on the shaft. The flat end of the hexagonal shaft is fixed in the T_y directions since it is laying in the zx axis. This back surface will not be moving in the y-direction at all so this is why it is fixed. The opposite shaft is two half moons with a distance of .19 inches between them. The two inner surfaces of the half moons were fixed completely to show they are not going to move when the force is applied.

The overall FE analysis ran quite smoothly and the results turned out as expected. The socket experienced very small stresses throughout the FE analysis. The maximum stress that the socket undertook was 4.38 ksi. The stresses in the socket are shown in Figure 7.8.

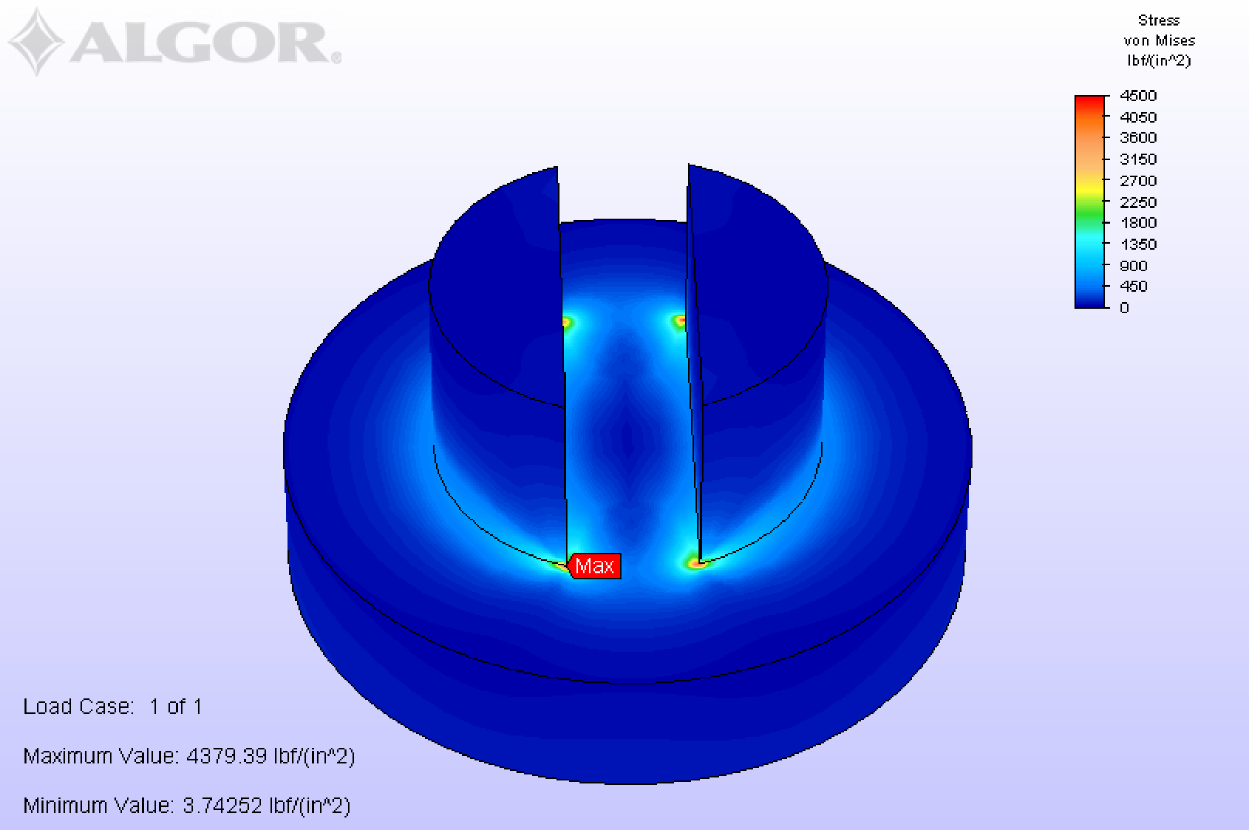

Figure 7.8: The max stress in the socket – 4.38 ksi.

The max stress is shown where the max tag is located. The highest stress values are shown in the edges of the half moons that grip the base and tighten the nozzle.

When running the test for convergence, it took several trials of finer meshes and refinement meshes to get the stresses to converge. Looking at Table 7.7, you can see how as the meshes grow finer, the number of nodes increase and the stress increases as well.

Table 7.7: Data of FEA for the Socket

Mesh size	Nodes	Stress (ksi)	Displacement (in)	Aspect ratio
0.1	1222	0.90	8.00E-06	2.2
0.075	2489	1.10	9.00E-06	2.7
0.05	8107	1.83	9.85E-06	1.64
0.025	56286	3.40	1.00E-05	1.65
Refinement Points on .05 Mesh			0.0025 radius	
0.015	10543	3.50	1.10E-05	4.15
0.01	12789	3.74	9.80E-06	6.26
0.0075	15044	4.21	1.08E-05	9.3
0.005	20181	4.30	1.00E-05	10.2
Refinement Points on .025 Mesh			0.0015 radius	
0.0025	27232	4.31	9.80E-06	9.6
0.0015	72807	4.38	1.00E-05	8.84

Table 7.7 shows all the data points of the FE analysis that was ran for the socket. The convergence justification occurs within the last two meshes. The last two meshes were done with a .025 overall mesh and refinement meshes of .0025 and .0015 with a radius of .025. Convergence is verified by noticing that the number of nodes has increased by more than double while the stress is only affected by .07 ksi. This shows that the max stress will be very close to 4.38 ksi.

The material that we are using for the socket is a 309 stainless steel. The yield strength of this material is 30 ksi. The ultimate strength of the material is 80 ksi. Since the max stress is 4.38 ksi, we will have no issues with the part fracturing at any point. The material will reach less than 1/6 of the yield strength. The stress used in calculated the max stress in the part was the Von Mises stress. This gives an accurate measurement of what the stresses will be on the part.

The aspect ratio of the final mesh was 8.84. This shows that the part meshed correctly and had no real geometry issues. The image of the aspect ratio and max values are shown in Figure 7.9. The deflection of the part was looked into as well, but there will be no deflection issues when using stainless steel. The material used for the socket will work quite nicely and give SW Resources a guaranteed assembly with no quality issues such as leaks or cracks in the seal. The socket will not deform do to the stresses either.

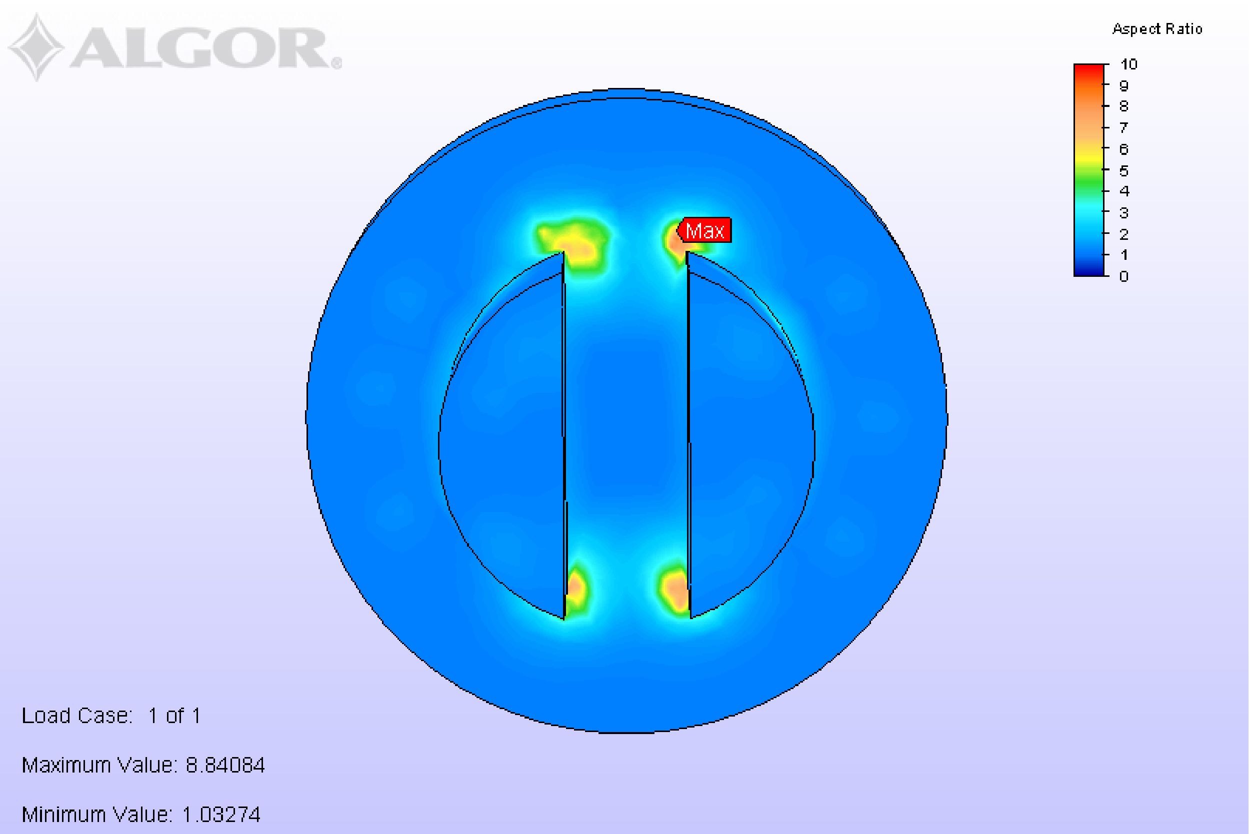

Figure 7.9: The max aspect ratio in the socket – 8.84.

7.3.4 Case 4 – Shaft

This case was the analysis of the socket on the shaft. This was done because it is known that the shaft breaks where it is connected to the socket when too great of a torque is applied. The shaft end of the shaft was cut off for this analysis to simplify the model. The ideal mesh length for this analysis was between .05” and .025”. The materials used in this analysis are 309 stainless steel for the socket and HDPE for the shaft. For both of these materials the default properties in the Algor property library were used.

The loads and constraints applied in this model can be seen in Figure 7.10. As seen in this figure there shaft, where it is cut, is fixed. The reason for this is because this is where the bottom of the threads are. Therefore, when the shaft is completely screwed into the case this part will not move. This is a simplified model of what is occurring when the torque is actually applied. Also there are two edge forces applied to the socket. These are the same edge forces applied in Case 3 and the methodology for these forces remains the same. Also, surface contacts were applied between the shaft and the "half moons" of the socket to simulate the socket turning the shaft.

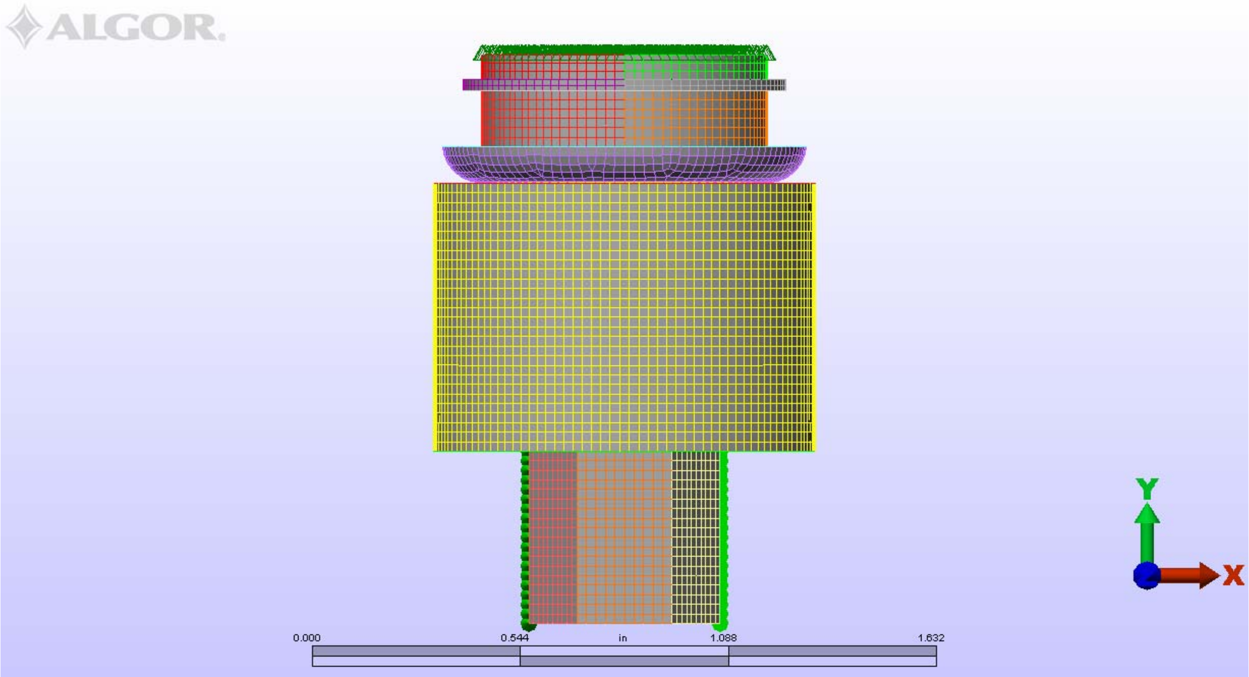

Figure 7.10: Loads and Constraints on the socket.

Figure 7.11 shows the stress results from the Algor analysis. This figure hides the socket, the stresses of the socket are addressed in Case 3. Also, this image is oriented to show the occurrence of the maximum stress. There are no other areas of significant stress in this model.

This model converged after running several different mesh sizes. Table 7.8 gives a summary of the Algor runs. The model behaved as expected with the stress increasing as the mesh size decreased. It is clear the model converged because at a small mesh size, .025 inches of ideal element length, the number of nodes increased by almost 200% and the maximum stress increased by less than 8%. 8% could be a significant increase in stress, but with that increase in nodes it is unlikely that the stress will increase significantly. Therefore, the highest stress can be estimated under 2000 PSI. Also, the aspect ratio supports a suitable model and convergence.

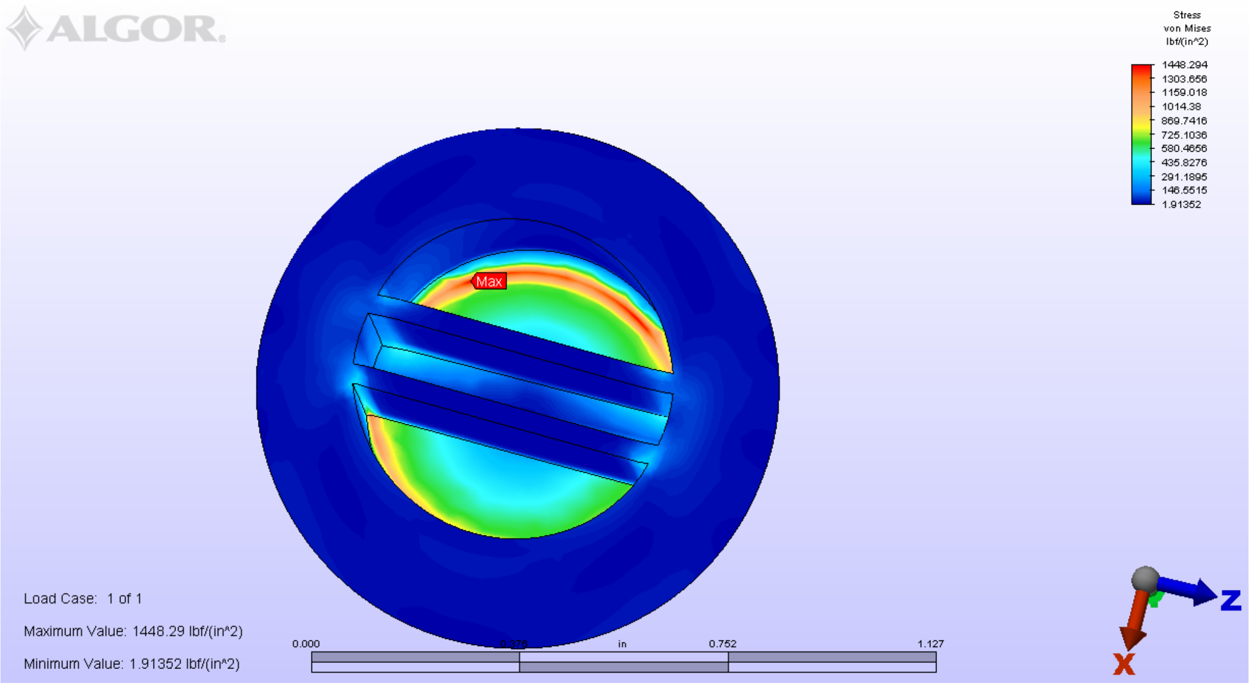

Figure 7.11: Maximum stress of the Shaft.

Table 7.8. Convergence for the Shaft.

Mesh Size (in)	Nodes	Stress (PSI)	Displacement (In)	Aspect ratio	% Nodes	% Stress
0.05	9306	1109	0.0004	7.2		
0.0375	21625	1394	0.0004	7.6	132.38%	25.70%
0.025	61439	1504	0.0004	10.6	184.11%	7.89%

The strength of the material is what is important for this analysis. The maximum stress can be observed on the part of the shaft where the socket applies the torque. This can be seen in Figure 7.11. This is where the maximum stress occurs; it has been supported by physical experiments. The maximum stress was found to be less than 2000 PSI and the yield strength of HDPE is 4800 PSI. This results in a factor of safety of over 2. It is clear that the torque applied to the socket will not break the shaft.

7.4 Mock-Ups and Experiments

There were three major experiments performed before the construction of our prototype was started. The three major concerns were the angle and dimensions of the funnel in the first part of the jig, the torque required to seal the nozzle, and the repeatability of the sealing process.

Tests were set up and performed to ensure the proper construction of the jig. These tests are detailed below.

7.4.1 Angle Testing

The purpose of this test was to observe how different countersink angles affected the ease of the jig's ability to align the small plug and the spring. The angle of the countersink is a significant characteristic to the jig because it acts as a funnel for the plug and spring so that they can be correctly positioned for the first step of the assembly.

The angle test examined different countersink angles of the funnel for the plug and spring. This is important to test because the plug and spring must drop into the tube for proper alignment so that the shaft can be inserted for the first step of the assembly. Testing for the proper angle can prevent problems that could occur such as binding of the plug or spring, failure to fall through the tube, and falling through the tube incorrectly. The result of the angle test was incorporated into the fixture block so that the first step in the assembly can be completed successfully and as easily as possible. An angle too low could result in binding of the plug and or spring in the fixture while an angle too high could prevent the shaft from inserting into the plug, thus the assembly would be unsuccessful. Therefore, the discovery of an optimal angle is important to the successful ease of use in the first step of the assembly while using the jig.

To perform the test, a single 3/4 inch diameter hole with a countersink angle of 82° was made in a block of wood while a smaller 13/32 inch concentric hole to accommodate the plug was drilled deeper in through the middle. This angle was tested by simply dropping the plug in the correct orientation from a few inches above the jig's top into the countersunk section which acted as a funnel in guiding the plug into the smaller 13/32 inch hole.

The test was evaluated on pass/fail criteria. If the plug fell into position with ease, then the angle was approved. Numerous amounts of trials were made, and each trial showed that the plug would go down into the hole smoothly and have the correct orientation. The test with the 82 degree angle was proven to be sufficient and that is why this angle for the countersink was chosen. Since it was a pass/fail experiment, there was no reason to test other angles for the hole.

The angle test concluded that an 82 degree angle will be sufficient for orienting the plug upright into the guide hole. With this angle, the plug is unable to get stuck on the countersunk funnel before it enters the guide hole. The angle on the countersunk funnel also keeps the plug upright so that it doesn't flip over before entering the hole and enter upside down. Since the test was a pass/fail experiment, there was no need to go into additional testing with other angles. The 82 degree angle passed the test and will be used for the jig.

7.4.2 Torque Testing

The purpose of this experiment is to test the effectiveness or ease of use of the jig by measuring and finding the optimal torque to seal the shaft into the pop nozzles outer casing. This optimal torque should seal the assembly so that the o-ring is not visible and that the assembly will not come apart easily by hand. Equation 7.2, the equation for torque, was used to find the required torque to seal the pop nozzle without under tightening or over tightening it.

$$\tau = rFsin(\theta) \qquad (7.2).$$

In Equation 7.2, r is the length of the moment arm, F is the force applied, and θ is the angle between the moment arm and the direction of the applied force. Under tightening the pop nozzle assembly could cause a leaking issue while over tightening could result in fracture. Either one of these defects would make the pop nozzle a rejected part and unable to be utilized.

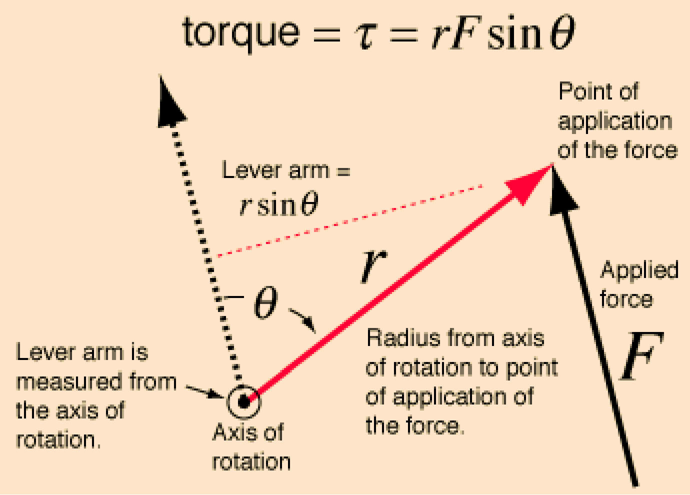

Figure 7.12: How to Calculate Torque (Torque and Equilibrium)

Figure 7.12 above defines the torque and demonstrates its calculation. Torque is calculated by first defining the lever arm to be a perpendicular distance from the axis of rotation to the point where the force is applied. The distance of the lever arm can be calculated by multiplying the length of the arm by the sine of the angle. The torque is then calculated as described in Equation 7.2.

This experiment was conducted to test the torque needed to completely seal the o-ring into the outer casing. Torque is the tendency of a force to rotate an object about an axis. The testing of the torque is important to the project because it has been required by DuPont that there cannot be a leak between the outer casing and the o-ring. The most feasible way to ensure the o-ring is completely sealed is to test the torque needed to optimally secure the seal, then set a torque wrench to that specified torque which will be used to tighten it. The results from the test will be used to set the torque wrench at a value which will be within a range that would not result in a defected part. This way we can ensure that the requirements set by DuPont for the pop nozzle assembly have been met. The inability to seal the o-ring, or breaking the pop nozzle could be the result of inaccurate and poor testing of the torque. Therefore, its value is critical to the jigs success.

In the preliminary torque testing experiment, the minimum torque required to make a seal that would pass visual inspection was tested using the experimental setup seen in Figure 7.14. The maximum amount of torque that the nozzle can withstand before breaking was also tested in this experiment using the same setup. From this range, an even more narrow range of torque was tested. This was a local range in the mid section of the maximum and minimum torque values. The local range was determined by examining how tight or loose the shaft-screw assembly was. The seal should not have been so tight as to give the user any hand strain while tightening the shaft-screw assembly into the outer casing. In addition, it should not have been so loose to the point where it would come apart during movement of the assembly. After this local range was defined, four different pop nozzle assemblies were tested. Each nozzle was tested three times with a 12 inch moment arm and digital spring gauge. A figure of the test apparatus can be seen below in Figure 7.14. A flow chart of the experimental procedure can be seen in Figure 7.15.

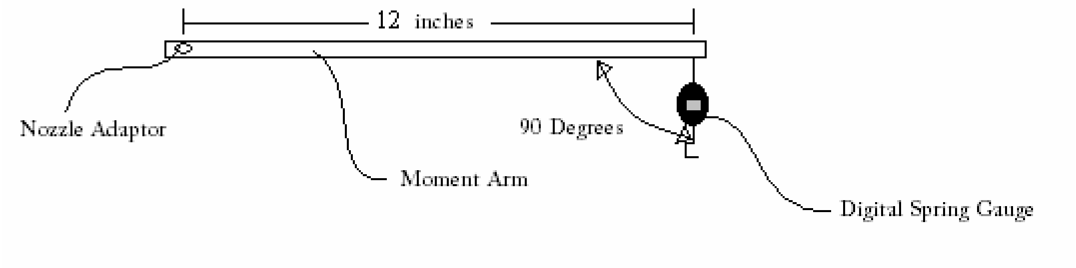

Figure 7.14: Torque Test Set Up

A second experiment was performed after the preliminary experiment. This test was more accurate than the first and served to gain more valuable information. Its setup was similar to the first in that the nozzle was attached to a nozzle adapter connected to a 12 inch moment arm. However, a more accurate digital force gauge was used in conjunction with a data acquisition system. The experiment was performed by tightening the assembly by hand, preserving the horizontal position of the lever arm, while the computer measured, recorded, and plotted the applied force over time. This operation was performed thirty times by three different testers using different nozzle assemblies.

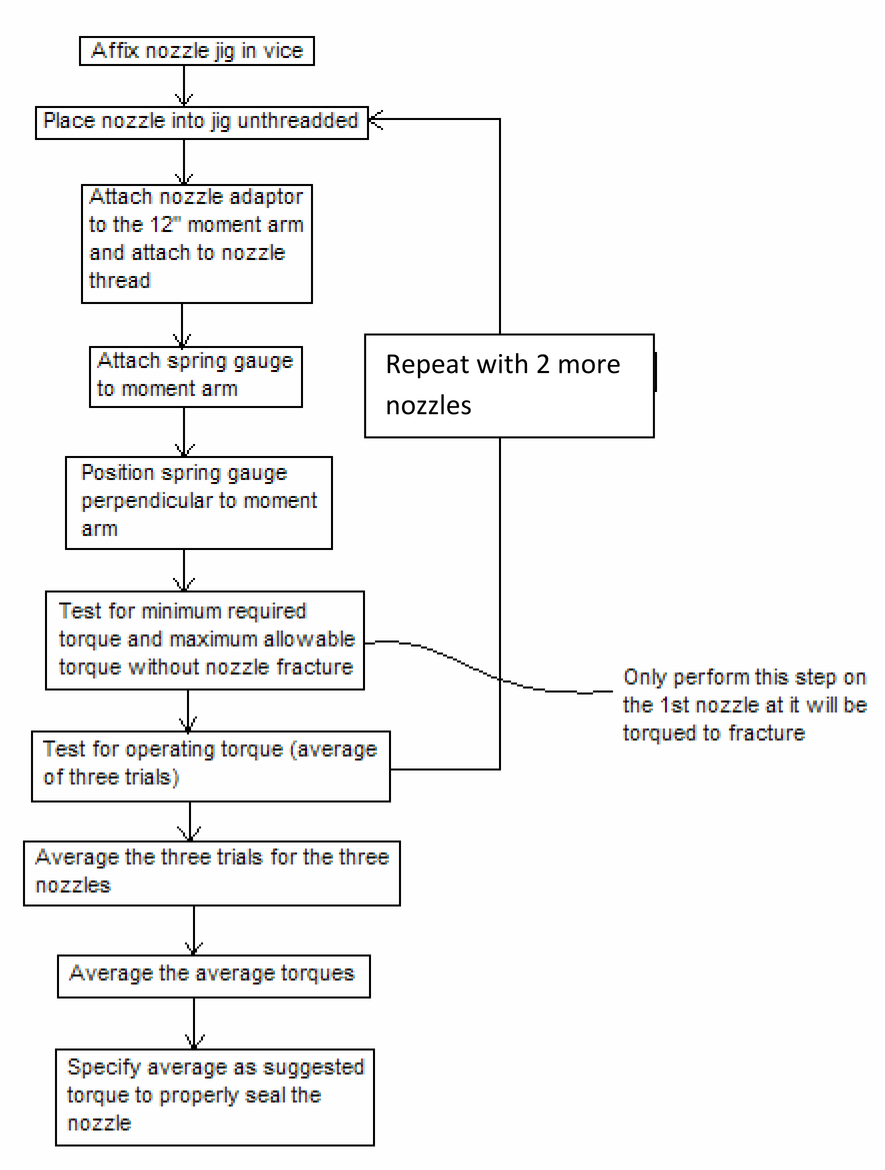

Figure 7.15: Torque Test Experimental Procedure Flow Chart

From the preliminary test, several values were found. The minimum torque to seal the nozzle was determined to be 12 inch pounds. The maximum torque before fracture was determined to be 48 inch pounds. The fracture occurred at the spokes on the shaft of the nozzle, not the casing. Also out of the preliminary testing the data found in Table 7.9 was generated.

Table 7.9: Preliminary Data

Nozzle #	Trial #	Force (lbs)

1	1	1.8
2	1	1.9
3	1	1.9
4	1	1.8

In reference to Table 7.9, each nozzle was put through one test to gain an idea of what force was to be expected for each one. The lever or moment arm used in this experiment was 12 inches. The range of force to seal the nozzle to the employer's specifications was between 1.8-1.9 lbs. The nozzles were also tested to measure what the minimum and maximum torque would be to seal the nozzle without leaks or cracks. The minimum torque required to seal the nozzle was 12 in-lbs, and the maximum torque allowed was 48 in-lbs. Although the threads and seal were not damaged during maximum torquing, the spokes on the base that is attached to the socket had broken. This tells us that 48 in-lbs will seal the nozzle, but the base cannot handle the torque, therefore it must be reduced.

Table 7.10: 1st Nozzle's trials for sealing to minimum torque

Trial	Force (N @ 12in)		
#	Trial 1	Trial 2	Trial 3
1	2.009	2.505	2.671
2	2.205	2.401	2.689
3	2.064	2.469	2.395
4	2.064	2.407	2.990
5	2.230	2.561	2.787
6	2.248	2.438	3.051
7	2.199	2.659	2.654
8	2.652	3.173	2.731
9	2.524	2.720	2.436
10	2.830	3.418	2.897
Avg.	2.302	2.675	2.730
Xbar	**2.569233**		

Local Range		
Min. Torque=	5.419694	In-lbs
Max. Torque=	9.220764	In-lbs
Avg. Torque =	6.931040	In-lbs

Table 7.11: 2nd Nozzle's trials for sealing to minimum torque

Trial	Force (N @ 12in)		
#	Trial 1	Trial 2	Trial 3
1	2.302	3.504	4.484
2	3.510	3.486	5.316
3	2.285	3.308	4.956
4	2.046	3.308	5.440
5	2.064	4.129	5.195
6	2.646	3.798	4.772
7	3.357	4.576	3.443
8	3.547	5.269	3.951
9	3.902	5.465	4.944
10	3.908	5.655	3.780
Avg.	2.956	4.249	4.628
Xbar	**3.944867**		

Local Range		
Min. Torque=	5.519509	In-lbs
Max. Torque=	15.25553	In-lbs
Avg. Torque =	10.6421	In-lbs

Table 7.12: 3rd Nozzle's trials for sealing to minimum torque

Trial	Force (N @ 12in)		
#	Trial 1	Trial 2	Trial 3
1	5.123	4.668	4.062
2	2.769	4.821	4.889
3	3.106	4.215	4.913
4	5.101	3.516	3.927
5	4.907	4.392	4.215
6	4.827	4.227	4.129
7	4.276	4.742	4.337
8	4.319	4.913	4.380
9	5.226	4.153	3.842
10	5.483	4.093	4.221
Avg.	4.513	4.374	4.291
Xbar	**4.393067**		

Local Range		
Min. Torque=	7.469952	In-lbs
Max. Torque=	14.79153	In-lbs
Avg. Torque =	11.85121	In-lbs

Table 7.13: Average Torques from Full Scale Test

Minimum Torque to Seal	2.06 in*lbs
Maximum Torque to Seal	50 in*lbs
Overall Average Torque	9.81 in*lbs

Tables 7.10-7.12 show the overall data of the torque test. The three sets of data were done by three different people using different nozzle assemblies. The data for the trials was measured in Newton's, with a moment arm of 12 inches. The minimum, maximum, and average values were converted into in-lbs in the columns to the right of the tables. Each tester tightened the nozzle to what they felt to be the correct torque. This is why each nozzle may have different forces applied on it due to the judgment of when each tester determined the nozzle was sealed. The trials had to follow the specifications of our employer that the nozzle must be sealed with no visible piece of the o-ring showing so that there would be no leaks in the nozzle.

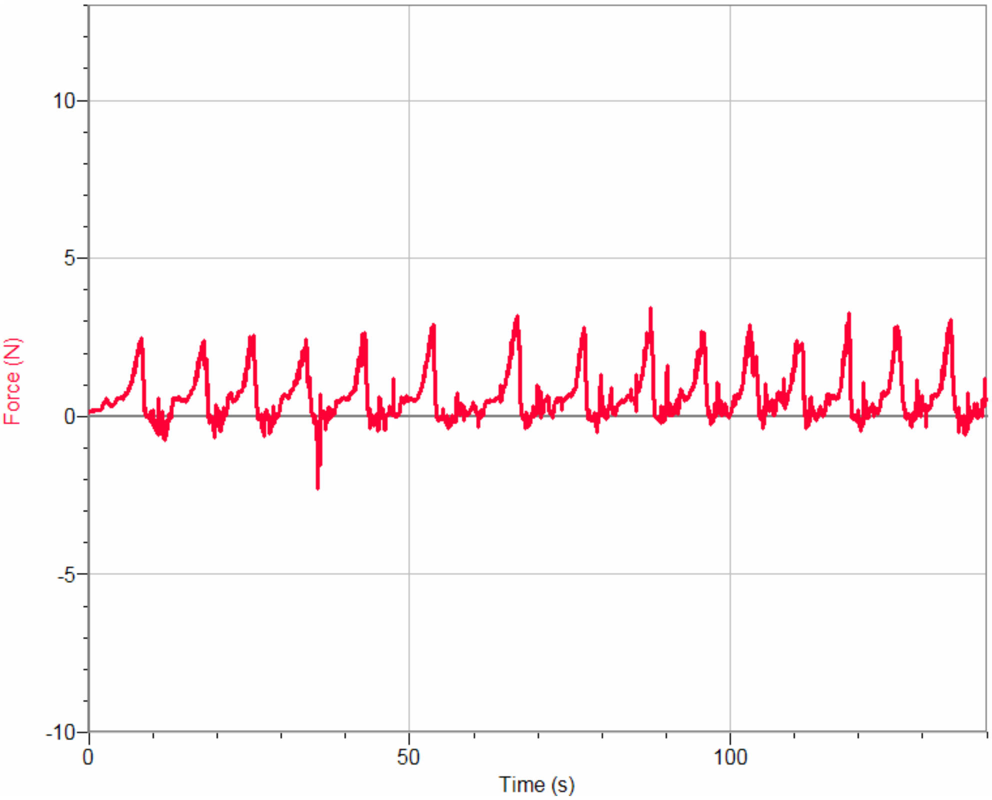

Figure 7.16: Data from the 1st Torque Test.

Table 7.10 shows the 1st nozzle's trials for sealing to the minimum torque. The three trials had very close data points. Figure 7.16 shows the plot of the data generated from this test. The data shows the peaks of the force from which the data was collected. The range of force went from 2.009 N – 3.418 N. The minimum and maximum values of torque in the local range were then calculated to be 5.41 in-lbs and 9.22 in-lbs. The overall average of this nozzle was 6.93 in-lbs.

The 2nd nozzle's trials are shown in Table 7.11. The range of force on the nozzle was 2.046 N – 5.655 N. The minimum and maximum values of torque were then calculated to be 5.51 in-lbs and 15.25 in-lbs. The overall average of this nozzle turned out to be 10.64 in-lbs.

The 3rd nozzle's trials for sealing it to the minimum torque are shown in Table 7.12. The range of force on this nozzle was 2.67 N – 5.483 N. The minimum and maximum values of torque were then calculated to be 7.46 in-lbs and 14.79 in-lbs. The overall average of this nozzle was 11.85 in-lbs.

After the data of all three nozzles was compiled and reviewed, an overall average of the torque needed to tighten the nozzle was calculated. These averages can be found in Table 7.13. The overall average torque needed to optimally seal the nozzle was 9.81 in-lbs. The absolute minimum torque was found to seal the nozzle just enough to remove any visibility of the o-ring. This value was 2.06 in-lbs. The absolute maximum torque that cannot be used is 50 in-lbs. The reason this is not able to be used is because when applying this amount of torque, the thin-walled section of the shaft, where it is fixed during torquing, actually broke. Therefore, a torque less than 50 in-lbs would be acceptable to use because at 50 in-lbs, the nozzle would be defected and rejected.

The torque determined through the experimental procedure was 9.81 in-lbs. Therefore, a 10 in-lb torque wrench will be ordered from McMaster-Carr. Though the range of torque that can be applied is 2.06 in-lbs – 50 in-lbs, we chose to go with a 10 in-lb torque wrench so the user will be able to use less force to tighten the seal. As a result, this will make it easier for the user to seal the nozzle, causing little to no stress or strain in the user's hands.

7.4.3 Gauge R&R

Gauge R&R stands for gauge repeatability and reproducibility. What it does is ensures that there is little to no error in the gauge. It looks at different users performing the same task with the same equipment and provides feedback as to the precision of the results. The repeatability aspect is that the same person will get the same results every time they perform a task. The reproducibility aspect is that if another person performs the same task they will achieve the same result. Basically, if person A measures the same dimension with the same tooling 100 times will they record the same measurement each time and will it match the results recorded by person B.

This is very applicable to Team Lean on MEs objective. The assembly process will be performed by up to 30 different people. Each person needs to achieve the same results over thousands of trials. Also, each of the thirty different people needs to be achieving the same results as the person sitting next to them. The quality of the final product after the assembly process is complete depends on the ability of all the workers to achieve the same results.

Team Lean on ME wanted to examine the reproducibility and repeatability of the current process used by SW Resources compared to Team Lean on ME's assembly jig. To do this two separate gauge R&R studies were done. A gauge R&R study consists of multiple trials by multiple users and then a statistical analysis of the data. Three members of Team Lean on ME performed the torque test, described in section 7.3.2, by hand. Each member did 30 trials, resulting in a total of 90 data points. This simulated SW Resources current process of tightening the nozzle, by hand with no indication other than feel of when the nozzle is sealed. The same three members then repeated the test, 30 trials each, but used the torque wrench to tighten the nozzle. This simulated the tightening process with the assembly jig.

After all of the data points were taken the gauge R&R study was performed using Excel spreadsheets. These spreadsheets, as well as information about gauge R&R, were provided to Team Lean on ME by Terry Russell, a member of the Mechanical Engineering Department Industrial Advisory Board who provided guidance to our team. The Excel spreadsheets detailing the data and results can be found in Appendices B and C.

The results of the study were conclusive. Results from the study are found in repeatability (% EV), reproducibility (% AV), and repeatability and reproducibility (% R&R). The accepted evaluation scale for the results is < 10% is satisfactory, 10%-30% may be satisfactory depending on the process, and >30% is unsatisfactory. Table 7.14 shows the outcome of the study for both methods. As seen in Table 7.14 the improvement of both reproducibility and repeatability was observed from hand tightening to using a torque wrench. Also, with the torque wrench nearly all values fall into the satisfactory range. It can be concluded that the 13% value is also satisfactory because of the large range of torques that are considered sealed.

Table 7.14: Results of Gauge R&R Study

Method	% EV	% AV	% R&R
Hand Tightening	54	66	85
Torque Wrench	8	10	13

7.5 Prototype Construction

The prototype was constructed using a CNC mill. There are several areas of complex geometry, such as the finger holes, that would make it very difficult to machine on a manual mill. To make the machining process easier standard bit sizes were chosen for all holes. Also, the T-slot was designed to the tooling that was available to prevent the purchase of a new T-cutter. During the construction of the final prototype all of the G-code used by the mill was saved. This would make it easier to construct a second prototype. The G-code would only need to be adjusted for those features that changed. Since the prototype and final design manufacturing are very similar, manufacturing details and plans can be found in section 9.2.

7.6 Prototype Testing

The only specification that needed to be quantifiably tested in our prototype was productivity rate. The goal that SW Resources has set forth is 20,000 assemblies per day. SW Resources is currently meeting that goal and averaging 22,000 to 24,000 assemblies per day. Therefore, if Team Lean on ME’s prototype meets the same productivity rate as the current process it can be inferred that the specification has been met.

To test the performance of the jig four different users with a range of abilities were measured using the current process. Time trials were taken for individual assemblies. Each worker was measured by four Team Lean on ME members to account for variations in the timing process. The data, 40 time trials per worker, taken using the old process of assembly is shown in Table 7.15. This data allowed a baseline to be established.

Table 7.15: Assembly Times Using Old Method

Worker 1	15.3225
Worker 2	18.0580
Worker 3	11.9523
Worker 4	17.9138

After those results were tabulated the two lowest functioning of the original four, Worker 2 and Worker 4, were tested with the jig. These were the only workers tested because Kellie Conrad informed Team Lean on ME that these workers fit the profile of the people that would use the jig. The testing process was the same and the averages of the 40 trials per worker with the jig are shown in Table 7.16. Worker 2 showed clear improvement with the jig, the average time decreased by 3.5 seconds. Worker 4 saw a little improvement, about .3 seconds per assembly. Based on these results it can be determined that the people that use the jig will still be able to meet the production goals and most likely be able to improve upon them.

Table 7.16: Assembly Times Using the Jig

Worker 2	14.4493
Worker 4	17.6663

In addition to increasing the production time the jig also improves the quality of the part. Using the old method SW Resources had 390,000 parts recalled for improper tightening. During assembly inspection, many of the nozzles had been over-tightened which causes an issue in warping its circularity. This, as described in the FMEA section and proved in the gauge R&R study, is not an issue for Team Lean on ME's jig since it utilizes a torque wrench that will properly tighten the nozzles to an optimal value every time. ✓

8.0 Design Refinement for Production

The main features of the prototype that have been considered for improvements in pricing and performance were the T-slot mounting fixture and the preset torque value for the T-handle torque wrench. The T-slot mount increases the manufacturing price by about $50 for the removal of all the material in addition to machining the T-bar. It also requires installation procedures of drilling 3 holes in the assembly table and mounting the bar onto it with three screws. The solution to replacing the T-slot fixture was to use Velcro as SW Resources is using for their current jig. Since the Velcro is already in operation, we know that it should be able to withstand the shearing force due to the applied torque when tightening the nozzle. However, testing will be implemented with our jig to verify its usability. In addition, testing for the new preset torque value will be performed on four separate pop nozzles. They will be tightened to torque values of 12, 13, 15 and 20 in-lbs and their sealing quality will be tested using SW Resources current testing procedure. Their procedure uses water and an air tube to make a qualitative observation if air bubbles leak out of the nozzle. If no bubbles are visible, then the nozzle has been tightened to the value required to properly seal it, and is considered usable. Once the feasibility of the Velcro and the preset torque value have been measured and verified, they will be incorporated into our jig. The Velcro will simply be glued to the bottom of the jig and a new torque wrench with a different value will be ordered.

8.1 Design Refinement for Production

There have been four main changes from the prototype design to the final design. These changes deal with the method of attaching the jig to the table, the pre-set value of the T-handle torque wrench, the material used for the jig, and chamfered edges for the top of the insert holes. All of these changes were for the purpose of minimizing cost or to improve the assembly process and quality of the assembled nozzle.

For the final design, team Lean on ME plans to incorporate the Velcro as the method for attaching the jig to the table. The Velcro will reduce the manufacturing costs by eliminating the machining needed for the T-slot. Using Velcro will not impede on the assembly process since it maintains the same valued characteristic of the T-slot as being able to be easily removed from the table for the purpose of cleaning and or error correction if the plug is improperly inserted.

The only change to the torque wrench is to the pre-set value. The 10in-lb wrench we used for the prototype turned out to be insufficient in tightening the nozzle to having an acceptable seal. After testing higher values for the nozzle of 12, 13, 15 and 20in-lbs, we chose the minimum value that showed no sign of leakage. The minimum value was chosen in order to minimize the amount of input force applied by hand when using the torque wrench in operation. In addition, a lower value of torque is gentler on the Velcro which will be experiencing shearing stresses with every nozzle that is tightened.

The material used to make the jig out of was considered for change as well. Switching from the Ultra High Molecular Weight (UHMW) polyethylene to High Density Poly Ethylene (HDPE) would save approximately $5 per jig in material costs. HDPE retains the similar properties to UHMW in that it has a low coefficient of friction, meets sanitation requirements, has a good impact resistance, and machines very well. The only negative difference between HDPE compared to UHMW is that it cannot withstand the water temperature of a standardized dishwasher. It is recommended for temperatures below 120 degrees Fahrenheit while dishwasher water runs at about 150 degrees Fahrenheit. However, this operation temperature difference should not be a problem given that SW Resources will be sanitizing the jig with a spray on sanitization chemical and a wiping cloth instead of using their preliminary dishwashing method. The reason why we cannot make the change from UHMW to HDPE is that HDPE is not sold by McMaster-Carr in the dimensions that the jigs manufacturing requires. A 3"x4"x12" block is needed and HDPE is not sold in that specific width and thickness. Therefore we ~~c~~are continuing production using UHMW.

The last main characteristic that was changed from the prototype to the final design was the chamfered edges on the jig. All of the top edges have a 45 degree .100 chamfer in order to make the removal process of the assemblies easier in addition to the purpose of eliminating any sharp edges in order to maintain user safety.

9.0 Final Design for Production

9.1 Design Description and Operation

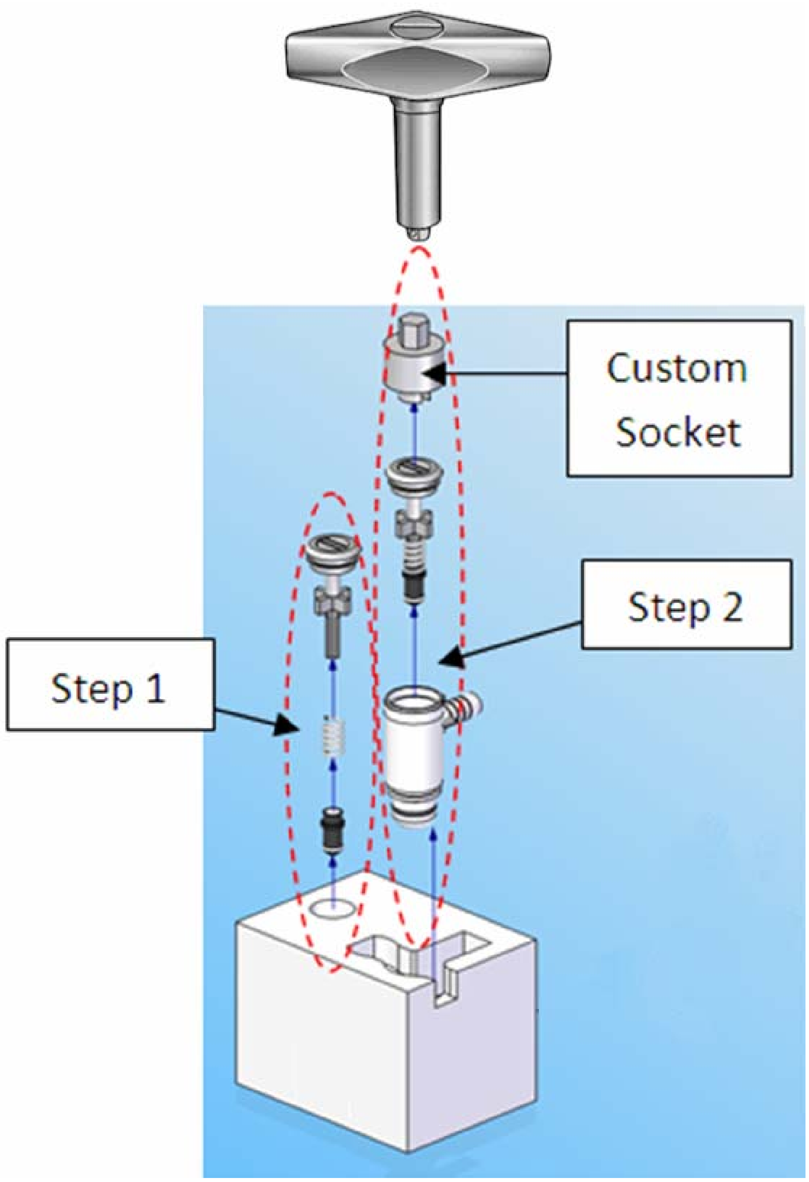

Figure 9.1: Final Design

The final design of the jig has no T-slot mechanism. Instead, it incorporates a Velcro bottom which attaches to its Velcro opposite on the table. The material for the jig is made out of Ultra High Molecular Weight polyethylene or UHMW. There are also chamfered edges on the tops of the part-insert holes. The T-handle ratcheting torque wrench is the exact same as it was in the prototype except for its preset torque value which has changed to 15 in-lbs which optimally seals the nozzle.

The design works the exact same way as in the prototype. The jig is first secured to the table with the Velcro attachment. Afterward, the outer casing is inserted into the hole in the right side of the jig, while the plug, spring, and then shaft are inserted and press fitted together in the hole on the left of the jig. The sub assembly is then placed into the casing in the right side of the jig then screwed together with the T-handle ratcheting torque wrench. The assembled part is then placed into the completed parts bin and the process is repeated. A full detailed description of the entire process can be seen in the User's Manual found Appendix D. ✓

9.2 Manufacturing

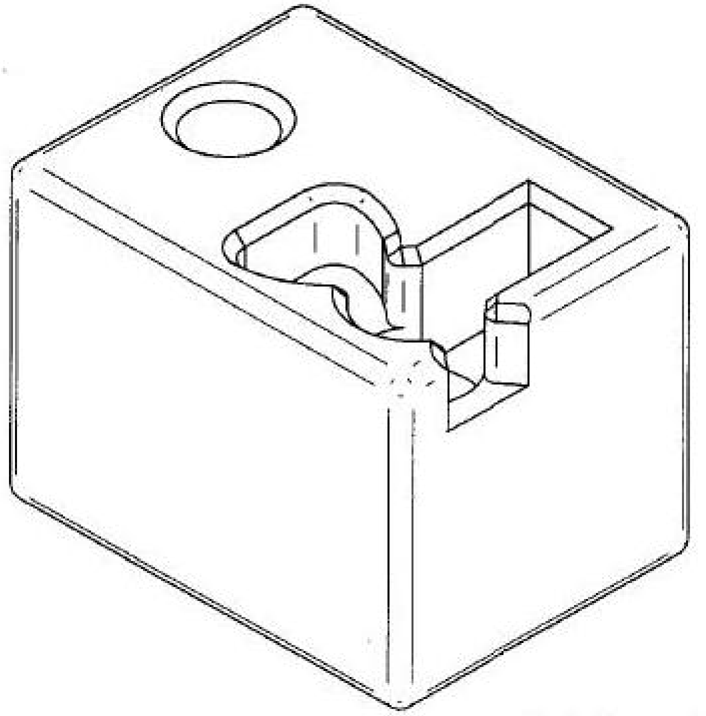

Figure 9.2: Final Design of Jig

9.2.1 Design Drawings, Parts List, and Bill of Materials

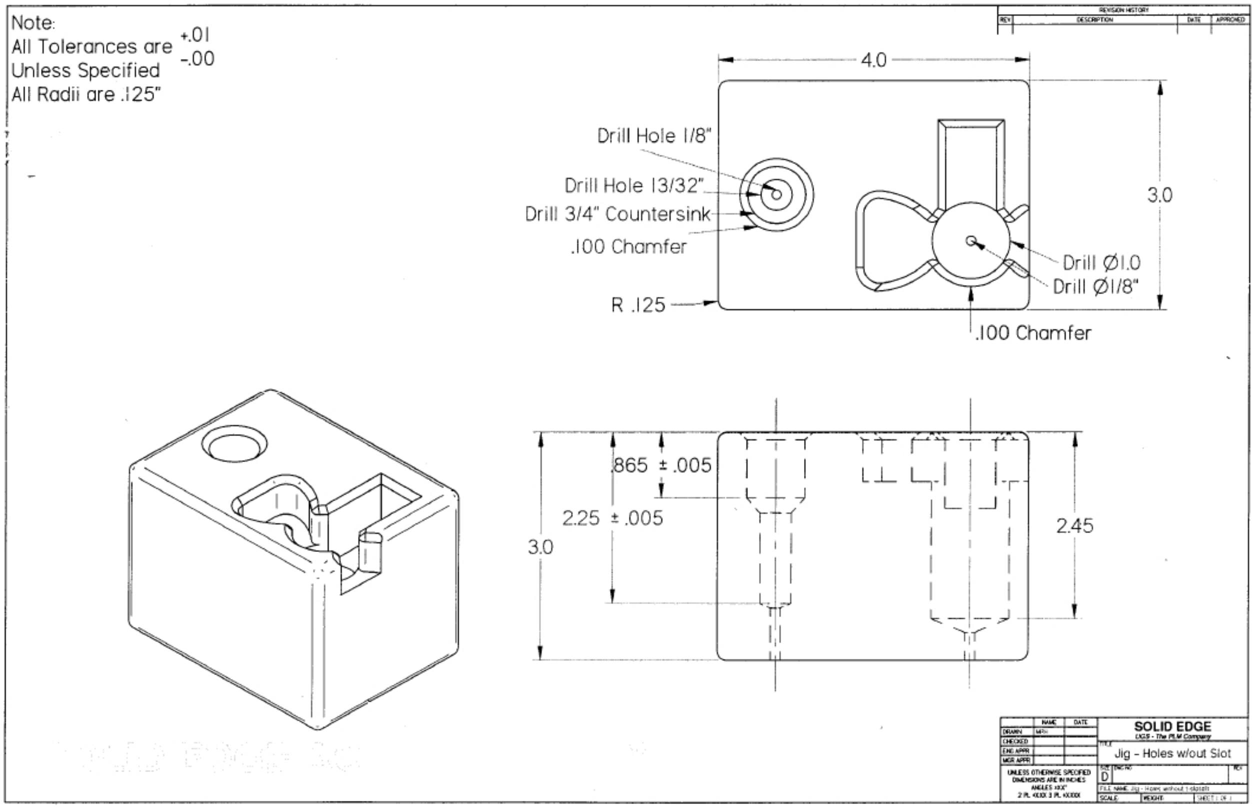

Figure 9.3: Manufacturing Drawing of Jig

Team Lean on ME's jig was designed so that it could be machined on a single vertical CNC mill. Since the jig has a simple design with the two holes being the main features, the machining cost is kept relatively low. All of the edges are rounded while the top corners of the holes are chamfered. These rounds and chamfers are for the purpose of user safety, yet don't add too much to the cost. The other main features are the finger slots and drainage holes. The drainage holes are simple pilot holes. Holes will have to be pocked through the Velcro once it is attached to the bottom of the jig in order to make the drainage holes useful. The finger slots, shown in more detail in Figure 9.4, require several passes in order to create.

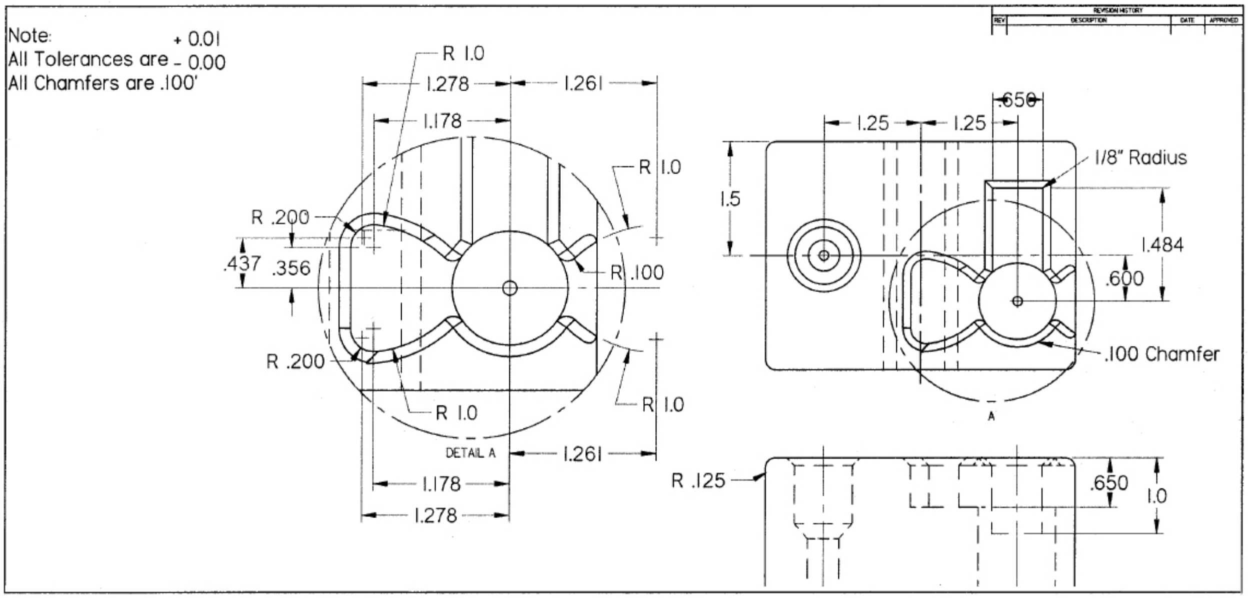

Figure 9.4: Manufacturing Drawing of Finger Slots

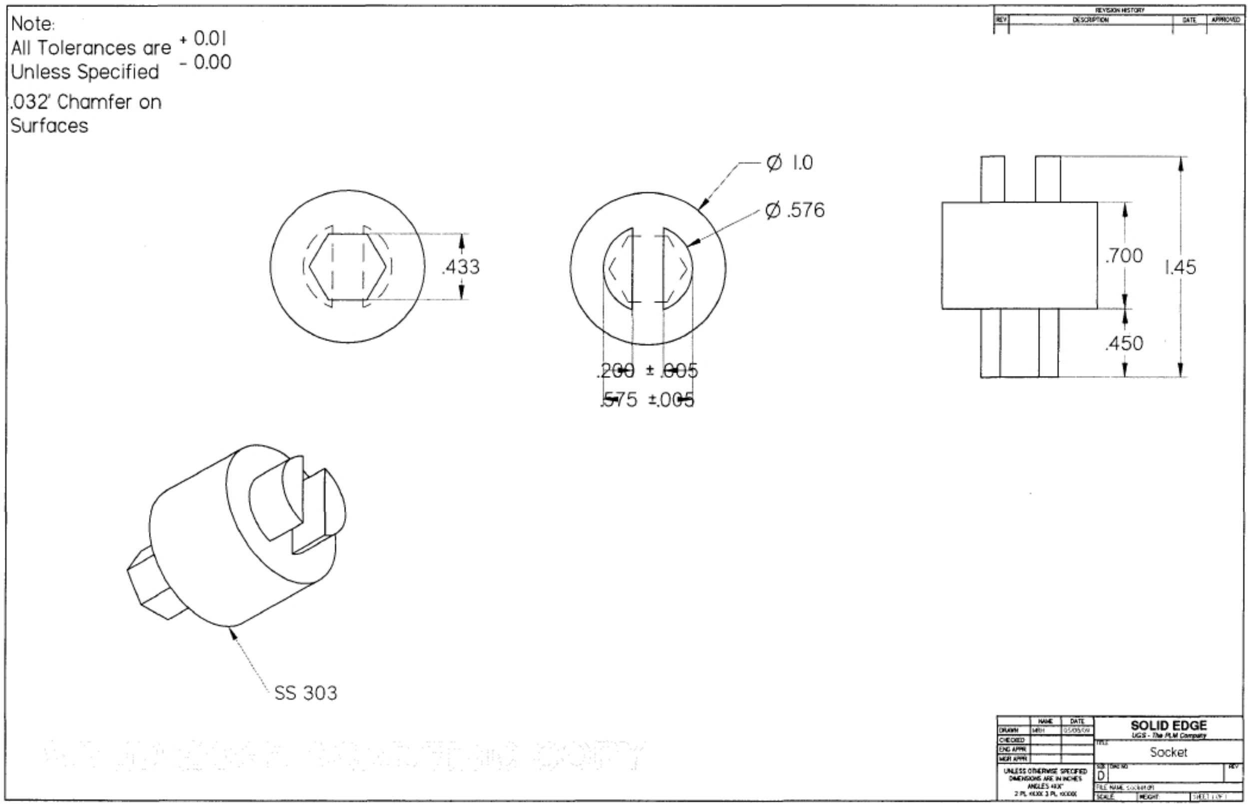

Figure 9.5: Manufacturing Drawing of Socket

The Delrin socket shown in Figure 9.5 is also manufactured on a vertical CNC mill. It has a hexagonal socket adapter with a two-pronged nozzle adapter on the opposite face. This is also relatively cheap to produce out of round bar stock.

Table 9.1: Bill of Materials

Part #	Item	Description	Source	Make/Buy	Price
5507A21	Torque Wrench	T-Handle ratcheting torque wrench	McMaster-Carr	Buy	$61.23
	Custom Socket	Delrin nozzle adapter		Make	$48
	Custom Socket*	SS 303 nozzle adapter (optional replacement)		Make	$91
95005K371	Velcro	2”x5’ 3500 cycle life adhesive backed Velcro	McMaster-Carr	Buy	$17.10
5543A28	Socket	¼” Drive 7/16” Socket	McMaster-Carr	Buy	$3.98
8702K54	UHMW	Bar stock 3”x4”x12” UHMW material makes 3 Jigs	McMaster-Carr	Buy	$40.83

The bill of materials in Table 9.1 includes initial price quotes from Beckman Machines. The prices listed are for material cost in addition to the manufacturing cost for one piece. The price is lowered with a higher order purchase. In addition, we have received quotes from another machine shop in Parkersburg, WV with cheaper manufacturing prices. However, the validity of their cheaper prices is unknown; therefore the more expensive prices are listed in the bill of materials.

10.0 Conclusions

10.1 Evaluation of Objectives

Team Lean on ME met all design objectives set forth at the beginning of the project. Table 10.1 displays all of the design objectives as well as the result. The productivity objective was already met by the current process but for lower functioning clients their assembly time was reduced up to 4 seconds per assembly. That results in roughly 360 more assemblies per eight hours worked by a low functioning client. All of the safety objectives were also met. The jig poses no danger to any operator and requires no protective equipment to operate. The cost of producing the jigs is 12.5% below the target. The jig is small enough that four jigs can be operated on a 3 X 8 foot table. Most importantly the jig provides a high quality product with each use. There is a low likelihood of future recalls when the jig is used because it ensures the proper torque with each use.

Table 10.1: Design Objectives

Objective	Target	Actual	Met?
Productivity	20 sec/assembly	15.2 sec/assembly	Yes
Safety	No pinch points, sharp edges, or PPE required	No pinch points, sharp edges, or PPE required	Yes
Total Cost	< $200 per jig	$174 per jig	Yes
Size	4 per table	4 per table	Yes
Quality	No leaks, No damage, Sanitary, Withstand a 4' drop	No leaks, No damage, Sanitary, Withstand a 4' drop	Yes

10.2 Evaluation of Readiness

It is Team Lean on ME's belief that this design is fully production ready. All analyses have been preformed and it the recommendation is made with full confidence. All of the design criteria have been met or exceeded. Local machine shops have provided quotes well within the budget of SW Resources and SW Resources should feel confident with an order of 12 assembly jigs.

10.3 Expectations after Delivery

With the jig being production ready there is very little future work to be performed. The only question that remains is the wear on the socket. Team Lean on ME was unable to provide a definitive answer that a Delrin socket would not wear over time. Therefore, the team has provided a recommendation that a stainless steel socket would be preferable. There is a cost associated with this recommendation. Therefore, it has been communicated to SW Resources that should they choose to order the Delrin socket while taking the precaution to examine it over time, looking for evidence of wear. If the wearing of the socket proves to be unacceptable, SW Resources should order stainless steel sockets.

Appendix A – FMEA Worksheets

Failure Mode One – O-ring is unsealed. The torquing action happens when the user fastens the shaft assembly into the outer casing.

Operating mode when failure could occur	***Potential Failure Mode***
Torquing of nozzle (User)	*O-ring is improperly sealed*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**5**	**5**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	7	2
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	3	2
Risk Priority Number (RPN=SEV*OCC*DET)	105	20

1. Include some discussion/justification for the rating for **severity** (SEV)

The part would not work at all, but would not pose a risk to the user.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

We do not have enough information to justify a lower number.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Failure would be visibly recognizable. The o-ring would be showing.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

We need to research the ability to perform the task, and ensure the torque wrench is calibrated properly in order to decrease OCC significantly.

5. Notes on **Completed Actions**:

The torque wrench underwent a Gauge R&R study showing that its repeatability was greatly improved. Also SW has set up a testing process for all completed nozzles so detection has been improved.

Appendix A – FMEA Worksheets

Failure Mode 2 – Breaking of the Part. The torquing action happens when the user fastens the shaft assembly into the outer casing.

Operating mode when failure could occur	***Potential Failure Mode***	
Torquing of nozzle (User)	*nozzle cracks or deforms permanently*	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**5**	**5**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	7	2
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	3	2
Risk Priority Number (RPN=SEV*OCC*DET)	105	20

1. Include some discussion/justification for the rating for **severity** (SEV)

The part would not work at all, but would not pose a risk to the user.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

We do not have enough information to justify a lower number.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Failure would be visibly recognizable. The crack or deformation would be evident.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

We need to research the ability to perform the task, and ensure the torque wrench is calibrated properly in order to decrease OCC significantly.

5. Notes on **Completed Actions**:

The torque wrench underwent a Gauge R&R study showing that its repeatability was greatly improved. Also SW has set up a testing process for all completed nozzles so detection has been improved.

Appendix A – FMEA Worksheets

Failure Mode 3 – Safety of the User

Operating mode when failure could occur	***Potential Failure Mode***
All operation modes	*Harm to the user (cut, pinch, etc.)*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**7**	**7**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	5	1
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	4	4
Risk Priority Number (RPN=SEV*OCC*DET)	140	28

1. Include some discussion/justification for the rating for **severity** (SEV)

The jig may still work, but it could be slightly dangerous.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

We have information on how it could be dangerous, but little data.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Dangerous portions of operation would be hopefully noticeable to supervisor.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform testing to see if operation is more dangerous than imagined. Also, discuss operation with supervisors.

5. Notes on **Completed Actions**:

As constructed, the prototype has no sharp edges or pinch points

Appendix A – FMEA Worksheets

Failure Mode 4 – Not Meeting Desired Production Rate

Operating mode when failure could occur	***Potential Failure Mode***
Assembly	*Not meeting production rate*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**4**	**4**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	8	1
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	5	5
Risk Priority Number (RPN=SEV*OCC*DET)	160	20

1. Include some discussion/justification for the rating for **severity** (SEV)

The jig may produce an assembly, but it would not meet required production rate.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

We have little to no information on the operation of our jig.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

This would be easy to detect, but after detected it would be difficult to avoid.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform testing to see if operation meets required rates.

5. Notes on **Completed Actions**:

SW is already meeting production rate and the jig should slightly improve production rate

Appendix A – FMEA Worksheets

Failure Mode 5 – Sanitation

Operating mode when failure could occur	***Potential Failure Mode***
Cleaning and Operation	*Part is not sanitary*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**7**	**7**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	5	5
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	4	4
Risk Priority Number (RPN=SEV*OCC*DET)	140	140

1. Include some discussion/justification for the rating for **severity** (SEV)

The jig may still work, but the part would be unusable.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

We have information on how to prevent this, but little data.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

This is difficult to detect but very easy to avoid.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform bacteria cultures to see if the part would pass sanitation.

5. Notes on **Completed Actions**:

No changes were made since the initial evaluation

Appendix A – FMEA Worksheets

Failure Mode 6 – Durability of the Jig over time (Wear)

Operating mode when failure could occur	***Potential Failure Mode***
Assembly/Operation	*The Jig physically deforms*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**2**	**2**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	9	3
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	3	3
Risk Priority Number (RPN=SEV*OCC*DET)	54	18

1. Include some discussion/justification for the rating for **severity** (SEV)

Even if the jig deforms it causes no real safety or quality issues.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Little to no information of chosen material and no testing.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

This would be easily recognized and we are confident we can engineer a solution.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform tests and redesign if necessary.

5. Notes on **Completed Actions**:

The jig has been analyzed with FEA and stresses are low. Also there is no sign of physical deformation at the end of the testing phase

Appendix A – FMEA Worksheets

Failure Mode 7 – Calibration of the Wrench

Operating mode when failure could occur	***Potential Failure Mode***
Torquing of the nozzle (Wrench)	*Wrench out of spec*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**4**	**4**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	8	2
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	5	5
Risk Priority Number (RPN=SEV*OCC*DET)	160	40

1. Include some discussion/justification for the rating for **severity** (SEV)

As wrench becomes out of spec the parts may not meet quality requirements.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Little to no information, but the information is easily accessible.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Some chance to detect and avoid.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Discuss calibration techniques with the wrench manufacturer.

5. Notes on **Completed Actions**:

Gauge R&R has been preformed and the wrench holds a tight tolerance

Appendix A – FMEA Worksheets

Failure Mode 8 – Operation of Jig

Operating mode when failure could occur	***Potential Failure Mode***
Assembly/Operation	*Plug is in the wrong direction*

	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**5**	**1**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	9	2
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	7	7
Risk Priority Number (RPN=SEV*OCC*DET)	315	14

1. Include some discussion/justification for the rating for **severity** (SEV)

The jig would be inoperable, but it would cause no danger.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Little to no information and testing.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

This would be relatively easy to recognize and difficult to solve.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform tests and redesign if necessary.

5. Notes on **Completed Actions**:

The effect is not as severe because of the quick release feature incorporated into the jig; mis-orientation would barely slow the production process. The potential cause is much lower because after observing the workers it does not appear to be an issue at all, when observed no worker ever mis-oriented the plug with the current or new process.

Appendix B – Gauge R&R for Torque Wrench

REV No.		DATE	4/13/02	People	3
GAGE NAME					

	OPERATOR A				OPERATOR B				OPERATOR C				OPERATOR D			
No	TRIAL 1	TRIAL 2	T 3	RANGE	TRIAL 1	TRIAL 2	TR3	RANGE	TRIAL 1	TRIAL 2	TR3	RANGE	TR1	TR2	TR3	RANGE
1	3.485	3.491	3.664	0.1790	3.537	3.456	3.395	0.1420	3.58	3.543	3.506	0.0740				0.0000
2	3.492	3.466	3.59	0.1240	3.567	3.419	3.37	0.1970	3.629	3.642	3.567	0.0750				0.0000
3	3.479	3.516	3.571	0.0920	3.5	3.487	3.419	0.0810	3.592	3.574	3.574	0.0180				0.0000
4	3.466	3.553	3.665	0.1990	3.382	3.351	3.271	0.1110	3.598	3.537	3.549	0.0610				0.0000
5	3.491	3.528	3.534	0.0430	3.438	3.401	3.339	0.0990	3.623	3.487	3.567	0.1360				0.0000
6	3.448	3.435	3.534	0.0990	3.425	3.425	3.419	0.0060	3.623	3.549	3.53	0.0930				0.0000
7	3.497	3.466	3.553	0.0870	3.524	3.463	3.456	0.0680	3.598	3.543	3.493	0.1050				0.0000
8	3.509	3.466	3.571	0.1050	3.5	3.425	3.444	0.0750	3.666	3.53	3.549	0.1360				0.0000
9	3.509	3.534	3.497	0.0370	3.456	3.475	3.327	0.1480	3.629	3.518	3.58	0.1110				0.0000
10	3.497	3.664	3.509	0.1670	3.481	3.401	3.456	0.0800	3.617	3.537	3.567	0.0800				0.0000
	3.4873	3.5119	3.5688	0.11320	3.4810	3.4303	3.3896	0.10070	3.6155	3.5460	3.5482	0.08890	0.0000	###	0.0000	0.00000
	X BAR A	3.52267		R BAR A	X BAR B	3.43363		R BAR B	X BAR C	3.56990		R BAR C	X BAR D	###		R BAR D

TRIALS	D4
2	3.27
3	2.58

UCL R	
UCL R 2	0.33005
UCL R 3	0.26041

MAX X BAR	3.56990
MIN X BAR*	3.43363
X BAR DIFF	0.13627

R DBL BAR	0.10093

Appendix B – Gauge R&R for Torque Wrench

REPEATABILITY - EQUIPMENT VARIATION (EV)

EV = (R DBL BAR) X (ALPHA)

% EV = 100[(EV)/(TOLERANCE)]

R DBL BAR	0.1009
ALPHA	3.05

# Trials	ALPHA
2	4.56
3	3.05

EV = 0.30785

% EV = 8%

REPRODUCIBILITY - APPRAISER VARIATION (AV)

AV = SQRT((X BAR DIFF*BETA)^2-(EV^2/(N*M))

% AV = 100[(AV)/(TOLERANCE)]

# Samples (n)	10
# Trails (m)	3
BETA	2.7

# People	BETA
2	3.65
3	2.7
4	2.3

AV = 0.36360

% AV = 10%

REPEATABALITY AND REPRODUCIBILITY (R&R)

R&R = SQRT(EV^2+AV^2)

% R & R = 100[(R&R)/(TOLERANCE)]

R&R = 0.4764

% R&R 13%

Appendix C – Gauge R&R for Hand Torque

Gage Repeatability and Reproducibility Report

Average & Range Method

Torque Test

GAGE No.		PART NAME		DIMENSION		Trials	3
DWG No.		PART NO.		TOLERANCE	7.4320	Samples	10
REV No.				DATE	4/13/02	People	3
GAGE NAME							

	OPERATOR A				OPERATOR B				OPERATOR C				OPERATOR D			
No	TRIAL 1	TRIAL 2	T 3	RANGE	TRIAL 1	TRIAL 2	TR3	RANGE	TRIAL 1	TRIAL 2	TR3	RANGE	TR1	TR2	TR3	RANGE
1	2.009	2.505	2.671	0.6620	2.302	3.504	4.484	2.1820	5.123	4.668	4.062	1.0610				0.0000
2	2.205	2.401	2.689	0.4840	3.51	3.486	5.316	1.8300	2.769	4.821	4.889	2.1200				0.0000
3	2.064	2.469	2.395	0.4050	2.285	3.308	4.956	2.6710	3.106	4.215	4.913	1.8070				0.0000
4	2.064	2.407	2.99	0.9260	2.046	3.308	5.44	3.3940	5.101	3.516	3.927	1.5850				0.0000
5	2.23	2.561	2.787	0.5570	2.064	4.129	5.195	3.1310	4.907	4.392	4.215	0.6920				0.0000
6	2.248	2.438	3.051	0.8030	2.646	3.798	4.772	2.1260	4.827	4.227	4.129	0.6980				0.0000
7	2.199	2.659	2.654	0.4600	3.357	4.576	3.443	1.2190	4.276	4.742	4.337	0.4660				0.0000
8	2.652	3.173	2.731	0.5210	3.547	5.269	3.951	1.7220	4.319	4.913	4.38	0.5940				0.0000
9	2.524	2.72	2.436	0.2840	3.902	5.465	4.944	1.5630	5.226	4.153	3.842	1.3840				0.0000
10	2.83	3.418	2.897	0.5880	3.908	5.655	3.78	1.8750	5.483	4.093	4.221	1.3900				0.0000
	2.3025	2.6751	2.7301	0.56900	2.9567	4.2498	4.6281	2.17130	4.5137	4.3740	4.2915	1.17970	0.0000	###	0.0000	0.00000
	X BAR A	2.56923		R BAR A	X BAR B	3.94487		R BAR B	X BAR C	4.39307		R BAR C	X BAR D	###		R BAR D

TRIALS	D4
2	3.27
3	2.58

UCL R	
UCL R 2	4.27280
UCL R 3	3.37120

MAX X BAR	4.39307
MIN X BAR*	2.56923
X BAR DIFF	1.82383

R DBL BAR	1.30667

Appendix C – Gauge R&R for Hand Torque

REPEATABILITY - EQUIPMENT VARIATION (EV)

EV = (R DBL BAR) X (ALPHA)

% EV = 100[(EV)/(TOLERANCE)]

R DBL BAR	1.3067
ALPHA	3.05

# Trials	ALPHA
2	4.56
3	3.05

EV = 3.98533

% EV = 54%

REPRODUCIBILITY - APPRAISER VARIATION (AV)

AV = SQRT((X BAR DIFF*BETA)^2-(EV^2/(N*M))

% AV = 100[(AV)/(TOLERANCE)]

# Samples (n)	10
# Trails (m)	3
BETA	2.7

# People	BETA
2	3.65
3	2.7
4	2.3

AV = 4.87030

% AV = 66%

REPEATABALITY AND REPRODUCIBILITY (R&R)

R&R = SQRT(EV^2+AV^2)

% R & R = 100[(R&R)/(TOLERANCE)]

R&R = 6.2931

% R&R 85%

Appendix D – User’s Manual

OWNER’S MANUAL

POP NOZZLE ASSEMBLY JIG

Appendix D – User's Manual

IMPORTANT: KEEP FOR FUTURE REFERENCE

!!!! WARNING !!!!

The Fixture Produced by Team Lean on ME contains many small parts. KEEP AWAY FROM CHILDREN.

!!!! WARNING !!!!

Use precaution when plunging parts, tightening parts, and removing parts, this can cause pinch points

This owner's manual explains how to use the Lean on ME pop nozzle assembly fixture properly and safely.

Parts list:

1) Fixture Block
2) T-Slot
3) (3) 10/24-3" bolts
4) (3) 10/24 nuts
5) (3) #6 washers
6) 7/16 socket
7) 10 in. lb. Preset Torque Wrench
8) Custom Socket head

Non-provided necessary Parts

9) Pop Nozzle Plug
10) Pop Nozzle Spring
11) Pop Nozzle Shaft
12) Pop Nozzle casing
13) Work table
14) Drilling device

Appendix D – User’s Manual

OPERATING INSTRUCTIONS

INSTALATION OF FIXTURE

- Drill 3 holes in a line 1 ½” apart from each other in the area where the T-Slot is to be secured down at. Align the bolts and washers into the T-Slot and into the table holes. Tighten the nuts securely so that the T-Slot will not be stable.
- Insert the fixture block onto the T-Slot

INSTALLATION OF TORQUE WRENCH

- Press the socket onto the torque wrench
- Secure the Socket head onto the socket

ASSEMBLE THE NOZZLE - (Figure 1)

- Drop the plug into the press hole and check to make sure it was completely dropped
- Drop the spring into the press hole and check to make sure it was completely dropped
- Orient the shaft through the spring and press into the plug
- Remove the plug, spring and shaft sub- assembly
- Drop the casing into the torque hole with the nozzle in the rectangular slot
- Drop the plug, spring and shaft sub-assembly into the casing
- Orient the Socket head (attached to the torque wrench) into the top of the shaft
- Screw the sub-assembly into the casing using the Torque Wrench
- Torque until the Torque Wrench clicks so that the desired torque is reached

Appendix D – User's Manual

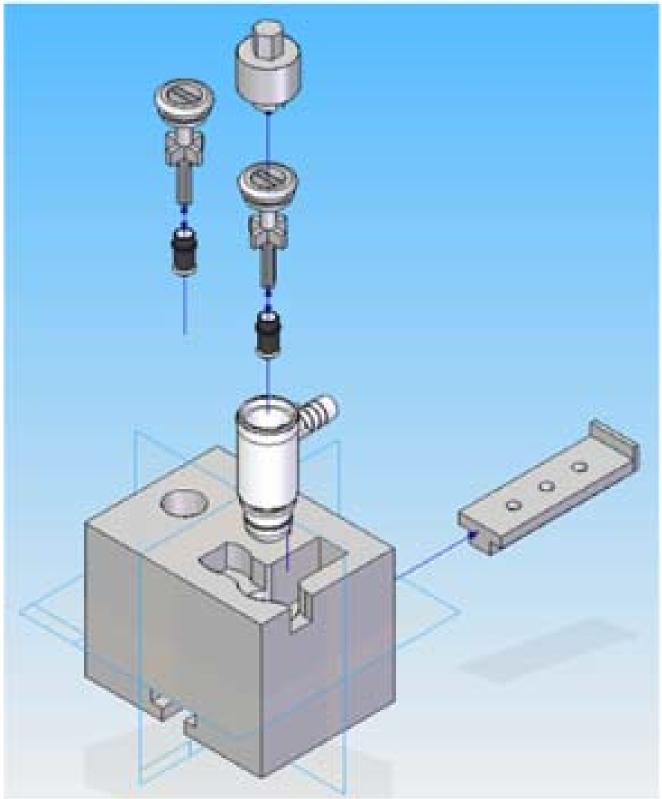

FIGURE 1: Operating order

REMOVAL OF THE ASSEMBLY

- Pull the Assembly out of the Torque hole using the Finger holes.

REMOVAL OF FIXTURE

- Slide fixture off of T-Slot
- Remove the nuts from the bolts and take the T-Slot off of the table

TROUBLESHOOTING AND SERVICE INSTRUCTIONS

T-SLOT STABUILITY

- If T-slot becomes loose tighten nuts and bolts
- Check nuts and bolts daily during Instillation and Removal

SANITAITION

- The Fixture must be removed daily for cleaning

TORQUE WRENCH CALIBRATION

- The torque wrench must be calibrated biannually to ensure proper tightening

SOCKET HEAD INSPECTION

- Inspect the adhesive between the socket and socket head. If the adhesive is failing reapply adhesive, let it dry, and continue operating normally

PLUG AND SPRING ORIENTATION

- If the plug and/or spring are incorrectly oriented during sub-assembly remove fixture from T-slot and flip the fixture upside-down to drop the plug and/or spring and restart assembly.

Appendix D – User's Manual

REPLACEMENT PARTS INFORMATION

TORQUE WRENCH
- The torque wrench was purchased from McMaster-Carr

SOCKET
- 7/16 socket can be found at various hardware stores

NUTS & BOLTS
- 10/24-3" bolts and nuts can be found at any hardware store

WASHERS
- #6 washers can be found at any hardware store

CUSTOM SOCKET HEAD
- see figure 9.5 for manufacturing information

JIG
- see Figures 9.3 and 9.4 for manufacturing information

Appendix E – Works Cited

Electronic Screwdrivers and Torque Measurement - Delta Regis. (n.d.). Retrieved 2009, from Delta Regis: http://www.deltaregis.com/index.php?id=1

Flexible Assembly Systems Inc. (n.d.). Retrieved 2009, from http://www.flexibleassembly.com/

NISH. (n.d.). Retrieved 2009, from www.nish.org

SW Mission Statement. (n.d.). Retrieved 2009, from SW Resources: http://www.swresources.com/html/mission.html

Torque and Equilibrium. (n.d.). Retrieved 2009, from http://hyperphysics.phy-astr.gsu.edu/hbase/torq2.html#tc

US Department of Health and Human Services. (n.d.). Retrieved 2009, from http://www.hhs.gov/